Influence of Small Control Levers of Grapple Loader on Muscle Strain, Productivity and Control Errors

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ABSTRACT

Small-sized mini-levers were compared to conventional levers in forwarder grapple loading of timber using a forest machine simulator in clear-cutting and thinning conditions. No effect on time consumption per burden was observed, but muscle constriction in the trapezius muscle measured using EMG was lower when the mini-lever option was used. Control errors were measured by counting the contacts between the remaining trees and the machine elements. These were interpreted to result in damage to the trees. The frequency of this kind of damages was significantly smaller when using the mini-lever option.

Key Words: *control levers, forwarding, productivity, muscle constriction, control errors.*

INTRODUCTION

Forest machine operators in the Nordic countries have two main health problems: pains in the back and shoulder regions [8,10]. It is assumed that the latter is influenced by muscle constriction in the shoulders caused by the use of control levers [15]. It has been found that the levels of muscle constriction in the upper trapezius muscle are rather high despite well-adjusted seats and good location of levers when using the conventional dual-lever system [1]. Lindbeck [12,13] found dependencies between lever resistance and electromyograms (EMG) of the deltoid muscle and between movement span and EMGs of the trapezius muscle. As a result, small-sized levers were introduced.

These "mini-levers" can be moved with the fingers without the operator having to move his arms. The first results obtained from tests conducted using simulators and real-life forwarders and harvesters in the field indicate lower muscle constriction levels in the trapezius muscle without any reduction in productivity [5,9].

In order to find out if these results are valid in the difficult thinning conditions, additional simulator experiments were made in the course of this study.

Another reason for studying the use of mini-levers was the hypothesis that very short movements made with the fingers may be more likely to lead to control errors. On the other hand, the nerve-muscle system in the fingers facilitates high precision of movement [2].

As argued above, the hypotheses of this study are:

- Mini-levers diminish the movement span of control levers and therefore the need to move the arms. This in turn reduces muscle constriction in the trapezius muscle.
- The above is also true in thinnings, although the need to avoid injuring the remaining trees increases the need to move levers and possibly imposes mental stress on the operator, which may promote muscle constriction in the shoulders.
- The short movement span of mini-levers may increase the frequency of control errors and of damage to the remaining trees. This, however, may be compensated by the enhanced ability of the nerve-muscle system in the fingers to execute precise movements.

MATERIAL AND METHODS

Muscle constriction, time consumption per log in loading a forwarder and the damage caused to remaining trees were chosen to be the dependent variables. The independent variables were control lever type (conventional and mini-lever), work conditions (clear-cutting and thinning), time passed from the beginning of the working day, time passed from the beginning of loading and the performance rate of the operator.

Experiments were conducted using a forest machine simulator consisting of normal-sized control devices and miniature forest and forwarder components in scale (1:7).

The machine elements move in a mock forest from one extreme position to another at maximum

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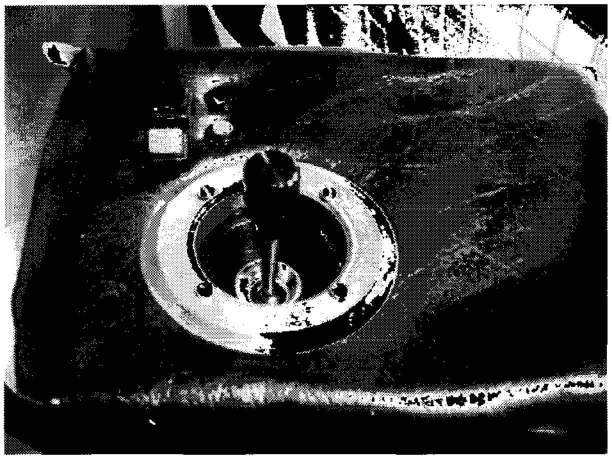

Figure 1. Mini-lever.

speed corresponding to the time consumption when operating a real-life forwarder. Consequently, the reaction time required is the same as that required of a real-life forest machine operator. The simulator used in this study has been illustrated previously in detail by Harstela and Maukonen [6]. The control levers used in the study were conventional (m/PikaX) levers and self-made mini-levers. The height of the former was 175 mm and latter 50 mm (Figure 1). The lever resistance of the former was 3.9 N - 11.8 N and that of the mini-levers 1.3 - 2.0 N. Control motions associated with mini-levers are similar to ordinary ones exept minor differences in opening/closing and rotating the grapple.

