A Comparison of Motor-Manual Cleaning Methods on the Norwegian West Coast

D. Fjeld
Norwegian Forest Research Institute
Bergen, Norway

K.B. Hagen
National Institute of Public Health
Oslo, Norway

ABSTRACT

Time consumption, heart rate, sagittal load moments for the low back, perceived exertion, and tool preferences were measured during motor-manual cleaning with chain saws and cleaning saws in western Norway. While no difference was found in heart rate or perceived cardiovascular exertion, the chain saw was observed to have the lowest time consumption per ha of the two tools. Calculated sagittal load moments and local feeling of strain in the low back were significantly higher for the chain saw than the cleaning saw. The difference in time consumption between the two tools was greatest for the least experienced personnel in steep terrain. However, because of the higher risk for low back pain, the chain saw could only be recommended on relatively steep slopes. The cleaning saw was preferred most often by the most experienced forestry workers in stands of high removal density.

Keywords: *Cleaning, motor-manual tools, productivity, ergonomics, forestry.*

INTRODUCTION

Much of the forest area on Norway's west coast consists of steep terrain. Spruce plantations in these areas often have a high site index and an abundance of deciduous vegetation. Even under these conditions, restrictions are being applied to the use of chemical vegetation control.

Costs are normally the dominant criteria for the choice of operating methods. Earlier studies have shown that the productivity of mechanized cleaning is influenced primarily by the number of residual stems and how easily they may be avoided with the cleaning head [4]. Studies of motor-manual cleaning showed that time consumption is influenced primarily by the number and size of removed stems [9]. Due to these basic differences, mechanized cleaning has the potential to be less costly than motor-manual cleaning in stands of high initial density.

Mechanized cleaning is technically possible in stands with relatively easy terrain where the crop trees are small enough to be straddled by the prime mover [4]. Over 50% of the forest area on Norway's west coast, however, has a ground slope of 33% or greater. In addition, rapid height growth makes these stands technically inaccessible after just a few years. In most cases young stands in western Norway are, therefore, not suitable for mechanized operations. As a result, the cleaning of plantations in western Norway is dominated by motor-manual methods. Under normal conditions, the use of a chain saw for cleaning would be seen as ergonomically unacceptable because of the stooped working position. However, the introduction of the cleaning saw in this region has not resulted in the same widespread use as in the other Nordic countries. The objective of this study is thus to examine the use of these two tools and to determine which is most suitable under Norwegian west coast conditions.

METHODS

The study was divided into two main parts according to the organization of the working day. The first part compared the two tools in detail during the actual cleaning of the stand. A detailed analysis of time consumption and ergonomic measures was made for each method under the same forest conditions. In the second part the distribution of time for all work at the work site was examined. This analysis was done using gross production statistics. This was necessary to determine the per cent of the time on-site that consisted of effective cleaning work.

Detailed Comparison Studies

The detailed comparison study was designed as a randomized block design. Each block was 0.1 ha in size and contained two identical treatment units that were cleaned by the same forestry worker. The cleaning was done in corridors parallel to the contour lines of the terrain.

The authors are Senior Scientist, Norwegian Forest Research Institute, and Senior Scientist, National Institute of Public Health, respectively.

Forestry Workers and Study Areas

Seventeen professional forestry workers performed the cleaning work. These individuals were selected as study subjects because they were the most experienced workers available in the municipality where the block was located. All were males and their age ranged from 20 to 56 years. All had considerable experience with the use of the chain saw from both cutting and cleaning work. Six had less than 0.5 year experience (continuous man-years) with the cleaning saw. Six had between 0.5 and 1.5 years experience. Five had more than 1.5 years experience with the cleaning saw.

The forest workers used their own equipment and were instructed to work at their usual pace. The workers were instructed to remove competing deciduous trees which were taller than one-third of the average crop tree height. The cleaning saws weighed 8 to11 kg and had a motor power of 2 to 3.1 kW. The chain saws weighed 5 to 6 kg and had a motor power of 2.0 to 2.7 kW. Most of the cleaning saws had a blade diameter of 20 cm. Most of the chain saws had a bar length of 33 cm.

