PHYSIOLOGICAL INPUTS TO MOTOR-MANUAL TECHNIQUES OF THINNING RADIATA PINE

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ABSTRACT

In a study of physical workload in a delayed second-thinning operation, average energy output was 1.8 MJ nett/hr. Heart-rate analysis indicated a high load, with no significant difference in physiological cost between various job elements. In a second study two techniques for motor-manual thinning were evaluated – the bench and the traditional technique for trimming and handling felled stems. Simulation of job elements identified stacking as the most strenuous with an energy output of 49 kJ nett/min for the traditional technique and 39 kJ nett/min with the bench technique. The bench technique results still came within the very heavy physical effort range of the British Medical Association's standards.

Both studies provide evidence that productive motor-manual felling in Australian plantations still entails very heavy to extremely heavy physical effort. A high to very high physical working capacity is therefore considered essential for this type of forest work.

INTRODUCTION

The job of the feller has been the focus of interest of numerous European work physiologists, ergonomists, and foresters for the last 30 years. Only one attempt at evaluation of the Australian feller's physical workload has been reported previously (Welsh 1971). That study was carried out under semi-experimental conditions and does not reflect the actual physical workload of a feller in harvesting work today.

From the practical point of view, however, it is known that work physiology data cannot be directly transferred from one country to another because of anthropometric, dietary, climatic, and other factors. Furthermore, it is widely recognised that although the future of Australian plantations will be based on highly mechanised work, a significant proportion of these plantations will still be thinned and clearfelled by motor-manual methods. Against this background, a clear understanding of the Australian feller's job and physical workload is essential in the redesign of felling work for the workforce of the future.

METHODS

The first study was carried out in the Australian Capital Territory (A.C.T.) in January 1981 using six subjects working in a delayed second-thinning. This study aimed to establish typical workloads of plantation fellers operating, in this area, on slopes of 8–18°.

The second study carried out in Gippsland, Victoria, evaluated two techniques for thinning work, the traditional or commonly adopted technique and the recent bench technique. In this study, restricted samples of the workday cutting random-length pulpwood (3.0–5.5 m) and simulations of particular work elements were used. Slope ranged up to 7°. Measurements allowing a 4-hour sample of productive time were made for each technique with each feller. Simulations were also made of each element in the job with sufficient rest periods between measurements to recover the oxygen debt.

The characteristics of the subjects in both studies are given in Appendix 1. In the first study, subjects were randomly selected within the constraint of working in similar terrain. In the second study, the subjects were chosen by the management of the co-operating company as being proficient in both techniques.

The three main physiological parameters measured in the studies were (i) oxygen uptake, (ii) ventilation, and (iii) heart rate.

From these basic measurements, the following derived indices were calculated: energy output according to the Douglas formula (in kJ nett/min), minute ventilation and percentage utilisation of maximum aerobic capacity, Borsky's index of static load, and nett heart rate.* Before each field study, preliminary examinations of the subjects were performed. The results of these examinations formed the baseline for analysis and included a medical interview and examination, physical working capacity test (Astrand-Rhyming), measures of physiological parameters at rest and questionnaires including the Jenkins Activity Survey and the Job Description Index.

Time studies were also carried out in the usual manner.

RESULTS

Typical Physiological Costs in Second-thinning Work

In the first study, the average energy output of fellers was 30 ± 2 kJ nett/min. The average energy output per hour of productive time was 1.8 ± 0.1 MJ nett. Average real nett (work + rest) energy output was 8.3 MJ whereas the standardised (7-hour day) energy output for work and rest was 11.1 MJ. The standardised day value is used because the workday in this particular sample varied between 270 and 485 min. Comparing these data with two commonly accepted standards on physical workload shows that the work efforts of these fellers can be classified as very heavy to extremely heavy. The results of other physiological parameters supported the evaluation based on energy expenditure (*see* Table 1). The percentage utilisation of maximum aerobic

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* Energy output nett and heart rate nett reflect the increase of these parameters over their baseline values at rest.

capacity (VO_2 max.) for five out of the six fellers was above the accepted standards for persons with high or very high physical working capacity, being on average 55 ± 11%.

The physiological cost in terms of the parameter heart rate was high, where a heart rate of 125–150 beats per minute reflects high cost according to Christensen (1953). On average, the heart rate varied between 138 and 141 over all of the work elements examined (*see* Table 2).

