

AN ERGONOMIC EVALUATION OF DOUGLAS FIR MANUAL PRUNING IN NEW ZEALAND

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ABSTRACT

This report summarizes the findings of an ergonomic evaluation of first lift manual pruning of Douglas fir under New Zealand plantation forestry conditions. Six subjects were each observed undertaking their normal work methods throughout their complete working day. Heart rate data were collected and analysed using several heart rate indices in order to determine the workload of first lift pruning. The average working heart rate was $112 \text{ bt}\cdot\text{min}^{-1} \pm 10.6 \text{ (SD)}$. Results indicate first lift pruning to be a moderate to heavy workload activity. The manual pruning work method may place severe pressures on the workers' tendons, related bones and nerves of the hand, wrist, and elbow. Alternative pruning methods may contain inherent health and safety risks which must be carefully considered by those involved in the occupation of professional tree pruning.

Keywords: ergonomics, workload, forestry, pruning, heart rate.

INTRODUCTION

New Zealand's total land area is 27.0 million ha, of which plantation forestry accounts for 1.3 million ha, or 5%. The two main tree species within New Zealand's plantation forest structure are radiata pine (*Pinus radiata*), accounting for 89.4% of the plantation area, and Douglas fir (*Ps menziesii*), which accounts for a further 5.1% of the total plantation forest area. In order to obtain maximum value from each tree within the plantation, several silvicultural treatments are undertaken to the trees during their effective growing life. By far the most common of these value-increasing silvicultural treatments is pruning.

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The pruning treatments are undertaken relatively early on in the tree's growing life so that any subsequent stem growth will produce the highly valuable knot-free "clear wood" for which a premium monetary value is obtained at clearfell age. Standard pruning regimes in New Zealand utilize three treatments, or "lifts," as they are more commonly called. These treatments consist of a 0-2 m "first lift" prune, a 2-4 m "second lift" and a 4-6 m "third lift" prune. First lift pruning does not require the pruner to leave the ground to prune, whereas any subsequent "lift" customarily entails the use of ladders and portable aluminium steps by the pruners. The age at which these pruning treatments occurs depends on the forest management regime being operated by the forest company or forest manager. Generally the final pruning treatment has been completed before the first half of the tree's productive life has been reached.

This paper describes the first major ergonomic evaluation to be carried out in New Zealand focusing on manual pruners undertaking first lift pruning of Douglas fir. An extensive review of international papers concerning tree-pruning methods from 1940 to 1989 [16] revealed that little work has been undertaken concerning the ergonomic aspects of pruning Douglas fir.

Previous work investigating the physiological strain of Douglas fir manual first lift pruning in New Zealand [7, 8] recorded average working heart rates ranging from 110 to 130 beats per minute ($\text{bt}\cdot\text{min}^{-1}$). This placed the first lift manual pruning task in the "heavy" workload category [18]. The aim of this study was to validate these earlier findings using a larger sample, and to identify which components of the pruning cycle were the most physically demanding. Accordingly, this study also used heart rate as the main physiological variable to estimate the physical strain of manual pruning tasks. By doing so, a direct comparison could be made between this study and the one undertaken by Hartsough and Parker [8].

METHOD

Pruning Technique

The pruning technique measured is known colloquially as the "first lift" prune. This involves removing all the branches from ground level up to a distance of 2 m (6 ft) above ground. As previously

mentioned, this process is undertaken relatively early on in the tree's growing life so that any subsequent stem growth will produce the highly valuable knot-free "clear wood." The trees being pruned in this study were 11 years old and had an estimated clearfell age of 70 years.

The branching characteristics of young Douglas fir differs quite considerably from that of the prevailing tree species found in most New Zealand plantation forests, namely radiata pine. Douglas fir branching consists of a heavy covering of small, relatively brittle branches from ground level to the tip of the tree. The first 60 to 80 cm of the tree trunk, from the ground upwards, is covered in fine hair-like branches called "epicormics." These epicormics must also be removed during the first lift pruning process or they develop into small, wiry branches which downgrade the overall value of the tree's eventual sale price.

Manual pruning Douglas fir involves removing most of the branches with small hand-held pruners called "Wilkinson" pruners, with any larger branches being removed with the larger "Lopper" pruners. The Wilkinson pruners weigh 1.1 kg and consist of two steel arms 57 cm in length containing a sharpened knife blade at the end of each arm. The arms cross over each other and are joined at a point 8 cm from the knife end of the arms. The steel arms have 13-cm-long rubber hand grips, 2.5 cm in diameter, located on the handles' far end, which provide insulation from the cold steel as well as a secure grip for the pruner's hands. The knives are placed around a branch and the handles closed together by the operator, creating a shearing motion which severs the branches from the tree's trunk. The Wilkinson pruners can accommodate branch diameters of up to 3 cm.