The productivity analysis was based upon thirty-four study blocks. These were distributed throughout 18 municipalities along the west coast from Rogaland county in the south to Trøndelag in the north. The blocks were placed in various forest and terrain conditions. A number of independent variables were estimated for the forest and terrain conditions within each block. These included the average and dominant tree height, average stand density before and after cleaning, and average ground slope. Between 5 and 10% of the area was systematically sampled with circular plots of 2 m radius.

The average dominant tree height for the 34 blocks was 5.3 m (range: 2–10 m). The average ground slope was 39% (range: 0–88%). The average tree height and stand density was 3.0 m and 34,000 trees per ha, respectively. The average density of residual crop trees after cleaning was 2,355 trees per ha. The stands with the highest number of trees removed were those that had the highest initial density. The same stands normally have the smallest trees. The stands with the highest number of trees removed are, therefore, normally associated with the smallest trees. This is shown below for the present study (Figure 1).

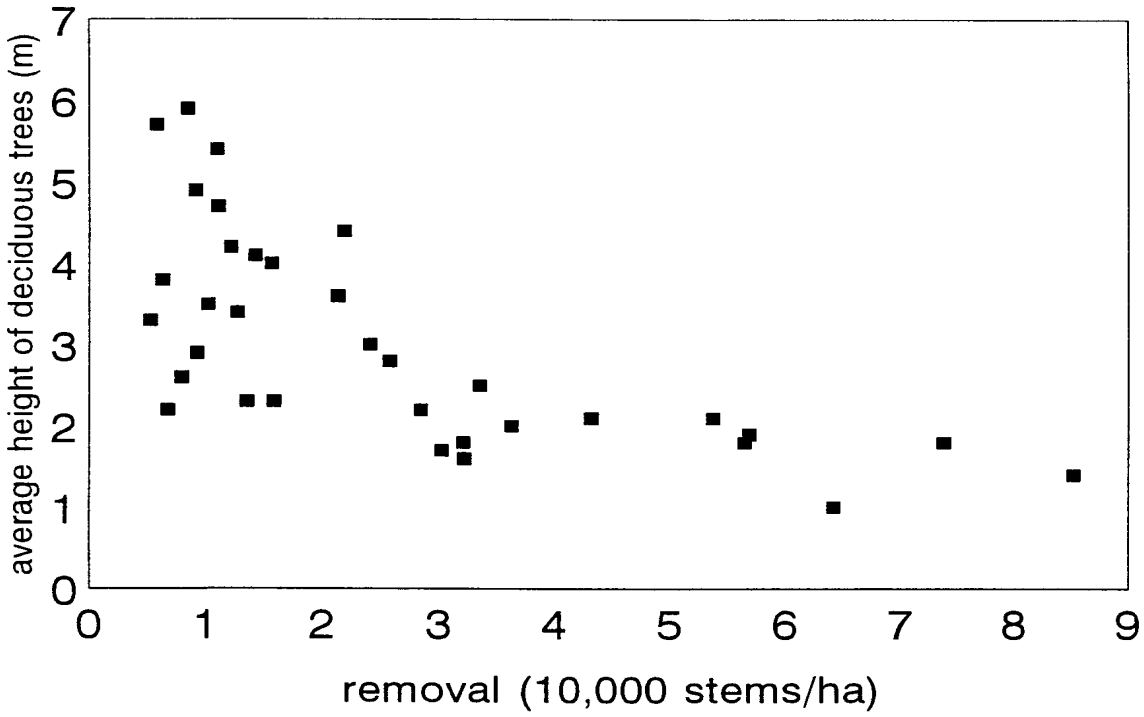

Figure 1. The average height of the deciduous trees (y-axis) and number of trees removed during cleaning (x-axis) for thirty-four blocks in western Norway. The ergonomic analysis was based upon 18 blocks. These were considered to be a representative sub-sample of the initial 34 blocks.

Variables

The analysis of time consumption in the detailed comparison studies was based upon one dependent variable,main work time consumption (MWt) per ha, which is defined by the IUFRO basic time concepts [2] as the time that is used to change the work object with regard to its form, position, and state within the definition of the work task. The main work in this study is defined as the actual felling of the trees and the walking between them. The main work time in the IUFRO nomenclature is assumed to be equivalent to the effective work time (E0) in the Nordic Forest Work Study Nomenclature [7].