The simulator was chosen for the experiments because it allows the application of identical conditions for comparing the two lever types. It is also a low-cost and fast method for producing results that can then be confirmed by field studies. The direction of observations and the work position in the simulator were standardized without altering individual adjustment requirements. This enhances the reliability of comparing the influence of the variables studied.

Four healthy male students were selected to be the test subjects. All subjects were righ-handed. Two of them had previous experience in operating forest machines and all of them were trained to operate the simulator using both conventional and mini-levers. The main characteristics of the test persons are presented in Table 1. The physiological characteristics of the test persons were not measured, because all EMG values were presented as percent of MVC. In comparative studies, controlling operators' characteristics is not as important as in other kinds of studies, because the influence of muscle strength, for example, is of the same direction in all cases compared and its influence on relative values is small. The seats and the arm rests were adjusted individually as well as possible for all test persons.

Table 1. Anthropometric data on test persons.

No	age,yr	length,cm	weight,kg
1	28	184	72
2	38	185	105
3	24	182	75
4	18	178	65
	X̄=27.0 sd= 7.3	X =182.3 sd= 3.1	X =79.3 sd=17.7

With the training period over, the research material was collected in four days in the following order:

Day	Morning Session	Afternoon Session
1.	Conv./thinning	Mini/thinning
2.	Mini/clear-cut	Conv./clear-cut
3.	Conv./clear-cut	Mini/clear cut
4.	Mini/thinning	Conv./thinning

The spacing of the remaining trees in thinning corresponded to 1,000 trees per hectare. The number of the logs to be loaded for each forwarder load was 26 and the number of loads per session varied from two to four.

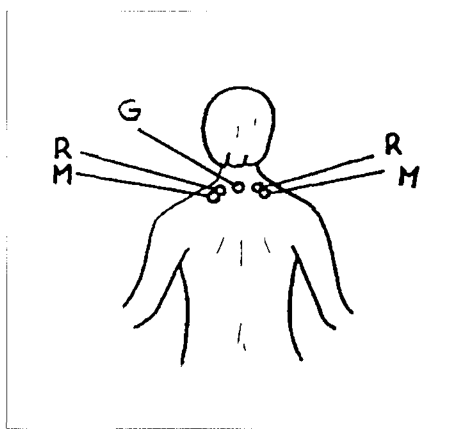

Figure 2. Electrode location. M = measurement, G = ground, R = reference.

Electromyograms (EMG) were taken using ME-10 RI (test persons 1 and 2 left side) and ME-3000 equipment and they were analysed using the root mean square (RMS-EMG) method. The recording interval of ME-10 RI was 0.1 s and that of ME-3000 was 1 s because of different signal processing. Electrodes were placed on the upper trapezius muscle as shown in Figure 2. The trapezius muscle alone was chosen as the object of study because it is the biggest muscle in the shoulder-arm system and the pains reported by operators focusing on this system are, generally, severest in this muscle.

Correlations between muscle constriction and RMS-EMGs have been observed to be very strong in former studies. The electrodes were placed every day as close as possible to the same places. The EMG value for the maximum voluntary constriction was measured every morning and the results were calculated as relative values of these maximum values (%MVC). A video-based time study was made using an electrical data logger. Regression analysis with dummy variable technique was applied in the analysis.

RESULTS

Muscle Constriction

Regression analyses were made of RMS-EMG in the trapezius muscle separately for both sides of the muscle. The following models include all the statistically significant variables according to the t-test($p < 0.001$). Because of the skewed distribution, it was necessary to carry out a logarithmic conversion of the EMG values.

Right trapezius:

$$LN(EMG) = -1.13 + 1.55S_1 + 0.98S_2 + 0.69L + 0.02T - 0.04N + 0.06C + 0.31E_1 + 0.02E_2 + 0.62E_3 + 0.68E_4$$

$$R^2 = 0.54,\ P_F = 0.000$$

Left trapezius:

$$LN(EMG) = -1.91 + 2.20S_2 + 0.40L + 0.03T + 0.26C - 0.03N + 0.45E_1 + 0.43E_2 + 0.51E_3 + 0.68E_4$$

$$R^2 = 0.72,\ P_F = 0.000$$

where:

EMG = RMS-EMG, %MVC

S_1, S_2 = dummy variables indicating the test persons

L = dummy variable, conventional lever = 1, mini-lever = 0

T = time passed from beginning of an experiment day, min.

N = ordinal from beginning of a repetition

C = dummy variable: thinning=1, clear-cutting=0

E_1-E_4 = dummy variables indicating work elements.

