Muscle Activity Patterns in the Neck and Upper Extremities Among Machine Operators in Different Forest Vehicles

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ABSTRACT

The goal of this cross-sectional study was to investigate the impact of different physical work station designs, expressed in two different brands of forest vehicles, on the muscle activity patterns in the neck and upper extremities among the vehicle operators.

Surface electromyography (sEMG) was continuously recorded bilaterally on the trapezius (TM) and the extensor digitorum muscles (EDM) during one working day among operators driving Timberjack and Valmet vehicles, either as harvesters (n = 7 and 6, respectively) or forwarders (n = 9 and 9, respectively).

Both the construction of the crane in relation to the chassis and the design of the control levers vary between the Timberjack and Valmet vehicles, which demand different ergonomic performance by the operators. The operators mostly handle control levers in the harvesters or forwarders, the latter with a more varied work load, in a fixed, seated working posture in the cabin for long hours with little rest. The sustained low-level muscle activity was quantified by periods with muscle activity above 0.5 percent EMG_{max} into 10 predetermined duration intervals from 1.6 to 5 s up to above 20 min (SULMA periods). These SULMA periods were analyzed both for number in the different intervals and cumulated periods above the predefined values. Amplitude and frequency parameters were analyzed and the number and total duration of muscle rest periods were calculated.

The operators driving Valmet harvesters had a significantly higher number of long cumulated SULMA periods above 10 min in the left TM, and showed a higher level of static muscle activity and less total duration of muscle rest in TM bilaterally. The operators driving Timberjack forwarders had a significantly higher number of SULMA periods between 10 and 20 min in the right TM. No difference was found between the operators in the EDM activity pattern.

The results of our study showed that operators driving Valmet harvesters had more sustained low-level activity in the neck than those driving Timberjack, including a higher number of long cumulated SULMA periods, higher static level, and less muscle rest. Despite a small sample, the results in muscle activity pattern raise the question of needs for improvements of the forest vehicle workstation design.

Keywords: *surface EMG, sustained low-level muscle activity, duration, trapezius, control levers, design, work-related, forest operations, discomfort/pain, ergonomics*

Introduction

The ergonomic designs of workplaces are important in prevention of work-related musculoskeletal disorders (Bernard 1997, Punnett 1998, Punnett and Wegman 2004, Vik 2005). Work postures with the neck in a more or less neutral position and support for the forearm during computer work are among the well-documented ergonomic factors that may prevent neck and upper limb disorders (Ariens et al. 2000, Aarås et al. 2002). Computer work with the use of a vertical mouse resulted in decreased muscle activity in the extensor muscles and reduced complaints (Aarås et al. 2002). Also, in mechanized forestry, findings of symptoms and sick leave among forest machine operators working with extremely pronated hands have been reported (Grevsten and Sjögren 1996). Hence, several indications exist that pronated hand positions should be avoided. The continuous activation of neck and arm muscles and fixed postures during long periods of lever operation have increased in forest operations over the past decades as part of a rationalization process (Attebrant et al. 1997, Atterbrant et al. 1992, Axelsson and Pontèn 1990, Schuldt et al. 1987). The work load in the upper extremities of persons operating forest machines for long hours has been shown to be associated with discomfort/pain in both a short- and long-term perspective (Østensvik et al. 2008a, Østensvik et al. 2008b).

For several years, there has been awareness of the new ergonomic problems in mechanized logging operations (Attebrant et al. 1995, Hägg 2001, Marras and Schoenmarklin 1993). This is attributed to the work posture of the hand/fingers (thumb and index finger in particular) on the control lever, in addition

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to e.g., the technical solution for the crane construction, involving non-neutral postures of the head and neck in order to get an optimal view for felling and delimbing processes. The bilateral control levers may be operated in a horizontal or vertical hand position or a combination of both. The additional task of attending to the internet-based VDU display while operating the control levers has increased the work load. After a study of different designs and sizes of levers, it was suggested that work station improvements alone may not be sufficient for eliminating the risk for neck and shoulder disorders (Attebrant et al. 1997).

Our view on the pathological mechanisms of muscle related pain is based on the "Cinderella hypothesis." This refers to the theory that the same few motor units are activated during low-level muscle activity and, thereby, constitute a risk for injury ('Cinderella is always working'). If the load conditions are not changed, a successive process will affect these muscle fibers slowly over months or maybe years (Hägg 1991). Interruptions of muscle action are, therefore, necessary in these conditions to reduce the load on the motor units' "Cinderella" muscle fibers. Long sustained muscle activity, even at a low-level, few short interruptions, and high general static muscle load may, on the other hand, be deleterious to the muscle and its function and may cause pain.

The primary goal of this study was to compare the muscle activity pattern in the upper trapezius and extensor digitorum muscles among operators in harvesters and forwarders of two different brands. A possible health effect of different muscle use will be discussed.