The ergonomic analysis examined four dependent variables: heart rate, sagittal load moments in the lower back, "central" perceived exertion for the cardiorespiratory system, and "local" feeling of strain in the lower back.

The subject's heart rate was sampled at one minute intervals during the cleaning of each treatment unit. This was done with a modified version of the heart rate monitor Sport Tester PE3000 (Polar Electro Oy, Finland). A number of examples of saggital load moments for the lower back were calculated using the computer program 2D Static Strength Prediction Program (The Center for Ergonomics, Michigan, USA). Program inputs included the subjects' anthropometry, body posture, as well as the load acting upon the hands. Body postures and joint positions were estimated from photos taken during the field work (Figure 2).

The forestry workers were asked to assess their perceived exertion during the cleaning work. They indicated their "central" perceived exertion for sensations involving the cardiovascular system three times during the cleaning of each treatment unit, whereas "local" strain of the lower back was indicated at the end of the cleaning of each treatment unit. The central and local perceived exertion was rated on a standardized numeric scale from 6 to 20, commonly known as the Borg RPE scale [3]. Every second number is accompanied by the following descriptive words: 7 = very, very light, 9 = very light, 11 = fairly light, 13 = somewhat hard, 15 = hard, 17 = very hard and 19 = very, very hard.

Since heart rate, central perceived exertion, and local feeling of strain in the lower back are measures of the individual's strain, comparisons of the ergonomic measures between subjects are not valid. Two mean values of heart rate and central perceived exertion were therefore calculated for each block, i.e., one for each treatment unit (chain saw and cleaning saw). To test for the significance of differences in the ergonomic parameters between the two types of tools, the paired t test was used. This was done by reducing a matched pair to a single sample by considering the difference between the two.

After both treatment units had been cleaned, each subject's personal tool preference was also recorded (for all 34 blocks). This evaluation included both ergonomic and work efficiency considerations, i.e., an overall tool preference.

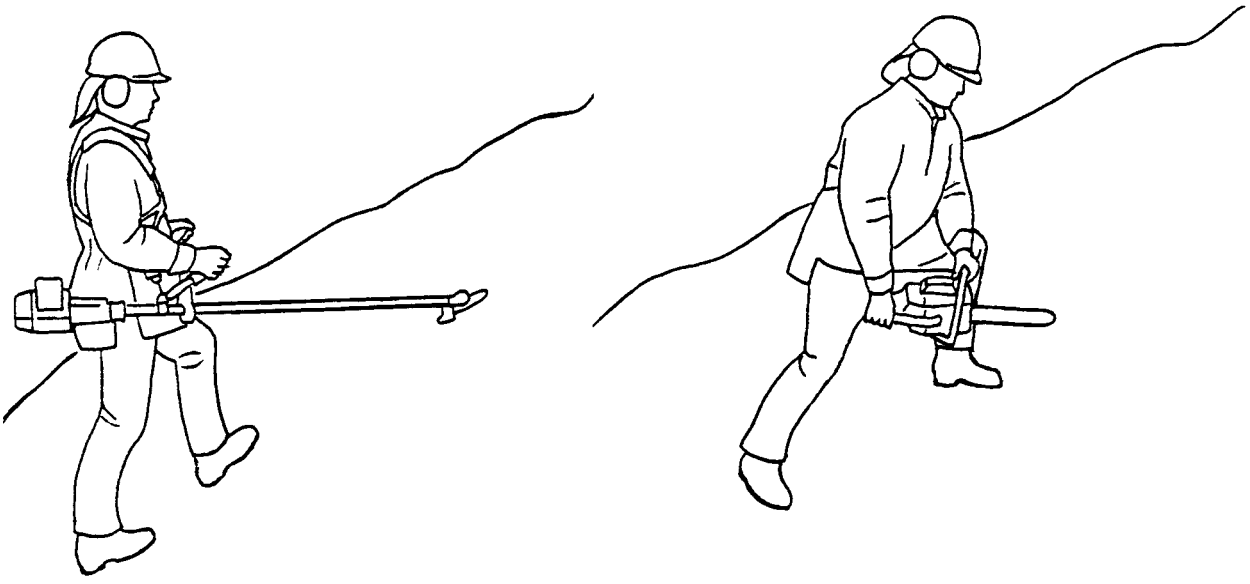

Figure 2. Body posture while cleaning on a 40% slope with the chain saw and cleaning saw.

