Session IV
Paper (a)

PHYSIOLOGICAL WORKLOAD IN AUSTRALIAN HARDWOOD FALLERS
IMPLICATIONS FOR HUMAN ERROR

MEL HENDERSON
Environmental &
Occupational Health,
Commonwealth Institute
of Health
SYDNEY UNIVERSITY

SUMMARY

Dimensions of physiological workload for a group of Australian hardwood fallers are given. The observed oxygen consumption and heart rates are considered in relation to other faller studies and commonly accepted recommended limits to workload. The difficulties of linking data on this potentially important factor to models of operator error and the psychology of the hardwood faller are discussed.

INTRODUCTION

Tradition

Very little was ever written about the skills of the old Australian bushmen(2). I have listened to retired workers for a number of hours as they recalled the old days of"..pushing big ones up out of the draw of a gulley with six to a dozen wedges","heading off an eight footer with an off set axe","walking half a mile through the bush to find just the right log for the mill". Skills and traditions were kept alive by handing them from father to son. You paid for your errors with hours of extra hard physical labour. The de-skilling of most craft trades is well documented and inevitable:one wonders how much of the approach of todays top hardwood fallers is still founded on the techniques of the axe and crosscut days.

Well before research ergonomics came into being in the 1940's,the axe and crosscut bushman was seeking to fit the younger man into the demands of the job. He was like any other rural craftsman with an apprentice. With some he had a good natural start,with others it was hard work for the "instructor" and the "trainee" from the very beginning. Today as,in the past,the life of the young faller is literally in the instructor's hands until the necessary foundation of skill and knowledge is established. This responsibility is one that few experienced men are willing to take up.

The instructor then as now would be asking:

> "What are the real demands of the job especially on a new worker?What are the physical characteristics and capacities he must possess,what psychological characteristics would best suit him for the work, what psychological abilities must he have, what skills should he develop first?"

The research ergonomist is asking the same questions but attempts to answer them in a different way.

Fitting the man to the job and fitting the job to the man

The fit of the man to the many demands of the job (FMJ) and of the job to the man (FJM) is central to ergonomic practice(19).

In motor-manual logging work the emphasis on FMJ means both the physical side in terms of actual physical work capacity, strength and skill and the psychological side, in terms of information processing and decision making ability on the one hand, and the way the man copes with real or imagined job stresses on the other.

At certain levels of production demand,the load on the operator as an information and exercise seeking machine could be too high leading to overload: equally importantly these demands could be too low - leading to decreased vigilance and attention.

The ergonomist seeks to objectively investigate the working conditions and hazards or risks of any job and to assist unions, management and most importantly the instructor,to prepare the operator for overcoming these adverse conditions and risks. The longer term health and productivity of the worker must also be pursued. The ergonomist seeks ways to make the work as low risk as possible given the capabilities, motivation and management back-up to the worker. This is especially the case in an error provocative environment like logging.

In 1981 Dr Fibiger and I considered the complexity of the hardwood faller error and injury problem(12). In that initial paper we described the candidate factors we thought important to consider when investigating so called risk-taking in hardwood falling. That paper also contained an algorithm of information processing and influencing factors for the "risk taking" of a hypothetical faller.

The data presented in this paper is part of a wider study with forty one fallers where the main thrust was on the psychological and information processing aspects of hardwood falling work. The research has a long term goal. This is to establish and validate the criteria for the" good" to" ideal" hardwood faller and to assess the contribution to injury control of adopting such criteria. This cycle of research and evaluation constitutes several years work. Military use of ergonomic research would probably be the best example of such a longer term approach.

In researching the webb of events leading to operator error a basic starting point is consideration of the actual degree of physiological overload that may exist for those currently in the job.

Work physiology

Numerous European and Scandinavian papers on the physiological demands of the fallers job have been published over the last 30 years or more. At an early stage it was demonstrated that physical work capacity was highly correlated to earnings in a sample of Swedish fallers (10). Studies in an increasing range of logging environments continue to demonstrate that the job of faller in all present forms must be regarded as a hard to very hard form of outdoor work(17,8,21,14). No data exists on the physiological demands of the unique and very varied conditions of hardwood falling in Australia.

Many people take the view that tiredness causes accidents. That is,excessively high physiological workload in blue collar work creates failures in holding and controlling hand-tools or machines and/or causes error in the perceptions and judgements of the worker through "fatigue" mechanisms in the brain.