The Lopper pruners are a larger, more robust model of pruner specifically designed for larger branches. The basic design and shearing principal are similar to the Wilkinson pruners. The Lopper pruners have handles 69 cm long, weigh 2.1 kg and have 11-cm-long rubber hand grips with a diameter of 4.5 cm. However, the Lopper pruners differ significantly from the Wilkinson pruners in that they have a second fulcrum point located 11.5 cm in from the knife blades and 3.5 cm below the joining point of the two knife blades. This second fulcrum point magnifies the physical muscle power being applied by the pruner onto the handles, thereby transferring

greater cutting power into the shear knives. As a result, larger diameter branches of up to 5 cm can be easily removed with the Lopper pruners.

Epicormics are removed with a piece of hacksaw blade, or a similar thin metal blade which has been sharpened to form a sharp edge on one side of the blade. Great care must be taken during the pruning process not to damage the very soft and delicate bark of the young trees. Bark damage can lead to scarring of the tree trunks, which will downgrade the value of the timber once sawn. Such damage can also allow disease to enter the tree which will effect its growing ability and/or kill the tree.

Study Location

The study was undertaken in southern Kaingaroa forest, in compartments 712 and 714. Kaingaroa forest is New Zealand's largest radiata pine plantation, producing almost one quarter of the national timber harvest. Kaingaroa forest is located near the centre of the North Island on an extensive, and virtually flat, volcanic plateau. It covers an area of 149 435 ha with radiata pine accounting for 109 139 ha and Douglas fir 14 529 ha.

Subjects

Participation of the subjects in the project was on a voluntary basis with each subject being provided with adequate and appropriate information about what their participation would involve. Each subject had the right to decline to participate in the project, or withdraw from participation at any time, without penalty of any kind and without providing reasons.

The study group consisted of six male individuals (pruners). All were well conditioned to the job of tree pruning, having on average two to three years pruning experience (ranging from three months to eight years). The average physical characteristics of the subjects are shown in Table 1. Each subject was observed for one complete working day. The subject's normal working day consisted of working from 0700 hrs until 1500 hrs each day with one rest break from 1100 hrs until 1200 hrs. All the men were paid on a contract piece rate dependent on the number of trees each individual pruned per day.

Productivity

The activities of the complete pruning cycle were separated into seven standardized work elements and recorded on a "Husky Hunter" field computer. The Husky Hunter is a completely self-contained hand-held field computer.

Eight work elements were designed for use during the study:

Walk & Select: At the completion of pruning, select next tree while walking forward.

Prune: Start to remove the branches from the tree.

Repair & Maintenance: Repair and maintain the pruning tools.

Walk In: Walk from the rest area into the forestry block to start work.

Walk Out: Walk out from the forestry block to the rest area.

Operational Delay: Delays in work caused by work-related concerns.

Personnel Delay: Delays in work caused by the subject's personnel requirements such as eating, drinking, toilet breaks.

Rest Breaks: Main rest break at mid-day in which all workers stopped to eat, drink, and rest for approximately one hour.

The time spent undertaking each activity was recorded using the continuous time study with the aid of the computer program "Siwork3" [18]. Siwork 3 is a Turbo/Pascal language program specifically developed for work study and data collection. Task-dependent factors such as tree diameter at breast height (dbh), ground slope, ground hindrance, and distance walked between pruned trees were also collected by the researcher for each cycle.

Tree diameters were recorded on completion of pruning using diameter tapes. Ground slope was measured using an "Suunto" inclinometer.

Hindrance rating was a subjective measure applied by the researcher observing the subject. The measure was based on a four-point scale, 1 being

easy walking and 4 being very difficult walking.

Distance walked between pruning operations was measured using a "Field Ranger" hip chain.

Heart Rates

The subject's heart rates were recorded at one-minute intervals using a "Sport Tester" Polar Electro 3000 portable heart rate monitor (Pe3000). Heart rate was recorded for the entire working day, including during the main rest break during the middle of the day.