Methods

Participants

Two groups of healthy, male machine operators driving harvesters (n =13) and forwarders (n = 18) participated in this cross-sectional study. The operators were recruited from the Machine Entrepreneurs Union in Oslo. From a broader study of 39 forest machine operators driving several brands of vehicles (Østensvik et al. 2007), the selection criterion for the subgroup of 31 operators to participate in this study, was to include only the operators who were driving Timberjack and Valmet. The contractors and the worksites were chosen on the basis of accessibility for the investigator because of economic and time constraints. The two occupational groups were comparable in terms of individual background and work-related factors (**Table 1**). The Regional Ethical Committee for Medical Research approved the study protocol and written informed consent was obtained from all of the volunteers in advance.

Table 1. ~ *Explanatory factors related to the work pattern among operators in the Timberjack and Valmet vehicles.*

	Harvesters		Forwarders	
	Timberjack	Valmet	Timberjack	Valmet
	Mean (SD) (n = 7)	Mean (SD) (n = 6)	Mean (SD) (n = 9)	Mean (SD) (n = 9)
Age (yr)	32.7 (4.8)	33.7 (12.0)	28.3 (7.9)	35 (12.8)
Height (cm)	181 (6.7)	180 (9.9)	184.2 (5.5)	178 (5.2)
Weight (kg)	87.6 (15)	78.8 (9.2)	91.6 (11.2)	83.8 (8.5)
Body mass index	26.7 (3.9)	24.4 (2.4)	27.0 (3.2)	26.4 (2.9)
Civil status - living with a partner (%)	100%	67%	67%	67%
Personal income[b]	1.7 (0.5)	2.0 (0.6)	1.9 (0.6)	2.0 (0.6)
Education (yr)	10.7 (0.8)	10.3 (1.0)	10.6 (0.7)	10.0 (1.0)
Present position (yr)	4.5 (2.8)	6.9 (6.5)	4.8 (4.3)	5.6 (6.5)
Working hours per week (h:min)	44:18 (4:30)	42:48 (4:42)	47:24 (10:18)	46:54 (7:30)
Lunch break (min)	14 (18)	21 (11)	8 (11)	15 (9)

[a] SD = standard deviation in parentheses.
[b] 1 = good; 2 = average; 3 = below average.

Industrial Forest Operations

Harvesting

The four work tasks are defined here as spotting, felling, delimbing, and crosscuts. The operator selects the tree, places the crane in the correct position, and grasps the tree around the lowest point of the stem with the aggregate that is placed at the end of the crane (**Figs. 1a and 2a**). By means of the aggregate, the operator cuts the tree, places it in a horizontal position, delimbs it, and finally makes the crosscuts at specific intervals. A computer supplies the operator with information based on the diameter of the stem, advising the operator where to make the most favorable crosscuts. Both the specific tree and accumulated production of timber in m^3 per day is digitalized in the computer as exact produced categories. The expected time consumption per tree measured for an experienced operator in Norway for performing the described tasks has been reported as between 0.16 and 7.31 min (mean 0.62) (Lileng 2001).

Forwarding

The work cycle in our study can be divided into loading timber at the worksite, travelling loaded to the forest road, unloading, and finally travelling unloaded back to the worksite. Per load, the grabbing crane picks up the timber approximately 50 to 60 times. The driving distance back and forth from the worksite varies, from approximately 5 to 45 minutes. A continuous ranking of the quality of the timber is done and a final stamping with different quality marks is performed.

Vehicles

The Timberjack and Valmet vehicles (**Figs. 1 and 2**) were selected among all of the brands because they represent approximately 40 and 30 percent of the Norwegian market, respectively. Within each of the two brands of vehicles to be compared, there are several models/sizes of both harvesters and forwarders (**Table 2**). Among harvesters there were seven Timberjack and six Valmet and for forwarders there were nine vehicles in each group. These vehicles handle the naturally regenerated stands in Norway, where the terrain varied from flat, stony, rough, and bumpy to quite steep hillsides (40% to 50%). The main species cut was Norway spruce, with a mean height of 15 a)

b)

c)

d)

Figure 1. ~ *Timberjack harvester with the crane in front of the cabin (a) and the accompanying control lever and VDU display (b); Timberjack forwarder (c) with the control lever (d).*

Table 2. ~ *Data on the Timberjack and Valmet vehicles.*

Brand	Model	Age	(N) per model	(N) per brand
		Harvesters		
Timberjack	870	1	1	
	1270B	3	4	
	1668	2	1	
	2628	0	1	7
Valmet	901	1	2	
	911	2	3	
	921	1	1	6
		Forwarders		
Timberjack	810B	2	2	
	1210A	2	4	
	1410	1	2	
	1710	0	1	9
Valmet	828	2	1	
	838	5	1	
	840	3	5	
	860	1	2	9

to 25 m; mostly clear-cutting but also some thinning harvesting systems were investigated.

Vehicle Design and Work Postures

Harvesters

In both brands of vehicles, the operator performs bilateral operation of control levers with a high demand for precision, continuously coordinating head movements in several non-neutral postures with frequent extreme neck movements, often for long periods without rest. The two most obvious differences in the construction of the harvesters between Timberjack and Valmet are the way the crane is attached to the machine and the design of the control levers.

