Felling Australian Hardwoods

An ergonomic study of a high-risk occupation

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Abstract

Felling of trees in native forests is a hazardous occupation characterised internationally by high accident, injury, and death rates. In the research reported in this thesis three fundamental components of performance, namely, physical work effort, the judgement and prediction of dangerous work outcomes, and tree felling accuracy, were examined through measures taken in the forest work setting with Tasmanian *Eucalypt* hardwood tree fellers. In addition, a signal detection paradigm was used in a controlled simulation to assess the ability of tree fellers to discriminate between normally and abnormally falling trees from information in a set of felling episodes on film. The goal of these studies was to further the development of scientific explanations of performance failures with this particular type of high-risk rural worker.

Only a small minority of the men in the sample were physically over-stressed in meeting energy (VO_2) demands during the field research day. Physical working capacities were in the very high category (Astrand and Rodahl, 1977) in some 63% of the sample, with PWC (VO_2 max) generally increasing with age. The majority of tree fellers were found to be working within the medical recommendation of 35% utilisation for their maximal oxygen consumption (VO_2 max), with only 3 out of 39 subjects consistently above 50% utilisation. Although the average heart rate nett across all subjects of 62.4 beats/minute was well above accepted medical standards for this parameter, the cyclic nature of the task and production delays possibly ameliorates this effect in many situations. Personality assessment on a fatalism measure and sub-scales of the Jenkins Activity Survey did not reveal patterns expected from the literature and discussions with felling instructors on the psychological attributes of the effective tree feller. Extrapolations from the work physiology data and implications for worker selection are discussed.

An exploratory model was developed of essential behaviours for felling accuracy and tree-to-tree survival. Tree felling decision processes were studied in the field and in an analogue setting. Actual tree falling time in the forest as measured on video film ranged between 2.6 and 9.7 seconds, with a mean of 5.8 seconds. In the field, workers predicted the direction in which the tree they were about to cut would finally fall, their certainty of prediction, and the risk and awkwardness of the fall. The instructions to subjects was for maximum tree felling accuracy. Nearly half of the subsequent falls during these tests exhibited noticeable felling error (defined as $> 5^0$). In over one third of all felling episodes there was a discrepancy of 10^0 or more between the intended direction of the fall and the actual position of the fallen

tree. In many of the falls involving error the worker responded with a high degree of certainty about his being able to achieve an accurate fall in the chosen direction. Contradicting current tree felling work-technique manuals the confident discrimination of the natural lean of the tree was not very evident. The perception of the tree's natural lean was not found to be a reliable basis for the choice of the felling direction. Correlation analysis showed no clear association between the measured characteristics of the tree and felling error. Neither certainty of felling direction, in particular, nor the men's ratings of risk or awkwardness before a fall were significantly related to target error. The men's own subjective assessment of their performance in the tests, their consistently short retreat distances from the stump, and their certainty of success in cases of felling error, indicated an unrealistic over-confidence in their own performance in the majority of cases.

The analysis of felling error in the field led to investigation of the tree feller's ability to discriminate between normally and abnormally falling trees on video film. In a signal detection simulation experienced tree fellers were slightly but significantly more accurate than a control group of forestry students in discriminating whether the tree they were viewing would fall normally or abnormally. They also anticipated the abnormal outcome at an earlier stage in the tree's fall. However, there were substantial differences between tree fellers in discrimination of these important outcomes.

Correlation of variables across the three levels of analysis indicated that neither workload, as indexed by heart rate or oxygen consumption, nor the particular psychological characteristics that were assessed were consistently involved in felling error. Felling performance in the field correlated significantly with signal detection performance in the first stage of the simulation. There is a possibility for the development of a selection test based on the methodology of the research.

Although the results show a minority of experienced Australian hardwood tree fellers are likely to be physically over-stressed during their work, newer entrants to the occupation show a more varied picture with generally lower physical working capacity and lower utilisation of VO_2 max. The job of Australian hardwood felling remains in the very heavy category for most men from a physiological point of view, but it has been shown not to be beyond the capabilities of the high, rather than very high PWC worker of appropriate size, weight, and of course skill. However, in spite of these positive work physiology results most workers still made significant errors in the prediction of outcomes and the felling control of the tree under the optimum condition of the research. Critical subjective judgments about the felling problem did not relate to error. There is evidence that signal detection by the worker in the final seconds of a tree's fall is currently not much better than that of laymen.