Gross Production Statistics

Forestry Workers and Study Areas

Eleven of the previously studied forestry workers supplied gross production statistics for normal cleaning operations. These data were collected for 62 stands where the workers themselves chose the tool they preferred. Twenty-four of these stands were cleaned with chain saws and 27 were cleaned with cleaning saws. Eleven were cleaned with a combination of the two tools. The average size for these stands was 2.1 ha (range: 0.2–22 ha). The average dominant tree height was 4.8 m (range: 1–11 m). The average slope was 20% (range: 0–60%). The average walking distance from the stand to the nearest truck road was 277 m (range: 0–2000 m).

Variables

The gross production statistics recorded the utilized time per site. Utilized time (Ut) is defined in the IUFRO basic time concepts [2] as the period of time that a production system or part of a production system is occupied, directly or indirectly, to complete a specified work task. The registration of utilized time was further divided into direct (DWt) and indirect work time (IWt). The direct work was further subdivided into the main work (MWt) of cleaning plus complementary work (CWt) such as walking from the truck road to the stand edge. Unavoidable delay times (UDt) such as the clearing of paths were also recorded as part of the direct work time. The work of preparing the saw in the morning (Pt) or maintenance during the day (Mt) was included in the indirect work time. The relocation time (Rt) that was used to move between work sites was also included in the indirect work time. Meal times and the time for commuting to the work site were not considered a part of utilized time.

To simplify the collection of the statistics the main work time was allowed to include delays shorter than five minutes. The main time, which is registered in the gross production statistics, is therefore the equivalent of gross effective time (E5) in the Nordic Forest Work Study Nomenclature [7]. Nine of the forestry workers were also studied in detail during normal cleaning operations. The purpose for this was to find out which proportion of the gross effective time (E5) consisted of delays shorter than five minutes.

Statistical Analysis

Statistical analysis was done with the SAS computer package (SAS Institute Inc., USA). A number of different procedures were used, including PROC TTEST, PROC ANOVA, PROC GLM, and PROC REG [8].

RESULTS

Detailed Comparison Studies

Labour Productivity

The average main work time consumption was 16.1 hr/ha for the chain saw and 18.6 hr/ha for the cleaning saw. The coefficient of variation (std.dev./avg.) was 55% for the chain saw and 52% for the cleaning saw.

A GLM analysis of variance showed that there were a number of independent variables that had a significant influence upon time consumption per ha. These variables were common for both the cleaning saw and the chain saw. The influence of these variables upon time consumption was estimated with linear regression. The regression analysis resulted in one function for each tool that described the main work time consumption per ha. The two functions are shown below.

Formula 1 - chainsaw

$$\text{hours/ha} = 7.713 + 3.540(\text{removal})10^{3} - 3.196(\text{removal}^{2})10^{-} + 2.800\left(\frac{\text{slope}^{1.5}}{\text{experience}}\right)10^{3} \quad (1)$$

$R^2 = 0.43$, $p < .001$

Formula 2 - cleaning saw

$$\text{hours/ha} = 7.447 + 5.110(\text{removal})10^{3} - 5.056(\text{removal}^{2})10^{-} + 3.640\left(\frac{\text{slope}^{1.5}}{\text{experience}}\right)10^{3} \quad (2)$$

$R^2 = 0.60$, $p < .001$

An analysis of variance showed that the difference (Di=Yi-Xi) in time consumption between the matched pair of the cleaning saw (Yi) and the chain saw (Xi) was also influenced by the ratio between the ground slope and the worker's experience. The influence of this variable was estimated by linear regression. The function is shown below and in Figure 3.

Formula 3 - Di = cleaning saw - chain saw

$$\text{hours/ha} = 1.567 + 1.05\left(\frac{\text{slope}^{1.5}}{\text{experience}}\right)10^3 \qquad (3)$$

$R2 = 0.19$, $p < .01$

Table 1. Heart rate (HR in beats / min.), central perceived exertion (CPE), sagittal load moment (SLM in Nm) and local feeling of strain (LFS) in low back for the study blocks selected for ergonomic analysis. Differences (Dj=chain saw - cleaning saw) with p-values greater than 0.05 were considered as not significant (ns).