The control panel in the Timberjack (**Fig. 1b**) is operated using mostly the thumb and index finger on small joysticks combined with a horizontal keyboard where the remaining fingers press buttons like a piano. In the Valmet (**Fig. 2b**) most functions are gathered in large joysticks which can be grasped by the palm of the hand in a vertical position, and the fingers can press the buttons like an accordion. The ergonomic difference between these two designs is that in the Timberjack there is a shift between a horizontal and vertical position of the hand/fingers, while in the Valmet the work load will be only in the vertical position of the hand. In both vehicles the cabin can be rotated 360°, but on the Timberjack the crane is installed directly on the chassis (**Fig. 1a**), while on the Valmet it is either in the middle or on the right side of the cabin (**Fig. 2a**). As a consequence of the design, the body postures for the operator in the Timberjack will involve increased twisting of the neck and trunk to follow the movements of the crane, while in the Valmet no such extra movement is necessary since the operator follows the crane/cabin movement.

a)

b)

c)

d)

Figure 2. ~ *Valmet harvester with the crane on the right side of the cabin (a) and the accompanying control lever and VDU display (b); Valmet forwarder (c) with the control lever (d).*

Forwarders

In the forwarders the basic design of the control levers differed between Timberjack and Valmet in the same manner as for the harvesters (**Figs. 1d and 2d**). The crane in the forwarder, however, is constructed on the chassis, which results in twisting of the neck and trunk during loading (**Figs 1c and 2c**). Operation of the control lever in the forwarder, however, is far less complicated with fewer functions to attend to and more variation in the tasks than is the case with the harvesters. The control lever function is only used here during loading and unloading at the work site. During transport between the worksite and the final piling site by the forest road, a steering system can be used that will give variation in the precision work of the hand. If the operator uses the crane to balance the vehicle when fully loaded to prevent tilting, he must use the control lever instead of the steering system.

Muscle Activity Pattern

Surface electromyography (sEMG) was used to measure the amplitude and frequency parameters in the right and left upper trapezius and right and left extensor digitorum muscles continuously during one working day (Akesson et al. 1997, Jonsson 1982, Petrofsky et al. 1982, Sommerich et al. 2000, Westgaard 1988, Winkel and Mathiassen 1994, Winter et al. 1992, Aarås and Westgaard 1987). The skin area of interest was shaved, sandpapered (Skin Rasp, Premed AS, Oslo, Norway), and cleaned with 70 percent alcohol to reduce skin impedance to acceptable levels for recording (< 10 kΩ). Two pairs of disposable non-gelled neurology electrodes (Neuroline, type 725-01-K, Medicotest A/S, Denmark) were applied. A four-channel EMG recorder (Physiometer PHY-400, Premed as, Norway, 1998) was used to collect the myoelectric signals. A portable microcomputer (HP200LX) acquired the data using a bipolar electrode technique (Fuglevand et al. 1992, Hermens et al. 2000), transformed the values to root mean squares (RMS), and stored these values at a rate of 10 samples per second. For further details of the method see Østensvik et al. (2007).

A period with SULMA is defined as a period with continuous (without interruptions) static muscle activity above 0.5 percent EMG_{max} for 1.6 s or longer. This means that shorter interruptions, i.e., EMG gaps that are shorter than 1.6 s, may have occurred, but were not registered as interruptions. Averages of 16 samples, each of 0.1 s duration, were analyzed for the number of periods with durations of continuous activity above 0.5 percent EMG_{max} during one working day. The averaging resulted in a slightly lower peak and a higher static level in the amplitude probability distribution function (APDF).

The number of sustained low-level muscle activity (SULMA) periods was calculated and analyzed for each of the four muscles in the following 10 predetermined intervals:

- $1.6 < x < 4.8$ s,
- $4.8 \leq x < 9.6$ s,
- $9.6 \leq x < 19.2$ s,
- $19.2 \leq x < 59.2$ s,
- 59.2 s $\leq x < 2$ min,

- 2 ≤ x < 4 min,
- 4 ≤ x < 8 min,
- 8 ≤ x < 10 min,
- 10 ≤ x < 20 min, and
- x ≥ 20 min.

The SULMA periods will for simplicity henceforth be designated as 1.6 to 5 s, 5 to 10 s, 10 to 20 s, 20 s to 1 min, 1 to 2 min, 2 to 4 min, 4 to 8 min, 8 to 10 min, 10 to 20 min, and > 20 min.

The number of SULMA periods was also expressed in 10 cumulative periods above the minimum value of the already predetermined 10 intervals designated as: > 1.6 s, ≥ 5 s, ≥ 10 s, ≥ 20 s, ≥ 1 min, ≥ 2 min, ≥ 4 min, ≥ 8 min, ≥ 10 min, and ≥ 20 min. This means, for example, that the cumulative period named > 1.6 s is the sum total of all SULMA periods above 1.6 s and so forth. Due to differences in the length of the working day, the figures are given per working hour.

The amplitude probability distribution function (APDF) was used to evaluate the static, median, and peak levels of EMG activities during one working day. The total number of EMG gaps/min below 0.5 percent EMG_{max}, the mean duration of the EMG gaps, and their total duration ("muscle rest" s/min) were calculated (Veiersted et al. 1990). The minimum values were adjusted to the lowest registered value electronically in the raw data.