The conclusion to be drawn from this study of a diverse sample of workers is that it is not a case of the voluntary acceptance of carefully calculated risk and consistently accurate outcomes, but more that of a pattern of inevitable and "normal" errors in spite of the mythology and tradition surrounding the skills of the occupation. There was ample evidence of the difficulty many of the research subjects had with the cognitive aspects of the work in particular, and in their discerning that such flaws in their own performance existed. In terms of an exploratory model of tree feller skill and performance failure, the results from all three chapters tended to confirm that a significant proportion of the men in the sample were not able to "read" and control the tree as is generally assumed, and as is described in overseas work-technique manuals. Because of the general lack of the key phenomena of accurate anticipation, the survival of many of the men must still be regarded as significantly related to the frequency of dangerous and defective trees, and other random failure (accident) factors in the forest environment.

The implication of these results for further research and other high-risk worker studies are discussed. The importance of physical stress or erroneous perception and decision making as main risk factors in <u>actual</u> felling accidents, has still to be confirmed. The current study provides ample evidence that these and further risk factors now need to be evaluated within a prospective research design of several years duration.

Declaration

Except where reference is made in the text of the thesis, this thesis contains no material published elsewhere or extracted in whole or in part from a thesis presented by me for another degree or diploma. No other person's work has been used without due acknowledgement in the main text of the thesis. This thesis has not been submitted for the award of any other degree or diploma in any other tertiary institution.

Melvyn Edward Henderson

Dated 30/1/1990

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At the end of a long project is it possible to give due acknowledgement in two or three pages to the many people who made the final product a reality? Though often unstated nowadays it is the process of apprenticeship that still underpins many kinds of professional development. For me the doctorate was yet another apprenticeship. One that I chose and from which I have benefitted greatly. An apprenticeship not to one person, but to several.

In terms of my first mentors in this project I must mention two men in the same breath, Dr Waldemar Fibiger, one-time leader of the ergonomics group of the Polish Forest Research Institute, and Mr Bill Holmes, one-time felling instructor for Forest Resources in Tasmania. Both these men were true specialists in their respective fields, and I was privileged to carry out the fieldwork of the thesis under their watchful eye. Both men were hard to work with because of their own exacting standards of professional practice. Both men were indispensable to the project. Bill Holmes was invaluable because of his intimate knowledge of the old techniques of the axe and cross-cut days, of the men we studied, and of the hardwood forests we traversed in Tasmania. It was Bill who was the cornerstone of the cooperation we achieved in the tree-feller workforce. Waldemar Fibiger came to CSIRO, Melbourne, from Poland at a critical time for the project. Without his in-depth knowledge and research experience in work physiology and ergonomics I would not have had the wherewithal to have started the work. Only he knows how much he taught me in the several years in which we were *co-workers* in CSIRO.

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Dedication

This work is dedicated to Bill, Waldemar, and Tom.

There is of course no substitute for work. I myself practiced constantly, as I have all my life. I have been told I play the cello with the ease of a bird flying. I do not know with how much effort a bird learns to fly, but I do know what effort has gone into my cello. What seems ease of performance comes with the greatest labour ... Almost always, facility results from maximum effort. Art is the product of labour.

Pablo Casals " Joys and sorrows."

Men, water, and cable-blades all find their own level in the bush.

W. H. Holmes.

Chapter 1

Introduction and background

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Introduction and background

1.1 The logging industry

1.1.1 Lumberjacks, bushmen, and chainsaw fellers

Throughout recorded history forests and their products have formed a significant part of the fabric of society (Baker, 1919; Cippolla and Birdsall, 1979). For many centuries timber encompassed all aspects of village and town life, from rough frames and beams for housing construction to exterior boards and internal panelling. Carts, wagons, tools, and farming equipment of all types as well as everyday furniture were all founded on wood. In the home smaller implements of time proven utility often consisted mainly of wood (Hartley and Elliot, 1925).

In today's modern industrialised economies, in spite of the dominance of petrochemical and high technology products, the market for all types of sawn timber remains. In addition there is the constantly expanding demand for reconstituted wood products such as particle board and "new wood", and woodchips for the pulp and paper industry (FAO, 1988). Up until at least the 1930s, in Britain, Europe and countries of similar cultural background such as Australia, crafts involved in the cutting and working of timber in the rural community still employed a broad range of hand skills (Edlin, 1949; Seymour, 1984). Up to the end of the first world war in some wood crafts, these skills were still held by the one worker who would select and fell the chosen tree with an axe and crosscut-saw, manually cleave or saw up the timber as tradition dictated, and finally use his own specialised hand tools and techniques to produce the finished product. Such work was said to require an intimate knowledge of the grain, texture, strength, and weaknesses of the various species in their natural and seasoned states. The differences between earlier rural craftsman both before and after the Industrial Revolution, and the gradual evolution of the various artisans and their guilds from Medieval times, is cogently described by Lucie-Smith (1981).