	Chain saw	Cleaning saw	Dj	Paired t test
HR	129.6	129.7	-0.1	ns
CPE	13.15	13.06	0.09	ns
SLM	156.3	14.1	142.3	<.001
LFS	12.96	10.96	2.0	<.001

Figure 3. The difference in effective time consumption between the cleaning saw and the chain saw (Di = cleaning saw - chain saw) as a function of the ratio between ground slope and the forestry worker's experience. Thirty-four blocks and seventeen forestry workers in western Norway.

Ergonomic Measures

As shown in Table 1, no significant difference was found in heart rate or central perceived exertion between the two cleaning methods. However, the estimated spinal sagittal load moments and the corresponding subjective measure, feeling of local strain in the lower back, was significantly higher for the chain saw than for the cleaning saw.

Tool Preference

After each block had been cleaned, the subject's personal tool preference was registered, considering both ergonomic and work efficiency aspects. For 14 blocks (41%) the chain saw was preferred, whereas for 16 blocks (47%) the cleaning saw was preferred. For four blocks (12%) the two tools were appraised as equal.

Some interesting differences in forest conditions and work experience were observed between the blocks where the different tools were preferred. The average removal was significantly lower (t test, p=0.02) for those blocks where the chain saw was preferred (1366 trees/ha) than for the cleaning saw (2833 trees/ha). The average work experience with the cleaning saw was also significantly lower (t test, p=0.05) for those blocks where the chain saw was preferred (0.44 year) than for the cleaning saw (1.32 years).

Gross Production Statistics

The utilized time at the work site consisted of 91.6% direct work time (DWt) and 8.4% indirect work time (IWt). Ninety-four per cent of the direct work time consisted of main work time (MWt including delays up to five min.). This means that the forestry workers used on average 71.2 minutes of utilized time per 60 minutes of the recorded main work time. These results appeared to vary slightly between the different tools but the differences were not found to be statistically significant. The coefficient of variation for this ratio (Ut/MWt) was small (6.7%). The detailed study of normal cleaning operations showed that each hour of main work time required an additional 6.3 minutes of delays that were shorter than five minutes each in duration. These results were almost identical for the two different tools. The coefficient of variation for the ratio between main work time with and without shorter delays was small (CV=3.3%).

The ratio between utilized time and main work time was found to vary significantly with the walking distance between the truck road and the stand ($p<0.05$). Table 2 shows the true ratio between utilized time at the work site (Ut) and the main time of effective cleaning work (MWt excluding shorter delays). These values have been corrected such that the shorter delays are moved from main work time to unavoidable delay times (UDt).

Table 2. The ratios between utilized time (Ut) and main work time (MWt) for different walking distances (m) from the road to stand.

Ut/MWt			
Walking distance (m)			
Avg.	**<500**	**500-1500**	**>1500**
1.31	1.30	1.33	1.39

Some differences were also observed between the conditions where the different tools were chosen for use. The average dominant tree height was greater for those work objects where the chain saw was used (6.45 m) than where the cleaning saw (3.67 m) was used. The average work object size was also smaller where the chain saw was used (0.9 ha) than where the cleaning saw was used (2.2 ha).

Synthesis

The utilized time consumption per ha (Ut hours/ha) was calculated by multiplying the regression functions for main time consumption (formulas 1 and 2) with the average ratio for Ut/MWt (Table 2). The results are shown in Figure 4.

DISCUSSION

Detailed Comparison Studies

The detailed comparison studies showed a higher average main work time consumption for the cleaning saw than for the chain saw. There may be a number of reasons for this that are related to the study conditions. First, while the average deciduous tree height in the stands was not unusual (3.0 m), the average dominant height in these stands was 2.4 m higher. This means that there must have been a considerable number of large trees in the removal, i.e., trees large enough to make felling with the cleaning saw difficult. Second, the average ground slope was steep (40%). In this type of terrain the larger cleaning saw may be more awkward to manoeuvre, particularly for less experienced personnel. Even though the average experience with the cleaning saw in this study was acceptable (approx. 1 continuous man-year) the variation in this factor was shown to have a significant effect upon the difference in time consumption between tools, particularly on steeper slopes. This should be communicated to forest workers during training.