Discomfort /Pain

Discomfort/pain in the upper extremities was rated within five categories according to the Standardized Nordic Questionnaire on pain (SNQ) scale (Kuorinka et al. 1987): 0 days, 1 to 7 days, 8 to 30 days, more than 30 days, and daily during the last year. The five levelled SNQ scale was then dichotomized into pain ≤ 30 days and pain > 30 days or daily.

Measurement Procedures

A mobile camping van was designed to perform all of the measurements among the machine operators at 14 different forest enterprises during the fieldwork. A questionnaire was put forward before the calibration procedure as a structured interview that included perceived physical work load. 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 wood bench, unable to touch the floor with their feet, subjects performed maximal shoulder elevations as voluntary contractions. These were performed with straight vertical arms pulling the straps that were connected to a force transducer that was mounted to a calibration platform (Premed AS, Oslo, Norway). The individual maximal shoulder elevations of the right upper trapezius muscle were used as references for the later EMG measurements (Aarås and Westgaard 1987). For further details see Østensvik et al. (2007). The EMG equipment was mounted on the body in water repellent bags where the physiometer and the portable computer were placed close to each other in separate bags connected with protected cables in the chest area. Wide adjustable longitudinal bands over the shoulders, together with a horizontal girdle with the bags attached, constituted a waistcoat adjustable both in length and width to fit anyone. The van was parked close to the worksite to achieve as long of a duration as possible for the sEMG recordings. The mean duration of the EMG measurements was 6:12 hours (3:35 to 7:48) for harvesters and 5:54 hours (2:48 to 8:12) for forwarders. Diaries were kept during the test day and contributed to the analysis of the sEMG data in terms of time schedule in relation to different work tasks.

Statistics

Differences in background variables between harvesters and forwarders were analyzed using analysis of variation (ANOVA) after confirming normal distribution of the variables (Kolmogorov-Smirnoff test). EMG data and the frequencies of SULMA periods of different duration during an entire working day were analyzed for differences between the harvester and forwarders by non-parametric tests (Mann-Whitney U-tests). Multiple stepwise regression analyses were performed in order to express the muscle work pattern in the right and left trapezius muscles as a function of supposed important variables. In a multiple stepwise regression model, "the cumulated number of SULMA periods more than 8 minutes" was selected as a dependent variable, due to earlier findings of association between number of long SULMA periods and neck pain (Østensvik et al. 2007, Østensvik et al. 2008b). As explanatory variables the following were introduced: age, duration of lunch break, dominant hand power, perceived stress in present work (scale 1 to 5), and dummy variables for married/common-law partner or not, driving Valmet or Timberjack machine, and daytime work or shift. Backward elimination was chosen as the selection procedure. The significance level of 5 percent was used in the investigation if nothing else is stated. The SAS system, release 8.02, was used (SAS© 1999) for data treatment and analyses.

Results

Timberjack harvester operators showed a significantly higher number of SULMA periods with short duration in the right upper trapezius (RUT) muscle (**Fig. 3a**). A non-significant trend ($0.05 < p < 0.10$) could be seen toward a higher number of cumulated SULMA periods > 4 and 8 min per hour in the RUT muscle among the operators in the Valmet harvesters (**Fig. 3c**). A significantly higher number of SULMA periods with a duration between 10 to 20 min in the RUT muscle were found among the operators driving Timberjack forwarders (**Fig. 3b**). The cumulated SULMA periods in the RUT muscle did not deviate between the two vehicle brands among the operators of the forwarders (**Fig. 3d**).

The operators of the Timberjack harvesters showed a non-significant trend of a higher number of short SULMA periods also in the left upper trapezius (LUT) muscle (**Fig 4a**), while the number of cumulated SULMA periods > 10 min per hour was significantly higher for the Valmet operators (**Fig. 4c**). Hardly any differences in SULMA patterns could be found between operators of the two vehicles in the LUT muscle among the forwarders (**Figs. 4b and d**).