TABLE 1—Energy output nett and respiratory parameters, A.C.T. study (No. of measurements: 18)

Variable	x	S.D.
Energy out/min (kJ)	30	2
Energy out/hr of prod. time (MJ)	1.8	0.1
Energy out/hr of standard day (MJ)	1.6	0.1
Av. real nett (work and rest) (MJ)	8.3	1.4
Energy out/standard 7-hr day (MJ)	11.1	0.9
Minute ventilation (*l*)	44.4	3.4
VO_2 consumption/min (*l*)	1.8	0.1
Utilisation of VO_2 max. (%)	55	11

TABLE 2—Physiological cost of the feller's job expressed by heart rate/min, A.C.T. study

Work element	Heart rate/min		Heart rate nett/min	
	x	S.D.	x	S.D.
Walking to tree	139	8	79	8
Preparing to fell	139	7	79	7
Felling	138	5	78	5
Trimming and docking	139	6	79	6
Hangers	141	8	81	8
Averages	139	6	79	8

The static load as reflected by Borsky's index was slightly high (55 ± 7) and according to his recommendation (1965) is unacceptable from the point of view of preventing rapid fatigue. Borsky's index for static load measurement has acceptable categories of very low, low, and moderate, whereas the categories of slightly high, high, and very high, are not regarded as acceptable. In the proportion of productive time, productive delays, and non-productive delays, the group provided a picture of considerable variation under similar working conditions. Productivity in terms of trees felled varied from 12 to 19 trees/hour.

Evaluating Two Techniques for Trimming and Handling Second-thinnings

This study investigated the reported benefits of reduced physiological cost of a bench technique for thinning work generally introduced in South Australia in 1978 (LITT 1980; Higgins 1979).

Taking the simulation results first, three elements emerged as discriminating between the two techniques. For the traditional technique, the energy output for the first element of walking to the tree was 22 kJ nett/min and with the bench technique the energy output was 30 kJ nett/min, a result of carrying the bench weighing approximately 15 kg. The next critical element was trimming where the energy cost was lower for the bench technique at 21 *v.* 25 kJ nett/min. The largest difference in energy output was found in the stacking simulation where the energy output with the bench technique was 39 kJ nett/min as against 49 kJ nett/min for the traditional technique.

The critical elements identified by energy output differences were significant in the analysis of heart rate (Table 3). For walking between trees the results were 124 beats/min for the traditional technique and 136 beats/min with the bench technique ($t = 17.05$; $p < 0.001$). The physiological cost of trimming was 134 beats/min traditional and 128 bench, a difference that was statistically significant ($t = 5.84$, $p < 0.001$). A similar significant difference in favour of the bench technique was found for the stacking element ($t = 4.72$, $p < 0.001$). For the other elements of preparing to fell and felling, no significant differences were found between the two techniques in terms of heart rate. The index of heart rate nett reflecting the physiological cost for the standardised 7-hour day showed a lower cost for the bench of only 1157 beats.

TABLE 3—Heart rate/min during simulated situations comparing the traditional and bench techniques

Work element	Technique			
	Traditional		Bench	
	x	S.D.	x	S.D.
Walking to tree	124	5	—	—
Walking to trees and moving bench	—	—	136***	5
Preparing to fell	130	6	129	4
Felling	131	6	132	4
Trimming	134	6	128***	4
Stacking	152	10	143***	8
x	135	10	132	7

*** Significant at the 0.1% level

For the 4-hour samples of work, the bench technique required the lower energy output of 27 ± 2 kJ nett/min. With the traditional technique, the over-all cost was 32 ± 3 kJ nett/min, giving a significant difference in over-all cost between the techniques (t =

3.34, 0.01 $< p > 0.001$). The average percentage utilisation of VO_2 max. was 53 ± 8 for the traditional technique and 47 ± 6 for the bench, differences that were significant only at the 0.05 level.

As far as the calculated energy output for a standardised (7-hour day) was concerned, the traditional technique cost 11.2 MJ nett and the bench 9.8 MJ nett. This provided an advantage of approximately 1.4 MJ nett for the bench technique over a full 7-hour working day. It is also necessary to stress that one of the subjects had a VO_2 max. of only 2.8 *l*/min which resulted in a very high utilisation of 93% VO_2 max. for stacking with the traditional technique and 71% with the bench. The over-all utilisation of VO_2 max. for this subject was 61% traditional and 53% with the bench technique.

An analysis of heart rate per work cycle (i.e., the time needed to fell, trim, and stack a tree) was made using the two subjects with the same level of physical working capacity. For the first 3 hours the superiority of the bench technique was clearly evident, the differences between techniques being statistically significant at the 0.02 to 0.001 levels (*see* Fig. 1). During the fourth hour of work, however, the heart rate per work cycle was significantly higher with the bench technique ($t = 4.84$, $p < 0.001$).

DISCUSSION

The data on energy output in both studies can be compared with the standards of the British Medical Association and Lehmann for heavy physical work (*see* Appendix 2). Such a comparison shows that a feller producing pulp logs and sawlogs in a delayed second-thinning on slopes of between 7° and 18° has a physical workload which is very heavy to extremely heavy. Similarly, in scheduled second-thinnings for random-length pulp logs where the slope is less than 7° and stacking is involved, the work is very heavy to extremely heavy using the traditional or commonly accepted technique. For the same work but using a felling bench, the physical effort involved is still in the upper level of the very heavy range of physical effort.