Due to logistical difficulties, theoretically true resting heart rates could not be obtained. Alternatively, immediately the crew vehicle completed the 50 to 60 minute trip to the work site, the subject would be taken aside and the Pe 3000 portable heart rate monitor would be fitted to his chest. The subject would then be asked to sit down on the ground for 10 minutes. At the end of this 10-minute time period the subject's heart rates were recorded and this was recorded as being the "pre-work" resting heart rate.

While acknowledging that this is not the prescribed method for determining a subject's resting heart rate, the payment system would impose severe time restrictions on whichever method of resting heart rate determination was to be used. Since each worker was paid on a contract rate determined by the number of trees pruned each day, the subjects were reluctant to wait for 20 to 30 minutes in the morning in order to have their resting heart rates determined.

An alternative could have been to pay the subjects an additional allowance for the required 30-minute test period. However, in this particular case no funds were available to do so. The eventual method used for determining pre-work resting heart rates was an acceptable compromise between scientific and production requirements.

Work Activity

The heart rate and work task data were merged using a 486 SXI personal computer (PC) and a spreadsheet package. Analysis by the statistical package "Statistix" enabled average heart rates for each element of the work cycle to be calculated.

Ambient Conditions

Measurements of ambient air temperature, wet and dry bulb temperature, and black globe temperature were taken at 15 minute intervals during the working day utilizing a Campbell Scientific Incorporated CR21 data logger. An attempt was made throughout the study to keep the climate station within 50 m of the subjects. A wet bulb globe temperature index (WBGT) in degrees Celsius was calculated using the formula: $WBGT = 0.7 nwb + 0.2 tg + 0.1 ta$ [16]. (Where nwb = naturally ventilated wet bulb, gt = black globe temperature and ta = air temperature).

RESULTS

Subjects

Three measures of the subject's physiological characteristics are shown in Table 1.

Table 1. Physical characteristics.

Characteristic	Average Value \pm SD
Age (years)	22.3 \pm 4.8
Weight (kg)	74.5 \pm 5.9
Height (cm)	171.8 \pm 2.7

Productivity

The average number of trees pruned per productive hour was 16.8 \pm 1.7. This equates to an average pruning time of 3 minutes 36 seconds per tree. Two distinct groupings can be seen in terms of pruning rates of trees per hour. The more experienced subjects (1, 4, 5 and 6) were more productive than the less experienced subjects within the crew (2 and 3). Terrain and tree values are shown in Table 3.

Table 2. Trees pruned per productive hour.

Subject	Productive Hours	Total N o Trees Pruned	Trees Pruned/ Productive Hours
1	7.3	140	19.1
2	3.7+	57	15.2
3	3.6*	53	14.7
4	6.7	121	17.9
5	3.4*	61	17.7
6	7.3	120	16.4
Average value (\pm S.D)	5.3 \pm 1.9	92 \pm 39	16.8 \pm 1.7

+Data lost due to Husky Hunter malfunction.

*Short day due to crew finishing early due to bad weather.

Table 3. Terrain and tree characteristics \pm standard deviation (SD).

Element	n	Range	Average \pm SD
Tree dbh (cm)	483	17 to 27	14.5 \pm 2.1
Ground Slope (°)	482	- 45 to + 70	13.0 \pm 14.4
Selected Distance (m)	494	3 to 50	7.3 \pm 5.4
Hindrance Rating	331	Light to Heavy	Moderate

n = Number of observations.

Heart Rates

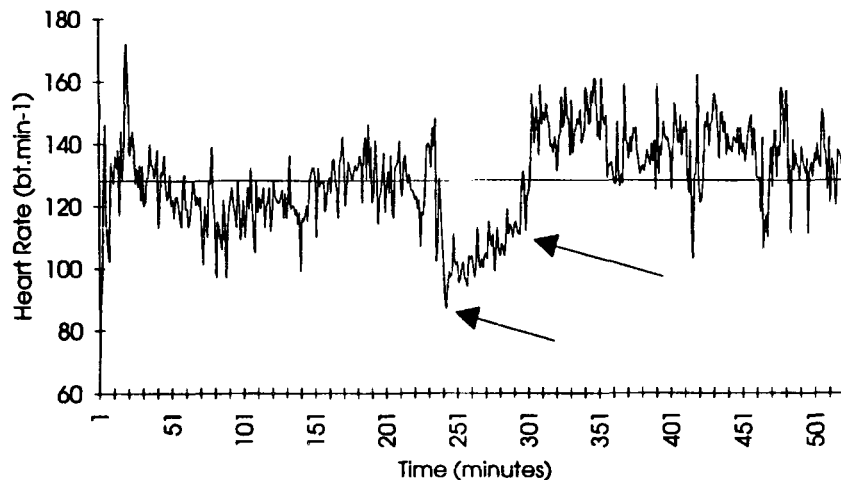
Heart rate results are summarized in Table 4. The average work heart rates ranged from 102 to 131 beats/minute (bt.min⁻¹), with the overall average being 112 bt.min⁻¹ ± 10.6 (SD). The pre-work resting heart rates ranged from 72 to 85 bt.min⁻¹, with an overall average of 77.8 bt.min⁻¹ ± 5.9. Average ratio of HR_w to HR_r was 1.45 ± 0.08 and the average relative heart rate at work was 22.5 ± 14.6. The average ratio of HR_w to 50% level was 0.82 ± 0.07.