The EMG-values were significantly lower when using the mini-levers as compared to using the conventional ones. A bigger difference was observed to

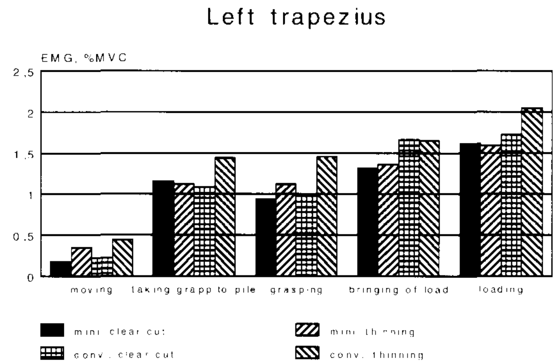

Figure 3. Muscle constriction during different work elements, left side.

apply to the right side of the trapezius muscle. Working in thinning conditions also caused higher EMG-values than in clear-cutting conditions. This is illustrated by Figures 3 and 4, showing the EMGs for each work element of loading. Straightening of logs in the load (loading) was the most strenuous

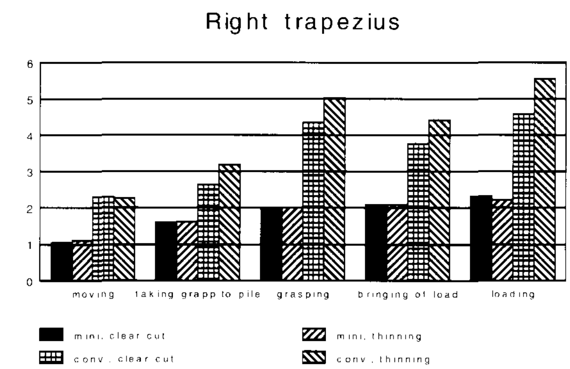

Figure 4. Muscle constriction during different work elements, right side.

work element. The other variables showing a significant intercorrelation with EMGs were the test person, time passed from the beginning of the experiment day and the ordinal from the beginning of the repetition.

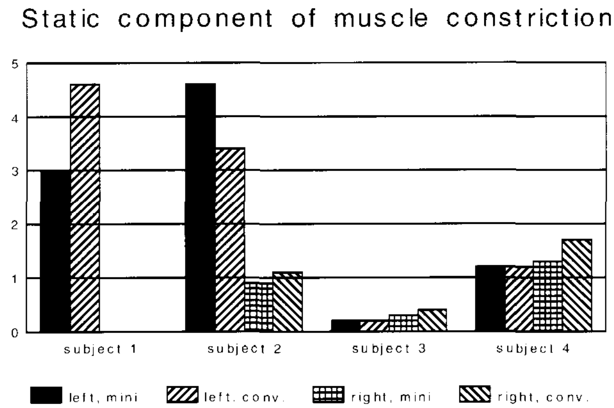

Figure 5. Static muscle constriction.

The static EMG component was measured by calculating the 10% fractile [8]. The results are presented in Figure 5. The static muscle constriction for all test persons was lower for the right trapezius muscle when using the mini-levers as compared to using the conventional levers. In the regression analyses, the only significant variable was the test person. The results for the left side of the muscle were contradictory. As seen in Figure 6, the EMG values changed very rapidly from one measurement moment to the next at intervals of one second. Thus it is problematic in the case of such a muscle as the trapezius if the static muscle constriction measured using the above method is a bigger source of circulatory problems than medium constriction.

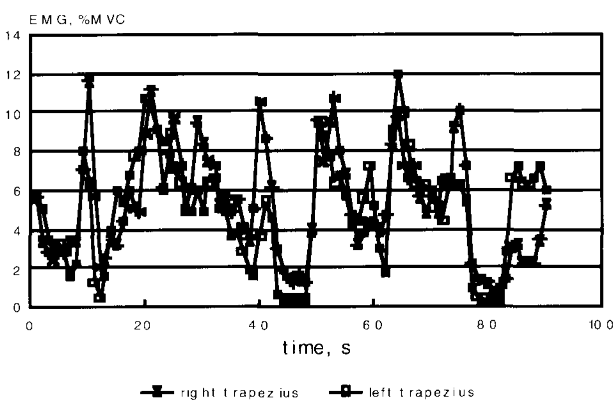

Figure 6. EMG-sample.