The question of "fatigue" and failure of performance has been a vexed one for many years and Cameron neatly explains the position for forest ergonomists even though he was talking of the role of fatigue in aircraft accidents. He suggested "..accidents are so rare and circumstances so variable that it is not often possible to isolate any fatigue component in the chain of accident causation (p.70)(4).

As the counter balance to the potential effects of high physiological workload we have at the very least the skill and motivation of the individual.Two quotations make the point.

> Motivation is undoubtably an important factor determining the endurance during heavy exercise. Well trained, highly motivated subjects may maintain the oxygen uptake at a maximal level for at least 15 minutes, although most individuals feel forced to stop after 4-5 minutes.(p.304)(1).

> Motivation - the willingness to continue to try to do a task well and the persistence and determination to find strategies that are effective is probably the most impoortant factor in human performance.(p.18)(18).

This applies with fallers as much as anyone else even if it is just the skill and determination to temporarily reduce physiological load by deciding,quote "..I'll lock that tree in behind the clump of rocks over there that'll keep that ......! skidder driver busy for ten minutes, then I can have a breather".

In our study of hardwood fallers many operators reported the physical strain of the job to be high. Rating of an operator's effort by an observer or the operator himself is notoriously unreliable under field conditions (see 11,Appendix II for a detailed discussion). The results detailed in this paper constitute an attempt at objective assessment of the problem.

SUBJECTS AND METHODS

The twenty three subjects were all volunteers working at various locations throughout Tasmania. They were all examined by a medical practitioner and pronounced fit for the job and research project. Their characteristics are given in Table 1.

TABLE 1-CHARACTERISTIC OF SUBJECTS

Variable	Mean	S.D.	Range
Age(Years)	33.8	9.1	19-47
Weight(Kg)	74.2	13.1	45-102
Height(Cm)	177	7.6	166-192
Experience(Yr)	10	8.6	<1-29
Heart rate(BPM)	67	6.9	54-80
Predicted VO2 max	3.6	0.8	2.0-5.0

The job involved the usual work content of felling with work study elements including:inspection and prepare to fall;scarf and back cuts;walk to trim;trim;crosscut;walk between trees; productive/nonproductive delays. Terrain and debris conditions varied widely as did average tree volume(range across all fallers 1.56 m3-22.46 m3). The predominant saw used was the Stihl 075/076,with two subjects using the Stihl 090. The approximate nett weights are 15.35 and 16.65 kilos respectively.

Falling quota covered a wide spectrum from 230-1000 tonnes per week with the majority of the fallers in the 250-350 tonnes group,seven of the fallers were above 600 tonnes and one was consistently cutting 1000 tonnes in five 'good' days.

Field measurements extended over approximately a five month period from summer to late autumn with temperature and humidity over the actual research days being 16.3 SD 4.6 c;77 SD 14%RH (range 3-25 c:54%-91% RH).

For the research period fallers were requested to work at their normal pace as if they were not on a quota. They were given a cash bonus or additional 100 tonnes quota for co-operating in this way.

The collection of the work physiology data involved periodic interruption throughout the work day for risk interviews on specially selected trees.

Maximum oxygen uptake was predicted from heart rates obtained at the work site,and the nomogram of Astrand corrected for age (1). Test workloads of 600, 900 & 1200 Kilopond/meters were employed using a Repco HP 5209 bicycle ergometer. Oxygen consumption on the work capacity test and in the field was measured using the Morgan Oxylog portable oxygen meter (P.K. Morgan,England). Measurements were made over one or more complete work cycles wherever possible,covering all job elements except inspect-prepare to fall. Heart rate was recorded at 30 second intervals using a high frequency telemetric system (H. Riddle, Melbourne, Australia). Time studies were conducted in the normal manner.

The Jenkins Activity Survey(JAS),a self report questionnaire focusing on Type A-Type B behaviour,was completed by the subjects during the preliminary examinations.The questionnaire is one of the best known measures of, quote "a style of behaviour with which some people respond to life situations ... where some elements of challenge are perceived to be present". Subscales of the questionnaire provide scores for Type A-Type B predominance, 'job involvement' and 'speed and impatience'. All are candidates for correlation with energy expenditure and effort(13).

RESULTS

More than one parameter of physiological workload was considered because of the complexity of physiological reaction. Results of energy output as indicated by oxygen consumption measurements are given first.

Energy output

The average oxygen uptake for the 23 fallers was 1.33 SD 0.30 l/min. A large range of energy output was found across the whole group of 0.84 l/min to 1.98 l/min. Where more than one measurement was obtained on a subject (N=13) the maximum difference between trees was 0.67 l/min with an average difference of 0.26 l/min between trees/subject.