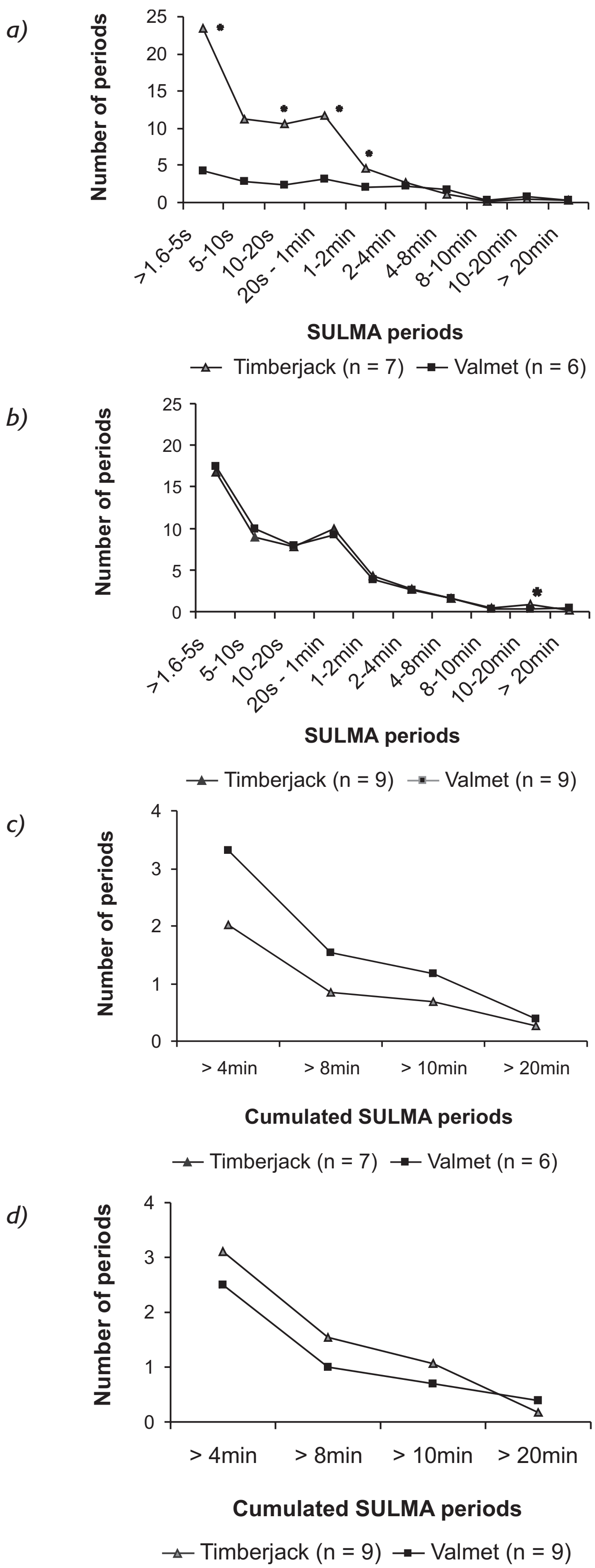

Figure 3. ~ *Number of periods with sustained low-level muscle activity (SULMA) in the right upper trapezius muscle among machine operators driving Timberjack and Valmet harvesters (a) and forwarders (b), and number of cumulated SULMA-periods for the harvesters (c) and forwarders (d).*

Table 3. ~ *Static and median muscle activity and muscle rest bilaterally in the upper trapezius and extensor digitorum muscles among operators driving Timberjack (n = 7) and Valmet (n = 6) harvesters*

		Harvesters		
Muscle group	EMG activities analyzed in APDF (units)	Timberjack (median values)	Valmet (median values)	*p*-value
Right trapezius	Static activity (10 percentile)	0.20	1.11	**0.003**
	Median activity (50 percentile)	2.21	4.70	**0.032**
	Muscle rest (s/min)	10.35	3.30	**0.010**
Left trapezius	Static activity (10 percentile)	0.21	1.04	**0.007**
	Median activity (50 percentile)	1.58	3.36	0.153
	Muscle rest (s/min)	13.34	3.07	**0.004**
Right extensor digitorum	Static activity (10 percentile)	0.20	0.26	0.886
	Median activity (50 percentile)	1.28	1.11	0.283
	Muscle rest (s/min)	9.97	14.85	0.317
Left extensor digitorum	Static activity (10 percentile)	0.28	0.35	0.943
	Median activity (50 percentile)	2.02	1.43	0.253
	Muscle rest (s/min)	10.93	10.10	0.391

[a] Numbers in **bold** are significantly different ($p < 0.05$).

In the right and left extensor digitorum muscles, no differences were found between operators in the Timberjack and Valmet harvesters or forwarders in number of cumulated long SULMA periods (**Figs. 5a, b, c, and d**) or in number of SULMA periods (data not shown).

Operators in the Valmet harvesters showed a significant five times higher level of static and median muscle activity and less muscle rest in the RUT muscles compared to those in the Timberjack. The same was the case for the LUT muscle, although the median values were not significantly different in this muscle (**Table 3**). No significant differences in EMG activities were found in the extensor digitorum muscles.

Multiple stepwise regression analyses with different explanatory variables (see methods) showed that the indicator variable "Valmet" (taking the value 1 if driving Valmet, else 0) was the most important one for explaining the variation in the number of SULMA periods > 8 min per hour for harvesters, although it was not significant (*p*-values in the range of 0.067 to 0.111). The functions for right and left upper trapezius muscle are given below:

Harvesters, right upper trapezius: number of SULMA > 8 min = 0.689 + 0.839*Valmet, n = 13, $R^2 = 0.30$, $p = 0.067$

Harvesters, left upper trapezius: number of SULMA > 8 min = 0.7242 + 0.767*Valmet, n = 13, $R^2 = 0.23$, $p = 0.111$

The ratings of discomfort/pain in the dichotomized SNQ scale showed a slightly nonsignificant higher amount of the Valmet operators who reported pain > 30 days (67%) com-