The heart rate trace for subject 1 is shown in Figure 1. The trace is representative of the five remaining subjects and shows the subject's heart rate from the start of the working day until its completion, including the rest period from 1100 hrs to 1200 hrs. The 40% cardiovascular load of the subject is shown on the graph as a solid horizontal line. The 40% cardiovascular load point is an important indicator since it is at this point, or lower, that a person can work continuously for an eight-hour period without becoming fatigued [9, 20, 4, 12].

Table 4. Average heart rate figures.

Subject	Age	n	HR _w ± SD (bt.min ₋₁)	HR _{rel}	50% Level	HR _w 50% Level	% CVL
1	24	481	131 ± 13.2	42	140	0.94	41
2	16	321	115 ± 10.2	25	145	0.79	25
3	28	235	103 ± 7.6	26	132	0.78	26
4	17	234	102 ± 9.5	22	138	0.74	23
5	23	448	110 ± 11.1	26	139	0.79	27
6	26	441	114 ± 10.5	34	134	0.85	34

n = Number of observations. HR_w = Average work heart rate (bt.min-1); HR_r = Average resting heart rate (bt.min-1); HR_{rel} = Relative heart rate at work; Ration = Average ratio of HR_w to HR_r.



NB: _____ = 40% cardiovascular load. Arrows indicate lunch period.

Figure 1. Subject 1 working heart rate (complete day).

Work Activity

The subject's working day was broken down into primary activities. The average time spent undertaking each activity together with the average heart rate for that activity are shown in Table 5. Due to difficulties in separating the "walk & select" heart rate data from the "prune" heart rate data due to the lack of a consistently definable break point between the two elements, the two elements were merged for analysis.

The greatest proportion of time was spent pruning, which accounted for 80% of total work time. The remaining activities all accounted for similar amounts of time. The exception was the rest break, which was the second highest time-consuming activity, accounting for 11% of the day.

Ambient Climatic Conditions

The average WBGT index for the four days was $9.9^{\circ}\text{C} \pm 2.4$ (SD). Statistical analysis using one way Analysis of Variance (ANOVA) revealed no significant ($p < 0.05$) difference between the WBGT index over the four days of the study.

DISCUSSION

Heart Rate Indices

Measurement of the subject's oxygen uptake was not possible since the researchers lacked the appropriate equipment. Accordingly, heart rate measurements were recorded and applied to several heart rate indices in an attempt to estimate the

degree of strain experienced for each element of the work cycle. The indices used were the relative heart rate at work index, [19, 13], ratio of working heart rate to resting heart rate [22, 5, 6], and 50% Level [11].

Both the relative heart rate at work index and the percent cardiovascular load (%CVL) index indicated that the subjects worked at, or below, the 40% aerobic capacity level recommended for prolonged continuous work [1, 2]. The subjects in this study selected a work pace equivalent to between 23 and 41% of their estimated aerobic capacity with the average % CVL being 29.3 ± 6.8 . As stated by Vitalis et al. [23], the relative heart rate at work index, a hybrid of the % CVL index, is being increasingly used instead of oxygen consumption to estimate the workload of a task.

Analysis of the average working heart rate ($112 \text{ bt} \cdot \text{min}^{-1} \pm 10.6$) indicates that first lift manual pruning of Douglas fir is a moderate to heavy workload [17]. The overall average for the ratio of working heart rate to resting heart rate was 1.45 ± 0.08 . This places first lift pruning in the same category as nursing work [5] and car assembly work [14], and slightly higher than cane cutting [22].