Over 75% of the utilized time at the work site consisted of main work time. Since the coefficient of variation for this portion of time was so large a suitable choice of transformation is important. The particular transformations which were used in the regression analysis were chosen because of their influence upon slope. Take, for example, the influence of removal density upon time consumption. Given that the most dense stands consist of the smallest trees with the shortest distance between

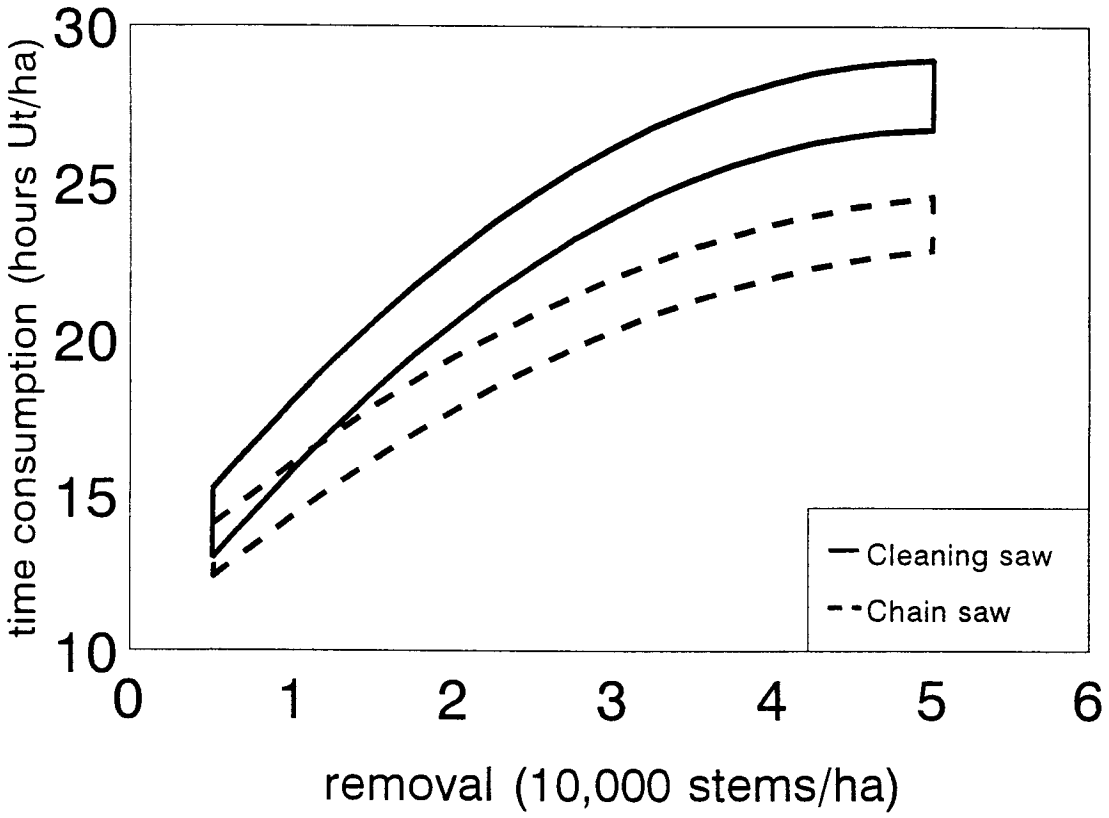

Figure 4. An example of the utilized time consumption (Ut hours / ha) for cleaning work with the chain saw and the cleaning saw. The figure shows the influence of the number of stems removed and the slope of the terrain. The lower boundary of each curve is for flat terrain and the upper boundary is for a 60% slope.

them, the felling time per tree will be lower. This means that the influence of removal density upon time consumption per ha should flatten out at high removal densities because of the shorter felling time per tree. The second degree polynomial transformation allows the curves to flatten out in a manner that is logical. The regression results of this transformation, however, are only valid up to a removal density of approximately 50,000 stems per ha.

Another example is the exponential transformation in the ratio between ground slope and worker experience, which is shown in Figure 2. The ratio between ground slope and worker experience can be better expressed as the product of two transformations: (ground slope) 1.5 and (worker experience) -1.0. In this study, horizontal area is used for all calculations, not slope area. This means that the steeper the terrain, the greater the walking distance along the slope that is required to clean the same horizontal area. The effect may be compounded by the increased time required per metre of travel in steep terrain. A power transformation (ground slope) 1.5 is used to express the increased effect of terrain upon time consumption on steeper slopes where movement is most difficult. The inverse transformation of worker experience yields a lower time consumption for higher levels of experience. The use of this transformation gives the greatest regression slope at low levels of experience and lowest regression slope at high levels of experience.