The values for the highest field oxygen consumption plotted against predicted maximal oxygen uptake (VO2 max) are given in Figure 1. The regression line of best fit has a coefficient of 0.203(p not sig.).

These data conform with studies of outdoor occupations that have examined the association between actual energy expenditure and VO2 max, for example,Finnish fallers (r=0.24)and African cane cutters(r=0.29)(14,5) In short an association between effort and capacity can be found but not to the extent some might expect.

Each data point represents one aspect out of many in an operator, that make up the complex story of his potential for production and chances for survival.

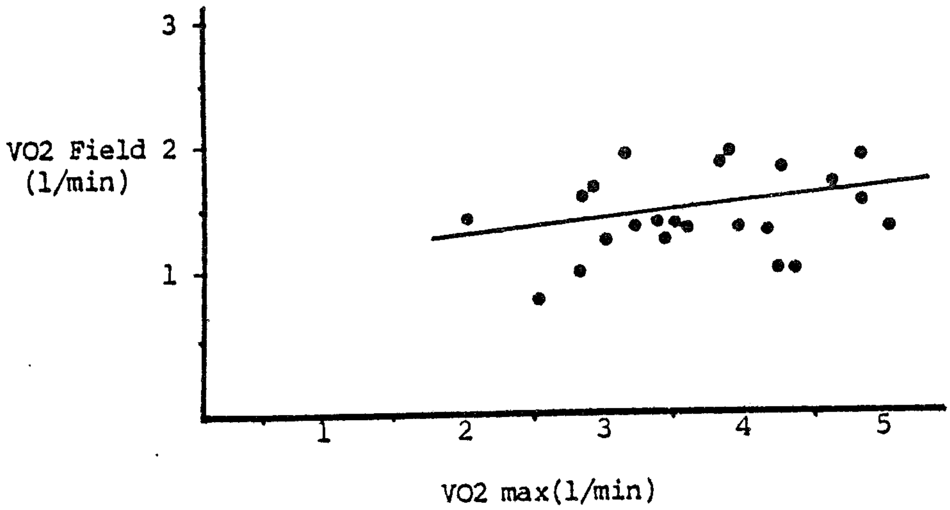

FIG. 1-The relationship between predicted VO2max and field energy expenditure

It is generally accepted that peak load is more important than mean energy expenditure in terms of strains imposed on the worker. The time interval of peak load is obviously important. A number of the fallers had oxygen uptake values above 1.6 l/min over a range of timber sizes corresponding to a mean utilization of 48.3% VO2 max. The maximum value recorded was that of a 45 year old faller,VO2 max 3.9 l/min,with a field value of 1.98 l/min:utilization 51%. A 36 year old faller,with the second highest VO2 max in the group of 4.8 l/min gave 1.88 l/min in the field,this being 39% utilization VO2 max. It appears that the maximum energy effect arising from the interaction of these falling conditions and fit fallers is around the 2.0 l/min level. This points toward the nature of the job as a limiting factor on productivity even with fit,skilled and motivated workers. The limitations of carrying the large saw and other equipment in difficult conditions and the cutting speed of current chain technology would be at least two things to consider.

Utilization of predicted maximal oxygen uptake

The average and range of predicted maximal oxygen uptake (VO2 max) are given in Table 1.

With each individual the percentage utilization of VO2 max is a product of the ratio of energy output to predicted VO2 max, for example a man with low VO2 max and relatively low energy output may still have a similar percentage utilization to a man with a higher VO2 max and relatively higher energy output.

When considering the acceptable level of utilization of VO2 max there is not complete agreement on the maximum level of physical strain of the work over a working life of 8 hour days. The most frequently applied limitation is a maximum utilization of 35% of VO2 max for workers in categories up to and including medium physical work capacity(PWC). For workers with a high to very high level of PWC a maximum of 50% utilization of VO2 max is considered appropriate. Some specialists would accept up to 60% utilization as the limit for persons with a very high PWC(Astrand cited in 7). There was a negative association($r=-0.63, p<0.001$)between field oxygen consumption and predicted VO2 max.

Fifteen subjects in the group (65%) were classified according to age in the high to very high physical working capacity (VO2 max) range, six subjects (26%) had a moderate PWC classification, and a very low PWC classification was given to two subjects (9%).