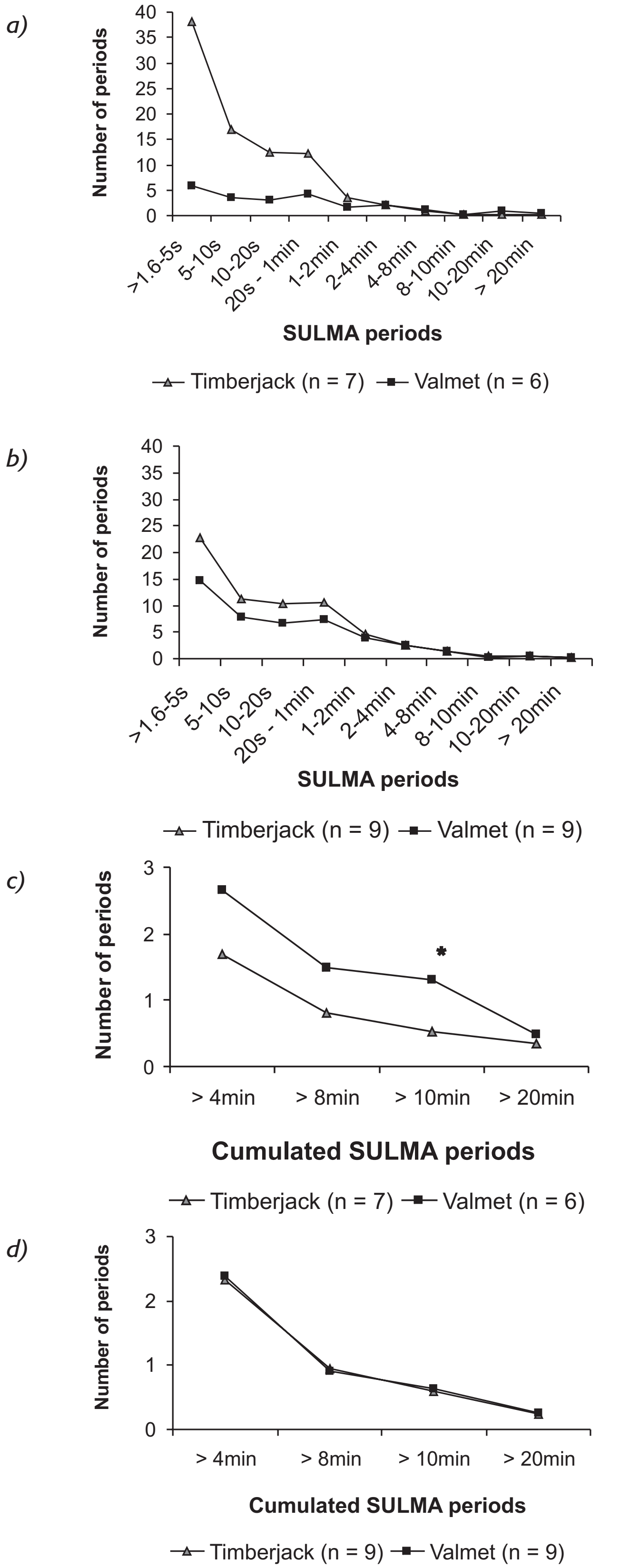

Figure 4. ~ *Number of periods with sustained low-level muscle activity (SULMA) in the left upper trapezius muscle among machine operators driving Timberjack and Valmet harvesters (a) and forwarders (b), and cumulated SULMA-periods for the harvesters (c) and forwarders (d).*

pared to the amount among the Timberjack operators (57%) (data not shown).

Discussion

The results show that the operators driving Valmet harvesters had a significantly lower number of short SULMA periods in the right upper trapezius (RUT) muscle and a non-significant tendency for a higher number of long SULMA periods compared to those in the Timberjack, while in the left upper trapezius (LUT) muscle the number of SULMA periods longer than 10 min was significantly higher among the Valmet operators. Earlier findings have shown a positive correlation between the number of long SULMA periods in the RUT muscle and discomfort/pain in the neck (Østensvik et al. 2007). The present investigation, therefore, indicates that the two brands of harvesters (Valmet and Timberjack) could, because of their different physical designs, give rise to differences in sustained low-level muscle activity and, thereby, predispose for differences in risk for neck pain. It must be stressed, however, that the number of operators in the present investigation was low and the findings were weak, and we could not directly state that there were any significant differences in reported neck discomfort/pain between the operators of the two brands of vehicles on the SNQ scale after an investigation lasting one working day. The level of static muscle activity was approximately five times higher and the total duration of muscle rest was almost four times less in the right trapezius muscles among the Valmet operators driving harvesters compared to those operating Timberjacks. The deleterious effect of static muscle activity has been stated as a risk factor for musculoskeletal disorders in several studies (Bernard 1997, Jensen et al. 2000, Jensen et al. 1993, Sjogaard et al. 2000). This also points to a negative effect on muscle work pattern among the operators of Valmet harvesters compared to those in the Timberjacks. The levels of static activity were rather low in this investigation (min 0.20% to max 1.11%) analyzed in the traditional amplitude probability distribution function (APDF). It could be argued that the level of, and the difference between the groups in, the numerical value found was small and does not have any clinical relevance. We think, however, that it is the duration and number of the static activity periods that are the most important in triggering the Cinderella syndrome, where only a few motor units are supposed to be involved.