In the first study, where a feller's workday was shorter than the average 398 minutes for the group (238 minutes in productive time) the real nett energy output for the feller was within Lehmann's upper limit for long-term heavy physical work. This limit is stipulated to allow the maintenance of the same high level of energy output with no long-term damage to health. As this limit applies only to workers with a high or very high physical working capacity, some physiologists have argued that the optimum energy output per 8-hour day of work should be 5 MJ nett (Zeleny & Stolarik 1962). This provides a standard for those with medium or lower physical working capacity. Even in such a proposal as this optimum limit, the bench technique produces a significant overload for the feller over the commonly accepted 7-hour workday.

It has been shown by Grandjean & Zeleny (Fibiger 1976) that a worker spontaneously lowers work tempo if the energy output per minute exceeds 29 kJ for any length of time. Alternatively, the person expending such an effort reduces his productive work time if at all possible. Such a reaction in a feller will be strengthened if large differences exist between energy demands and physical working capacity. Research in work physiology has also shown that the long-term workload for people with medium

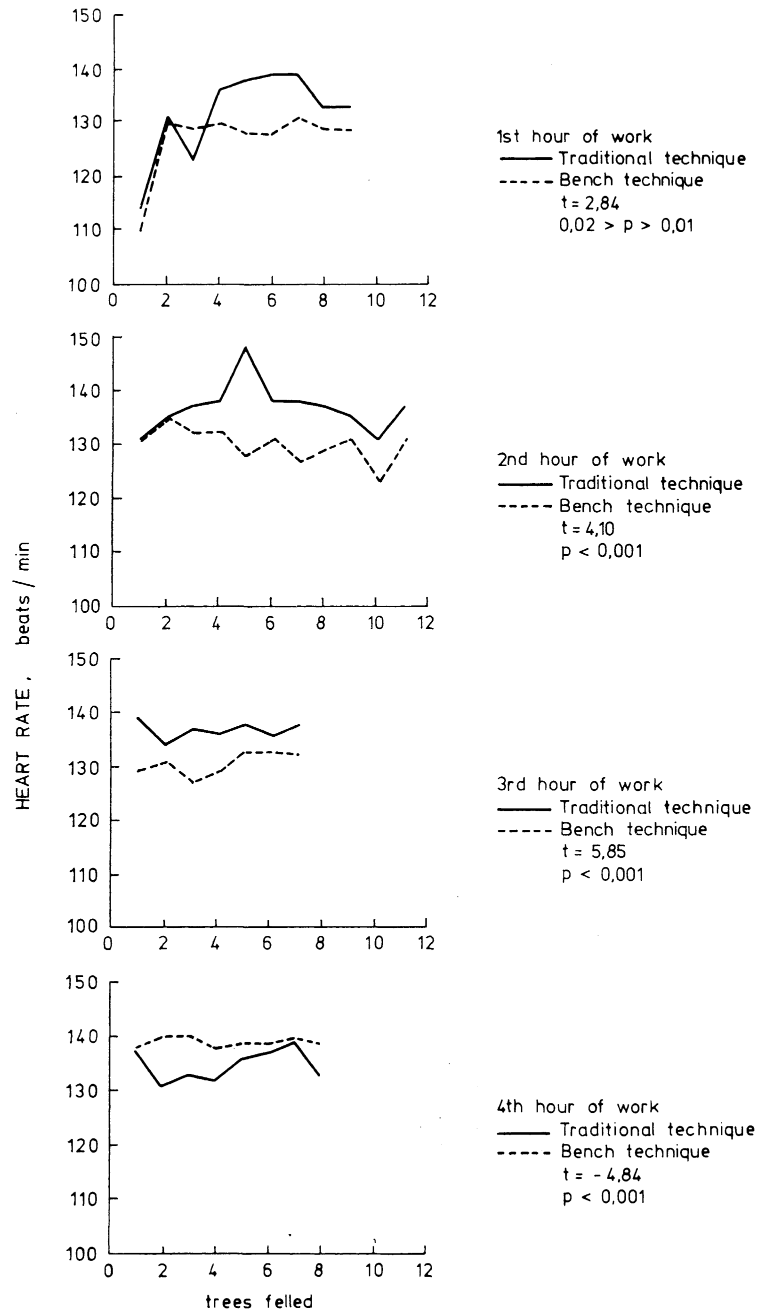

FIG. 1—Physiological cost/work cycle.

and low physical working capacity should not exceed 35% of their VO_2 max. while those with high physical work capacity have a limit of 50% VO_2 max. (Astrand 1960; Bink 1964; Kozlowski 1970). All except one of the six fellers in the A.C.T. study were working at above the 50% VO_2 max. limit, and one of the three fellers in the second study was working above this top limit. Thus only three fellers out of a total of nine were really capable of meeting the energy demands of the job in the long term. With the remaining fellers whose physical working capacity varied between 2.8 and 3.5 l 0_2/min, a decrease in physical working capacity or health deterioration in various forms could be expected in the long term. High labour turnover representing a reaction to these outcomes could also be expected.