For those fallers classified as high to very high PWC their mean percentage utilization of VO2 max was 34.6 SD 9%. One of the fallers had a utilization of 51% VO2 max, and several had utilization close to 20%. Of the fallers with a moderate PWC classification the mean percentage utilization VO2 max was 45 SD 10% with three subjects having between 50-60% utilization VO2 max and three having 35% or slightly above. Of the two subjects with very low PWC one achieved a 33% utilization and the other in the 40 plus age group revealed a 72% utilization of VO2 max.

Heart rate

The average heart rate per work cycle across all subjects was 133.8 SD 9.9 with a HR nett(i.e.field minus heart at rest values) of 66.9 SD 12.6 beats/min. The average heart rate over all oxylog measurement trees was 132 SD 11.8 beats/min confirming the similarity of the oxylog tree to other trees of the day in terms of physical demand.

DISCUSSION

General validity

The normality of the faller's work pace and behaviour during a day of regular interruptions can be questioned. Based on actual production rates and a 30% ratio for non-productive time for a standard 8 hour day (drawn from previous studies in hardwood and softwood)it was calculated that of the 21 men on quota :2 could cut their allotted quota in less than a day;15 could cut theirs in 3 days or less; 3 in 5 days or less and 1 man would have taken more than 5 standard days to cut his particular quota. In hardwood tree volume and percentage defect can have a major effect on productivity. In a piecework system this means marked differences in energy costs per dollar earned. For the purposes of estimation defect was considered equivalent across cases.

The results strongly suggest that workpace was in most cases normal to above normal for the fallers.

Work physiology

Compared with the oxygen uptake found by Fibiger and Henderson of 1.77 SD 0.12 l/min for a small group of Australian pine fallers, this index of physiological load is considerably lower for hardwood fallers(8). The greater range in energy expenditure for the hardwood group should be emphasised, and indeed expected, if one compares the variety of trees and terrain confronting hardwood fallers with the relative uniformity of an even aged pine plantation.

In a recent study of Finnish fallers where heavy bunching was also involved, the oxygen uptake of 1.9 SD 0.31 l/min was again higher than the Tasmanian result(14).

Based on these data approximately 30% of this hardwood faller group were working at or just above the recommended percentage utilization of VO2 max for their physical working capacity class. Over half of the predominantly very high PWC group(34% of total) had oxygen consumption values lower than 35% utilization of their VO2 max.

On the basis of HR nett results the job for all fallers is above the limits suggested by Grandjean (30 bpm) or Holman(40 bpm) in order to reduce the risk of overload in long term high production work. Production delays and spontaneous rest pauses (as found in the Fibiger Henderson study for example) could influence the importance of these results. Compared with the other studies cited the average heart rate levels are high relative to oxygen uptake levels.

Astrand amd Rodahl have suggested that "..the level of activity in many industrial tasks is actually self regulatory in that the rate of work and spacing of rest pauses are set by the individuals level of physical fitness" (p.446)(1). This does not seem to apply to hardwood fallers where the job appears to demand a utilization of VO2 max within acceptable limits in most cases with some of the high working capacity workers operating at a relatively low level of VO2 max.

These oxygen uptake findings provide little evidence of overload. Their similarity to" normal" work has been detailed. At this stage we cannot conclude that whole body physiological overload and attendant general fatigue is an important factor in the productivity of the workers as studied. Psychological and psycho-social factors are most likely to play the largest role in determining energy expenditure,effort and work pace in all but the highest production fallers.

The heart rate results suggest studies under field simulation conditions on arm work and static load with these heavier hardwood saws. The levels of local muscle fatigue in this job and the importance of skill in minimizing it might then be determined. Such problems of isometric or static load in upper body/arm work may not be a critical issue in the case of the more skilled faller.

Maximum production conditions must be excluded from these conclusions but such a study,at the limits of human performance, would probably be too hazardous for all concerned to attempt.

Motivational influences on energy expenditure

A positive and significant correlation between field VO2 and scores on the (JAS) speed and impatience scale was found which was larger than that between field VO2 and predicted VO2 max($r=0.47, p<0.005$). This offers support to the points in the beginning of the paper on the role of motivation even in more "physical" jobs. A smaller correlation between field VO2 max and job involvement was observed but not significant($r=0.28$). Positive correlations were found for field VO2 with quota($r=0.24$) and average tree volume($r=0.15$),neither were significant.

The workload findings,risk taking and operator error.

The fact that this group of men have been shown not to be under excessive physiological load does not detract from the dangers and difficulties of the job whatsoever. Ample evidence confirms the continueing high-risk nature of falling work(6,16).