Additionally we found that the Valmet operators had significantly shorter duration of breaks (EMG gaps) during the day. A low number of muscle rest periods (EMG gaps) has been demonstrated as a risk factor for musculoskeletal disorders (Veiersted et al. 1993). There is little evidence, however, concerning the optimum length of rest breaks (other than for heavy physical work) in industrial settings (Tucker 2003). In general, Tucker claimed that rest breaks can be an effective means of maintaining performance, managing fatigue, and controlling the accumulation of risk over prolonged task performance, and concluded that the scarcity of epidemiological evidence in this area highlights the need for more research (Tucker 2003).

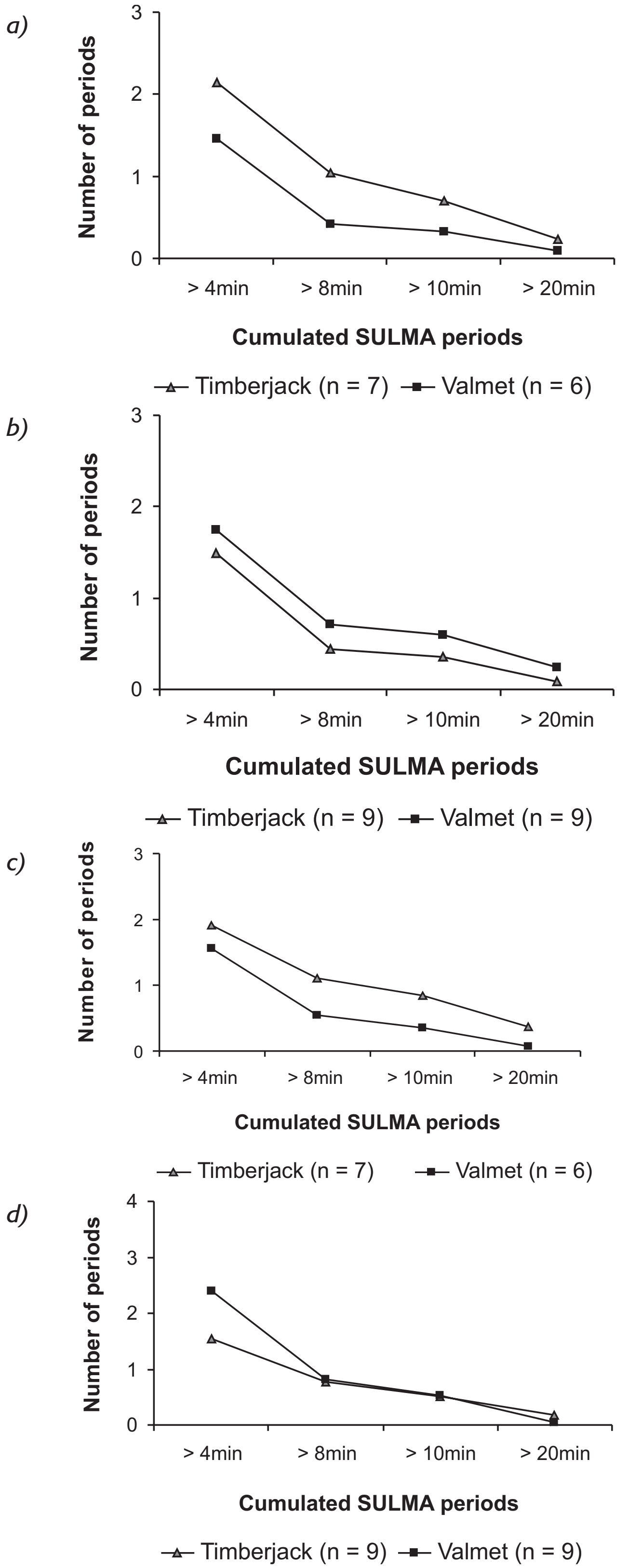

Figure 5. ~ *Number of cumulated periods of sustained low-level muscle activity (SULMA) in the right extensor digitorum muscle among machine operators driving Timberjack and Valmet harvesters (a) and forwarders (b), and in the left extensor digitorum muscle among operators of harvesters (c) and forwarders (d).*

A limitation in our study is the low number of operators investigated. Another important issue is the possibility of undiscovered confounding factors. Although we have demonstrated through the multiple stepwise regression analyses that several variables that might influence muscle work pattern or pain had no explanatory power in the analyses of number of long SULMA periods, we cannot rule out their influence. The relatively poor fit of the regression analyses, where SULMA periods > 8 min were explained by the machine brand, also opens for undiscovered factors of importance. But, given the relatively homogenous background variables of the groups operating the two brands, we suggest that the results strongly indicate that the physical construction of the brands could be of key importance.

In explaining the differences in work load between the operators in the Timberjacks and Valmets, we think the different constructions of both the control levers and the operating cranes in relation to the chassis are of high importance. The trapezius muscle activity has been reported to be lower when using a mini-lever option compared to more conventional levers (Asikainen and Harstela 1993). This might contribute to explaining the difference in effect also seen in our study, where the operators in the Timberjack harvesters worked with smaller levers compared to those in the Valmets. An additional argument may be that in a comparison between the effect of joystick handle size and display control, the short handle was recommended, also leading to a decrease or no change in physical load (Huysmans et al. 2006). This agrees with our results, in which the operators in the Timberjack harvesters had less static activity and increased duration of muscle rest in the trapezius muscle compared to those in the Valmets.