Figure 5 indicates that most static values of EMG were below the exposure limits for injurious constriction (2-5 %MVC) as suggested by Jonsson [7], for instance. The left side static values of only test persons 1 and 2 exceeded these limits.

Time Consumption and Control Errors

Time consumption per log in loading was used as the variable describing the performance rate. It was analysed using the following regression model.

$$t = 61.35 + 12.59\,S + 9.56\,C - 9.29\,\ln N$$
$$R^2 = 0.65,\ P_F = 0.000$$

where:

t = time consumption per log. cmin.
S = dummy variable : test person 1=0. others=0
N = original from beginning of a repetition
C = dummy variable: thinning=1. clear-cutting=0

The type of the control lever was not a significant variable in the analysis. As is known from studies in real-life conditions, work conditions and the human factor explain a big part of the variation in time consumption. The logarithm of the ordinal from the beginning of the experiment was also a significant dependent variable most likely indicating the learning process, especially in the beginning of the experiment.

The frequency of damage to the remaining trees in thinning conditions was an independent variable in the regression analyses. All contacts between the remaining trees and the machine elements were recorded as incidents of damage. In this way they were assumed to illustrate control errors and thus the precision of control actions. One value of the variable corresponds to one load. The model used with all test persons was the following one.

$$D = 20.70 + 1.92L - 16.63S_1 - 3.82S_2 + 2.23S_3 - 0.08t$$
$$R^2 = 0.65,\ P_F = 0.000$$

where:

D = damage to remaining trees. number per repetition
L = dummy variable: conventional lever=1, mini-lever=0
S_1, S_2, S_3=dummy variables indicating test persons
t = time consumption per log, cmin

Working with mini-levers caused significantly less damage than when using conventional levers. Another damage factor was time consumption per log. An increase of about 20% in the performance rate influenced the frequency of damage as much as changing over from conventional levers to mini-levers. The differences between the test persons were great, but in real-life conditions not all contacts with the remaining trees lead to actual injury to the tree. Therefore, the differences between operators and the frequency of damage to remaining trees may be smaller than in this study.

DISCUSSION

Working with mini-levers as compared to conventional levers did not influence time consumption in grapple loading in the case of the forest machine simulator, but it did lead to lesser muscle constriction in the trapezius muscle as measured by RMS-EMG. This was especially true of the median and mean values. These results agree with earlier ones [5,9]. The results for the lowest EMG fractile of 10% were not as clearly unambiguous, but it is still unclear as to how static muscle constriction should be measured.

Follow-up studies among forest machine operators have indicated that pains in the neck, shoulders and arms have decreased once the persons in question have started to use mini-levers [3]. Some contradictory cases have been reported but these are most probably due to incorrect adjustment of the levers. If the levers are too far from the arm rests, moving the levers may require the use of the arms instead of only the fingers.

The smaller amount of damage inflicted on the remaining trees when using mini-levers indicated an even greater precision of control motions as compared to using conventional levers. Although accurate motions are, generally speaking, easier to execute with longer movement spans, the hand and the fingers with the small muscles of the distal joints are especially suitable for executing short, fast and precise movements typical for mini-levers. Conventional levers are mainly moved with the bigger muscles of the arms [2]. In field conditions forest machine vibrations may effect on the accuracy, but in a preliminary experiment with one test subject no difference was detected.

While the EMG-values (%MVC) were below the exposure limits for injurious constriction, it must be borne in mind that working with a simulator is a simplified work situation as compared to actual forest machine operation. The EMG values obtained in field studies have been much higher [1]. The aim here was only to produce comparable relative values for the two lever types.

RMS-EMG is not the best method for measuring muscle fatigue. The increased use of the method has, however, indicated muscle fatigue in some studies while other studies report no changes to have taken place [10,13,14]. In one study even the lifting up of the arm resulted in decreasing trapezius muscle values [4]. In this study, most of the test persons displayed an increasing tendency in this direction during the experiment day, but there were some exceptions too. A spectral analysis would be required to provide proof of possible muscle fatigue [11].

Mini-levers replace arm movement with finger movement. Whether this results in new problems is not certain. A new ailment has been reported among people working with VDUs. This is most probably caused by working with the fingers. Scientific research results on the relations between the symptoms and work are still lacking.

In a follow-up study done among forest machine operators, the symptoms in the fingers and arms decreased after a twelve-month period of using mini-levers [3]. The proper adjustment of the levers and the arm rests, together with "finger gymnastics" during rest periods, may lead to positive experiences with mini-levers.

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