No difference in heart rate and perceived cardiorespiratory exertion was found between the two working methods. However, both the estimated spinal sagittal load moments and corresponding feeling of strain in the lower back, were significantly higher for the chain saw than the cleaning saw. Since a combination of subjective and objective measures has been found reliable to assess both the local and central work loads for different types of work tasks [5], we can confirm that the cleaning saw is generally preferable from an ergonomic point of view.

Regarding the spinal load, the biomechanical analysis in the present study is two-dimensional, i.e., only forward bending movements were analysed. Since also lateral bending and twisting of the trunk have been cited as risk factors for low back pain [1], three-dimensional analyses should be carried out for a complete evaluation of the load acting on the lumbar spine during work.

The ergonomic variables are mainly measures of individual strain. Therefore the present study design does not allow us to investigate the influence of forest and terrain conditions on these variables (i.e., each subject has cleaned a limited number of study blocks). Regarding the cardiovascular measures, we would expect that an increasing ground slope would not favour the cleaning saw, given its weight and size. Clearly, an increasing ground slope also will decrease the difference in spinal load between the two tools, since the trunk flexion can be minimized when felling trees with chain saws in steep terrain.

In Figure 4 the intervertebral disc compression in the lumbar spine (L5/S1 level) is simulated for one of the subjects when felling with a chain saw under different terrain slopes. The calculated values are compared to defined hazard levels specified by NIOSH [6]. The Action Limit (AL) is established at a compression force of 3400 Newtons[770 lb] about the L5/S1 joint, and can be tolerated by most people. The Maximum Permissible Limit (MPL) is established at about 6400 Newtons[1430 lb], and cannot be tolerated by most people. Lifting tasks resulting in compression values between AL and MPL are considered unacceptable without administrative or engineering controls. As shown in Figure 5 the spinal compression values are above AL at 0% and 30% ground slope and below at 60% and 90%, indicating that the spinal load is acceptable when felling with a chain saw at ground slopes of 60% or higher. However, the influence of terrain and forest conditions on the ergonomic measures should be studied more fully, before drawing any conclusions.