The scientific basis for investigation of physiological workload has been well established for many years. It is fair to say that no such position exists in applied psychology. This discipline has yet to arrive at a unified theory of human error and mental workload,or at methods of investigation that are easily applied to the work situation(15,3,9). Risk taking is one of a family of closely connected terms that include human error, mental workload, and accident.

Risk taking can be defined as...making judgements and taking actions in a state of high uncertainty about future outcomes. A skilful faller,like any other skilled operator, must be able to anticipate what is most likely to happen across many situations, with consistency and accuracy. Risk taking is central to learning on the job. It is the consequences that make the difference for these fallers.

Responses to questions on the reported frequency of risk taking for all forty one subjects of the full study are given in Table 2.

TABLE 2- Reported frequency of being aware of having taken a risk (n=41)

	n	Percentage	
Several times a day	4	10%	...how often do you
Once or twice a day	8	21%	know or realise when
On average once a day	5	13%	you have taken a chance
1-2 a week	10	26%	as we described,in this
1-2 a month	6	15%	present type of bush?
No risks taken	1	3%	
Equivocal/other	5	13%	

The person may be aware or unaware of the risk he is taking especially when pressures of one sort or another do not allow time to search for all the necessary information and alternatives.

The phrase risk-taking has the connotation of actively seeking something out, risk acceptance refers more to accepting the potential consequences because no viable alternative can be seen of getting that tree, and those dollars, down on the ground.

Risk-taking is a broad everyday term for the fine detail of human error that the researcher must grapple with. The fine detail, that is, ofthe continual cycles of perception-decision-response and errorin dangerous work.

Singleton provides one of the most succinct descriptions of this cycle of human error from the point of view of information processing. It bears reading more than once.

> Thus the operator may fail to detect the signal for reasons of over-load or underload or excessive noise associated with the signal. He may detect it but make an incorrect identification because he is set for the wrong signal, there is a conflict of the various cues available, or there is inadequate differentiation of the cues available. He may detect the signal and identify it correctly but then go wrong because he does not attribute to it the right importance ... He may get all these things right and then go wrong because he selects the incorrect action ... Finally he may detect signals, identify them correctly, attach the correct importance, decide on the correct action but still go wrong because the correct action does not emerge (p.127)(20).

This describes what can take place at various levels of behaviour when a person is, what is more commonly called, "taking-a-risk". The idea can apply in falling work to broad cycles of behaviour like making a long assessment of hazard in three old trees standing close together or in a split second decision on the best escape route as a tree is halfway to the ground.

The preceeding sections have explored the hypothesis that limitation of effort and energy expenditure for this group of Australian fallers is mainly determined by physiological capacity. In doing so we have established average and peak physiological demands. As far as oxygen consumption - our main indicator - is concerned only five men were working significantly above the 50% VO2 max level.

It is concluded that whole body physiological workload probably plays little part in faller error for most of these men and the types of conditions they were studied under. The role of fatigue in particular muscle groups leading to physical loss of control of the larger chain saw is yet to be addressed.

These first work physiology results are a small part of the picture of the hardwood fallers fit-to-the-job. They lead toward the more psychological, information processing view of causes of error in falling work. We are always brought back to the instructors original question. What are the characteristics and skills-the criteria-of the "good" to "ideal" hardwood faller? The four key variables; two physiological, two motivational, focused on in this paper were.

- Physical working capacity vs job demand
- Average energy output across a wide range of conditions
- Speed and impatience
- Job involvement

Explaining error and injury is not dependent on an individual being a "risk-taker" or simply being fatigued but on a complex set of changing states within the man as he copes with the changing conditions of trees and their surrounding environment. The faller remains the controlling element through skill and anticipation. It may well be that an inclination toward speed and impatience cannot be shown to have an association with the several error measures in the main study. This is yet to be tested. Physical working capacity, speed and impatience and job involvement are only parts of the complex jigsaw in risk evaluation, risk acceptance, and escape from non-recoverable errors. We have only taken a small step towards identifying and measuring parts of this ergonomic jigsaw that are critical for the Australian hardwood faller's survival.

ACKNOWLEDGEMENTS

I am grateful for the help and encouragement of the following people and particularly all our research subjects. To Rex McDermott in the collection and collation of the data. To Bill Holmes for the organizing of subjects and his extensive knowledge as a top instructor and bushman. To Dr Waldemar Fibiger, coworker and scientific mentor, for his continuation of my training. To the companies, particularly Forest Resources, and the Tasmanian Foresry Commission, for the support of this research. I am also grateful to my new colleagues at the Commonwealth Institute of Health for assistance in production of this paper, particularly Dr John Brotherhood for his many helpful suggestions at various stages.