The assessment of the physical exposure to SULMA, especially when operating control levers, did not include information on the stature of the workers in relation to work equipment (Miranda et al. 2008), which, of course, is important. The seats and accessories were, however, highly adjustable and all of the operators made their individual adjustments for best ergonomic comfort, so effects of this were not focused upon in the study.

Production data, e.g., the time aspect of the working cycle of the operator and the total m^3 timber produced per day, were not included in our investigation, but rather the effect on the muscles of operating the vehicle during a whole working day.

In line with our findings, the work load among operators of Swedish harvesters required a high precision, short cycle movement pattern with the arms and hands for up to 50 to 90 percent of the working time while in a fixed sitting position, and musculoskeletal symptoms were found associated with the use of operating control levers (Grevsten and Sjögren 1996). In their study an extreme pronated position adopted for a long period of time was a risk factor causing musculoskeletal symptoms (Grevsten and Sjögren 1996). This could indicate that the differences in muscle work pattern addressed by the vehicles of different brands could give rise to discomfort/pain, even though we were not able to confirm that in our study. To improve the joystick design, an approach of modelling the joystick and operator's upper limb as a closed linkage system has been suggested (Oliver et al. 2007).

Rotatable cabins and moveable drivers are aspects of workplace design that have been claimed to be important for head posture among forest machine operators driving vehicles (Eklund et al. 1994). This principle is the way the slewing ring is constructed to rotate the cabin in the Timberjack harvester, where the crane construction forces the operators to frequent movements and rotations of the head in a way that might be advantageous compared to the operators in the Valmets, who are more or less sitting with the head in the same position whether the crane is on the right or left side of the chassis. This extra head movement could in fact be a positive variation in an otherwise negative muscle working pattern with long SULMA periods due to static postures with too few movements of the neck.

The working environment among all-terrain vehicles is considered to be harmful for the musculoskeletal system, especially for the neck and upper extremities (Rehn 2004). They claim further on, that musculoskeletal symptoms and disorders may be a result of the typical exposure situation. According to their findings, whole body vibration varies substantially, depending on characteristics of the vehicle type, driving technique, and alterations in the terrain (Rehn 2004). With reference to our findings, there could be differences in vibration levels in the investigated vehicles of different brands and this could give rise to differences in discomfort/pain. The present study was not designed to investigate these effects.

A non-significant tendency of a higher number of long SULMA periods was found in the extensor digitorum among the Timberjack harvesters compared to the Valmet harvesters, which was opposite to the muscle pattern found in the trapezius muscles. No difference in the static muscle activity and muscle rest was found for the extensor digitorum muscles between operators of the two machine types. This was surprising since the Valmet control lever leads to more use of a vertical hand posture that should reduce the muscle activity. This has previously been found for vertical mouse use (Aarås et al. 2002). The lack of findings in the activity pattern of the forearm muscles might be explained by the different anatomical structures in the forearm compared to the neck, which demand more appropriate calibration and normalization routines (Hägg et al. 2000).

Another question could be why extensor digitorum muscles were chosen and not flexor digitorum superficialis, since both play an important role in the maintenance of the grip and pinch, especially when the interphalangeal joints of the index finger are straightened (Basmajian and De Luca 1985), as was often the case in this study. Our choice was to measure the extensor digitorum muscle because the electrodes on this muscle would disturb the work being done by the operator as little as possible. In addition, extensor muscle activity has previously been associated with tennis elbow as one of the most common musculoskeletal disorders of the arm (Bernard 1997).

The study showed no differences in working pattern among the operators driving Timberjack and Valmet forwarders, even though the constructions of the control levers are very similar to those of the harvesters. The explanation is probably that control lever operation is quite a minor task in forwarder operation; the control levers are simpler with fewer functions. We believe that the operator has more variation and rest periods in the work cycle compared to the harvester operators, e.g., the possibility to use the steering system instead of the control lever while driving loaded probably gives extra release to the hand during a working day.

In conclusion, in spite of the low statistical significance, effects of different ergonomic designs between the two vehicle brands were found. The operators of Valmet harvesters had an activity pattern with a high number of long SULMA periods in the trapezius muscles, which presumably was more deleterious than that of the operators in the Timberjack harvesters. Additionally the Valmet harvesters had more static work load, less EMG gaps, and less total muscle rest, also supposed to be a risk factor for musculoskeletal disorders. No or minor significant differences were found for the extensor digitorum muscles bilaterally and for all muscle activity in forwarder operators.

Conclusions

This study indicates that harvest operators driving Valmet vehicles had a higher number of long periods with sustained low-level muscle activity (SULMA periods) in the upper trapezius muscles compared to those in the Timberjack. Since a working pattern with a high number of long SULMA periods has previously been shown to predispose for discomfort/pain in the neck region, the results indicate that the construction of the harvester (control lever and crane) might be important for the occurrence of discomfort/pain in the neck region.

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