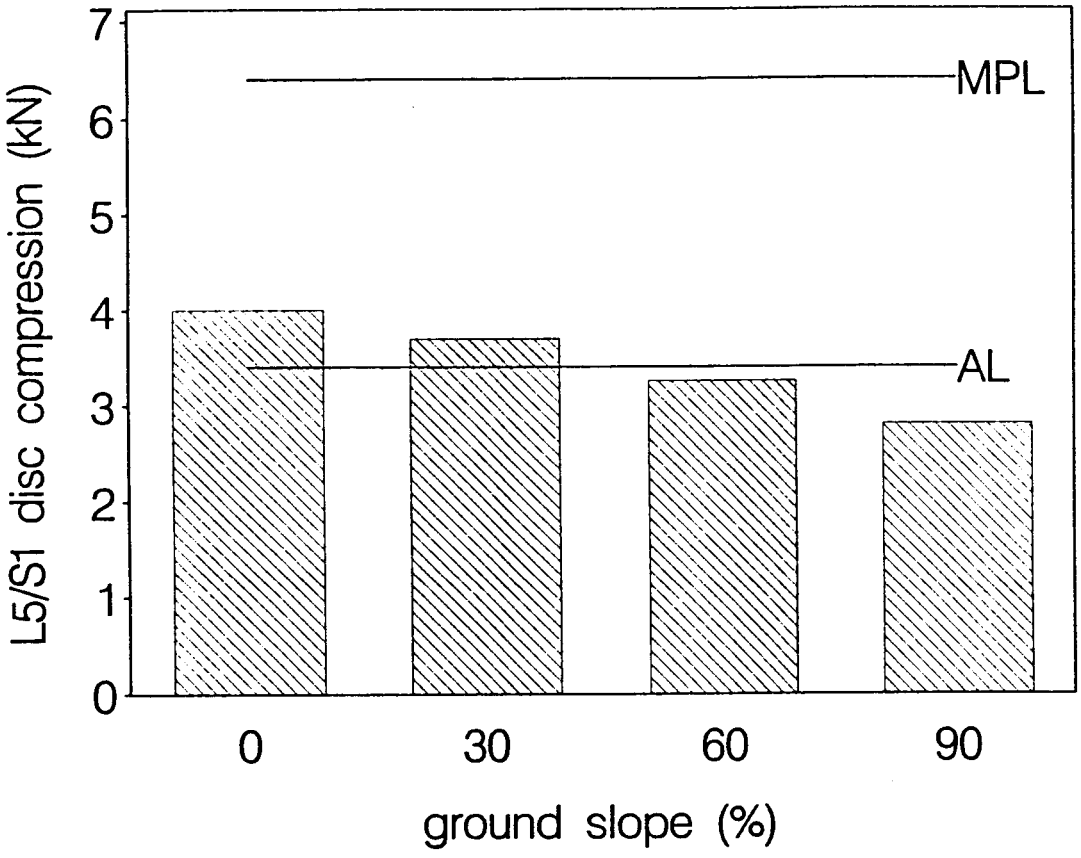

Figure 5. Intervertebral disc compression in lumbar spine (L5/S1 level) simulated for one of the subjects when felling with a chain saw under different terrain slopes. The calculated values are compared to defined hazard levels specified by [6].

It was initially expected that the ratio between utilized time and main work time would be greater for the chain saw than the cleaning saw. This was based upon the assumption that a stooped working position would lead to longer or more frequent rest pauses. This was not the case in this study. In fact, the results suggest, even though these differences were not statistically significant, that the average ratio between utilized time and main work time was higher for the cleaning saw than the chain saw. This could have been caused by more service and repairs required by the more specialized tool. The general impression from the field studies was that the most important factors for frequency and length of rest pauses were exogenous variables such as climatic conditions.

Concluding Remarks

The greatest differences in time consumption between the two tools were correlated with a combination of difficult forest conditions and limited experience on the part of the forest worker. The study has not shown any difference in the forest worker's perceived or measured cardiorespiratory strain between the two working methods. A higher spinal load was estimated for the chain saw which indicates a greater risk for low back problems while using this method. These findings are supported by the fact that most experienced workers preferred the cleaning saw in stands with highest removal density. While the chain saw was used frequently in smaller work objects of larger tree sizes, a simulated analysis indicates that the spinal load is not acceptable until the ground slope approaches 60% or higher. This study concludes that even in the rugged terrain of Norway's west coast, a more widespread use of the cleaning saw, together with better forest worker training, may result in more effective cleaning operations.

ACKNOWLEDGEMENTS

This study was supported by grants from the Norwegian Foundation for Rural Development. We also thank research technician Hans Nyeggen for coordination of the field studies.

REFERENCES

[1] Andersson, G.B.J. 1981. Epidemiological aspects on low-back pain in industry. Spine 6: 53-60.

[2] Björheden, R. 1990. Basic time concepts for international comparisons of time study reports. Proceedings: XIX IUFRO World Congress, Montreal, Canada. 3:124-134.

[3] Borg, G. 1970. Perceived exertion as an indicator of somatic stress. Scand J Rehab Med 2-3:92-98.

[4] Freij, J. 1991. Cleaning technology and methods. Report No. 2, 1991. The Forest Operations Institute of Sweden. 56 pp.

[5] Hagen, K.B. 1994. Physical work load and perceived exertion during forest work and experimental repetitive lifting with special reference to lifting technique. Thesis, Karolinska Institute, Stockholm.

[6] NIOSH. 1983. Work practices guide for manual lifting. National Institute for Occupational Safety and Health, Cincinnati, Ohio.

[7] Nordiska Skogsarbetsstudiernas Rąd. 1978. Nordisk avtale om skoglig arbeidsstudienomenklatur. Norwegian Forest Research Institute. 130 pp.

[8] SAS Institute Inc. 1988. SAS/STAT users guide, release 6.03 edition. SAS Institute Inc., Cary, N.C. 1028 pp.

[9] Strømnes, R. 1986. Tidsstudier av avstandsregulering med motorrydningssag i ung granskog. Rapp. Nor. Inst. Skogforsk. 8/86. 23 pp.