As suggested by Lammert [11], and used by Vitalis et al. [23], the 50% level can be successfully used as a simple and effective way of measuring strain. Lammert [11] states that if heart rate at work/50% level is equal to 1, then the work being undertaken can be classified as hard continuous work. Based on these findings, first lift manual pruning of Douglas fir falls short of this criterion (average = 0.82 ± 0.07), and therefore cannot be classified as being hard continuous work.

Table 5. Work activity, average heart rate and task duration.

Activity	n	Average HR \pm SD	% Time
Prune	2361	114 ± 13.5	80
Repair & Maintenance	35	105 ± 6.9	1
Walk In	50	107 ± 20.0	1.5
Walk Out	98	117 ± 14.1	3
Operational Delay	70	96.6 ± 8.9	2
Personnel Delay	58	95.2 ± 13.4	1.5
Rest Breaks	310	95.5 ± 12.6	11

n = Number of observations.

In summary, the various heart rate indices used during the study indicate that first lift manual pruning of Douglas fir falls within the "moderate to heavy" workload category. These findings differ from those of Hartsough and Parker [8], who found first lift manual pruning of Douglas fir to be a "heavy" workload activity. The different results between the two studies could be attributed to situation and sample size factors. The single subject observed by Hartsough and Parker [8] was involved in a feasibility study and may have worked at a faster pace so as to obtain a favourable appraisal. The six subjects in this study were under no such pressures and therefore tended to perform their work activities at their normal working pace.

Work Activity

The majority of the day was spent pruning, with one main rest break at the middle of the working day, lasting one hour. The terrain in this study was predominantly of an undulating nature, but bisected by the occasional short steep bluff. As a result, the subjects tended to spend the day walking along a mixture of both up and downhill slopes. Occasionally the subjects were forced to either climb up or down the short steep slopes of the bluffs. This was, however, an infrequent event, and tended to be the exception rather than the norm.

The work was self-paced and constant, with few interruptions. This resulted in the subjects having to work at a level which was sustainable throughout the eight hour working day. Previous research [9, 20, 4, 12] has shown that when given the chance to select their own working pace, people will tend to work at, or below, 40% of their aerobic capacity. Apud et al. [1] also noted that when work is self-paced, the workers tend to naturally adjust work and rest periods, and normally the average workload is within reasonable limits.

The higher productivity of the more experienced subjects may be attributed to one of two factors, working harder and/or employing a better work technique. The heart rate indices shown in Table 4 reveal that subjects 1 and 6 worked at higher levels of their %CVL, relative heart rate, ratio, and working heart rate over 50% level than the other crew members. This would tend to imply that they are physically working harder than the other members of the crew in order to obtain their levels of productivity. The experienced subjects 4 and 5 have indices similar to those of the less experienced sub-

jects 2 and 3, yet their productivity is higher. This indicates that since they are all working in the same area with the same terrain, climate, and tree characteristics, subjects 4 and 5 must have a more efficient work method which results in a higher productivity rate per hour.

Health and Safety

Manual pruning requires strenuous and repetitive wrist and elbow motions associated with the actual work method of manual pruning. The manner in which the pruning tool is used causes radial deviation of the wrist, pronation, and dorsiflexion. This combination increases the pressures between the head of the radius and the capitulum of the humerus in the elbow [21]. Such repetitive movements may lead to the development of cumulative effect trauma involving the progressive damage of tendons, tendon sheaths, and related bones, and nerves of the hand, wrist, elbow, and arms [13]. As a consequence, professional manual pruners can suffer from the affliction commonly known as tennis elbow (*epicondylitis*).

One alternative to manual pruning which may alleviate this repetitive strain-type injury is the chainsaw pruning method. It should however be noted that while the chainsaw pruning method may have the potential to alleviate the repetitive strain-type injuries associated with the manual pruning method, such a method may contain inherent health and safety risks associated with their use, i.e. severe lacerations, noise, vibration, exhaust fumes which have been previously recorded in overseas forestry operations [10, 3] and should be fully considered.

CONCLUSIONS

The heart rate indices used in this study indicate that first lift pruning is a moderate workload activity producing an average working heart rate of $112 \text{ bt} \cdot \text{min}^{-1} \pm 10.6 \text{ (SD)}$. The work pace of the first lift manual pruning was self-paced and constant with the subjects consistently working at a level which was sustainable throughout the 8 hour working day.

Current alternatives to the manual pruning method, such as chainsaw pruning, may contain different health and safety issues which should be carefully considered before determining which pruning techniques to employ.

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