The importance of physical working capacity was demonstrated by a significant correlation in the first study between physical working capacity and non-productive delay time ($r = 0.71$, $p < 0.01$). This suggests that non-productive delays are indeed a restitution time for fellers with a low or medium physical working capacity which effects productive time and productivity, and lowers energy output per workday.

At this point it should be stressed that the results of the energy output measurements for both studies, though generally higher, were not very different from those for European studies. For example, Fibiger (1976) reported an energy output per 8-hour day of clearfelling of 7.6–10.1 MJ nett. Durnin & Passmore (1969) found that the activity of felling on its own required an energy output of 23 kJ nett/min. Butora (Fibiger 1976) found an energy output for the same activity of between 22 and 43 kJ nett/min; this large variation occurred because of widely differing terrain and tree characteristics.

Heart beats per minute (reflecting physiological cost elements) did not differ significantly in the first study. This can be explained by the overlap of the body reaction in these short elements. In the second (simulation) study, heart rate for the elements "preparing to fell" and "felling" also did not differ significantly. In other words, the effort compensation patterns in these elements as far as heart rate was concerned were similar (excluding interpersonal variability).

The first study clearly demonstrated the necessity for continued improvement of felling work from a physiological point of view. In the second study, an evaluation of such an improvement revealed that only a relative decrease in energetic and physiological cost had occurred. The role of fatigue in the two techniques is not easily determined. The analysis of heart rate per work cycle using two subjects gave a high workload with both techniques, though with a statistically significant advantage to the bench in the first 3 hours (Fig. 1). The question arises, however, of the significantly higher physiological cost of the bench by the fourth hour. With little variation in tree size and a low incidence of hangers or missed bench, could this be a fatigue effect? Such an explanation would simplify interpretation but one could almost expect a similar increase in heart rate per work cycle by the fourth hour for the traditional technique. The variability of heart rate is the smallest in the fourth hour with the bench. It may be that the degree of skill with a particular technique assumes a different level of importance as the day progresses.

CONCLUSIONS

These studies once again provide evidence that, despite the improvement in forestry and felling technology, the job of motor-manual felling is a very heavy one from a physiological point of view. In practical terms, this will mean the continuation of problems familiar to many plantation managers – high labour turnover, relatively low productivity, and significant workers' compensation costs. It has also been shown that even good single technical solutions (e.g., the bench technique) are not sufficient to significantly decrease this high level of physiological overload. The need therefore still exists to investigate more integrated approaches to the problems, which should include pre-employment medicals and selection as well as carefully evaluated training. Of equal, if not greater, importance is the consideration by management of overseas and local innovations in work organisation that require development in this country.

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APPENDIX 1

CHARACTERISTICS OF THE SUBJECTS

Variable	N=6 A.C.T. study			N=3 Comparison of two techniques		
	$\bar{x}$	S.D.	Range	$\bar{x}$	S.D.	Range
Age (years)	32.5	4.6	27–41	36.7	10.6	27–48
Weight (kg)	78.1	7.4	68–90.5	89.7	12.4	74–99
Height (cm)	178.5	6.3	171–187	182.7	4.2	178–186
Months of experience as feller	24.3	4–60	4–60	141.3	149.1	4–300
Physiological parameters at rest:						
Heart rate (beats/min)	60	6	54–68	71	9	60–76
Minute volume (l)	8.9	2.3	5.4–10.6	7.9	1.2	6.8–9.2
Oxygen intake (ml/min)	312	79	200–400	240	20	220–260
Energy output (kJ/min)	6	2	4–8	5	—	4–5
Maximal aerobic capacity:						
VO_2 max. (l)	3.4	0.8	2.8–4.9	3.4	0.6	2.8–3.8
Jenkins Activity Survey:						
Number of Type A	1	—	—	1	—	—
Number of Type B	5	—	—	2	—	—

APPENDIX 2

THE PHYSICAL EFFORT STANDARDS

(kJ nett)

Lehmann		British Medical Association	
Level of effort	Energy output per 8 hrs work	Level of effort	Energy output per hour
Light	Up to 2 093	Very light	0– 293
Moderate	> 2 093– 4 187	Light	> 293– 419
Moderately heavy	> 4 187– 6 280	Moderate	> 419– 837
Heavy	> 6 280– 8 374	Heavy	> 837–1 256
Very heavy	> 8 374–10 467	Very heavy	>1 256
Extremely heavy	>10 467		