****

REFERENCES

1. Astrand,P.O.,and Rodahl,K.,1977,Textbook of work physiology. N.Y.:Mcgraw-Hill.

2. Beckett,R.,1983,Axemen stand by your logs.Sydney:Landsdowne Press.

3. Brown,I.D.,1982,Measurement of mental effort:Some theoretical and practical issues. In G.A. Harrison(Ed)Energy and effort. Symposium of the Society for the Study of Human Biology.Vol.22.London:Taylor and Francis (p.27-37).

4. Cameron,C.,1974,A theory of fatigue. In A.T.Welford(Ed)Man under stress.London:Taylor and Francis.

5. Collins,K.J.,Brotherhood,J.R.,Davies,C.T.M.,Dore,C.,Hackett, A.J.,Imms,F.J.,Musgrove,J.,Weiner,J.S.,Amin,M.A.,Awad El Karim,M.A.,Ismail,H.M.,Omer,A.H.S.,& Sukkar,M.Y.,1976, Physiological performance and work capacity of Sudanese cane cutters with Schistosoma mansoni infection. American Journal of Tropical Medicine and Hygiene,25,410-421.

6. Crowe,M.,1983,Hardwood logging accidents and some counter-measures for their reduction.Dissertation,Graduate Diploma in Occupational Hazard Management.Ballarat College of Advanced Education.

7. Fibiger,W.,1978,Energy cost of work and physical working capacity (in Polish).Warsaw:IWCRZZ.

8. Fibiger,W. and Henderson,M.E.,1982,Physiological inputs to motor-manual techniques in thinning radiata pine. New Zealand Journal of Forestry Science,12(12):162-170.

9. Fibiger,W.,1983,The concept of mental workload and its measurement. In T.Shinnick and G.Hill(Eds)Ergonomics in the community. Proceedings of the 20th Annual Conference of the Ergonomics Society of Australia and New Zealand. Sydney:Erg.Soc.Aus. & N.Z.

10. Hansson,J.E.,1964,The relationship between individual characteristics of the worker and output of work in logging operations. Proceedings of the Second International Congress on Ergonomics,Dortmund.London:Taylor and Francis.p.113-122.

11. Harrla,R.,1981,Productivity measurement in logging operations. Canberra:Harvesting Research Group,CSIRO Division of Forest Research.

12. Henderson,M.E.,and Fibiger,W.,1981.The concept of "risk taking" in tree falling work. In W.H.Gladstones(Ed)Ergonomics and the disabled person. Proceedings of the 18th Annual Conference

of the Ergonomics Society of Australia and New Zealand. Canberra:Erg. Soc. Aus. & N.Z.

13.Jenkins,C.D.,Zyzanski,S.J.,and Rosenman,M.D.,1979, Jenkins Activity Survey - Manual. N.Y.:The Psychological Corporation-Harcourt,Brace,Jovanovich.

14.Kukkonen-Harjula,K.and Rauramaa,R.,1984,Oxygen consumption of lumberjacks in logging with a power saw. Ergonomics,27,1,59-65.

15.Moray,N.,(Ed),1979,Mental workload:Its theory and measurement. Volume 8, NATO Human Factors Series.NY:Plenum Press.

16.Pettersson,B.,Aminoff,S.,Gustafsson,G.,Lindstrom,K.-L.,and Sundstrom-Frisk,C.,1983,Enhanced safety in foresty-A campaign of action for one branch of industry.(InEnglish).Drottninggatan, Sweden:Skogsarbeten.

17.Samset,I.,Stromnes,R.and Vik,T.,1969,Cutting studies in Norwegian spruce and pine forests. (In Norwegian with English summary).Vollebekk:Norwegian Forest Research Institute.

18.Sheridan,T.B.,and Ferrell,W.R.,1974,Man-machine systems :Information, control and decision models of human performance.Cambridge,Massachusetts:MIT Press.

19.Singleton,W.T.,1972,Introduction to ergonomics.Geneva:W.H.O.

20.Singleton,W.T.,1972,Techniques for determining the causes of error.Applied Ergonomics,3,3,126-131.

21.Smith,L.A.,Dennis-Wilson,G.,and Sirois,D.L.,1983,Work physiology of southern forest harvesting tasks.Forest Products Journal, Vol.33,9,38-44.