Today, in spite of the high technology of pulp and paper mills and the increasing introduction of computerised saw milling in some countries (Fibiger et al., 1986; Hallock, 1974), tree felling in most natural forests is carried out by the individual worker with a chainsaw who continues to use techniques based on the work methods of the axe and crosscut days. This manual felling of trees is a particularly hazardous occupation characterised internationally by high accident, injury, and death rates (Broberg, 1986; Macfarlane, 1980; Paulozzi, 1987).

A familiar image of the logging worker is that of the rugged and indomitable lumberjack carrying his trusted axe and crosscut between tall majestic timber. Such an image originates from the logging in the wilderness forests of Canada's Pacific provinces, and in the vast western mountain forests of America that began to be heavily exploited in the 1820s in a manner not previously seen in European history. The harsh realities of the task in these early years and the range of working conditions in American logging camps is well documented by Williams (1976). Australia has its own unique history of logging dating from the early years of European settlement (e.g., Beckett, 1983; Penny, 1910; Rowe, 1980). The traditional job titles of lumberjack or bushman, as he is termed in the case of Australian logging, are synonymous. The term chainsaw tree-feller is the more contemporary Scandinavian expression in the era of the high performance softwood chainsaw. The past work skills of the axe and crosscut bushman in Australia, and the noteworthy levels of hand-eye coordination, find their expression in the early photographs of tree felling and the squaring of beams and jetty piles exported from Tasmania and other states in the nineteenth and early parts of this century (see Appendix 1). Even at the beginning of this period much of the sawing and preparation of timber was still carried out in the forest, and the skills of a good sawyer and adze man were as prized as those of the tree feller. Calder (1980) describes the life and work of those early close knit communities in the rural mill towns that are the heritage of Australian hardwood logging today. As the jobs in the timber industry became more specialised and larger centralised sawmills were established, the axe and cross-cut bushman who knew the subtleties of felling the best trees by hand remained a respected craftsman of the community (Beckett, 1983). Though these particular rural skills have been in serious decline for some time, professional chainsaw timber fellers can still be seen competing in axe and sawing competitions at agricultural shows, and Tasmania has a reputation for having provided some of the best axe and cross-cut champions in Australia.

Eucalypt or hardwood logging continues on an extensive scale along the length of the eastern coast of the Australian mainland, in the southwestern forests of Western Australia, and in Tasmania. Some of the large logging operations combine the felling of trees for sawmills, pulp and paper plants and woodchips, a practice commonly termed integrated logging (Walker, 1982). This contrasts with selective logging of the past which meant the careful selection and felling of trees for the best result in the sawmill *and* the forest. Selective tree felling was considered to require the greatest skill in axemen of the day, and the same term is used in the industry today. Much of the logging of the native forests in America and Australia, as in many other countries, has not been selective but has often involved clear felling. A significant proportion of the trees harvested by today's loggers are used for the production of wood pulp or chips for paper making rather than needing to be felled for sawn timber (e.g., Kemp, 1982; Meadows, 1982; Risby, 1987).

Although a large part of Australia's forest industry consists of softwood plantations that began to be established during the 1930s, eucalypt or hardwood logging still supplies over 10.2 million tonnes or approximately 67% of the total annual cut of all timber in Australia (Anon, 1989). It is estimated that the national hardwood cut will remain close to current levels over the next decade and will increase to a level of approximately 12-13 million tonnes that will be maintained well into the next century. The question of the contribution of plantation eucalypts to these future predictions is not clear, but hardwoods are expected to remain a significant export earner for the industry through the continued supply of woodchips to Japan (Anon, 1988; Cameron and Penna, 1988; Walker, 1982).

Natural hardwood forests in Australia have more in common with the forests of Canada, the west coast of America, and in some cases tropical rainforests than with their European and Scandinavian counterparts. The hardwood forest is characterised by diverse and often rugged terrain as well as trees of widely differing size with significant levels of fire damage or decay (Hillis and Brown, 1978). In terms of average height and volume, tree shape, growth stresses and cutting characteristics the eucalypt species are also distinctly different from the softwood species of Europe, and Scandinavia (Jacobs, 1965). Loggers often describe a natural eucalypt forest as old growth, meaning the original forest condition, or regrowth, meaning a forest which has regenerated between 50 to 100 years ago following clear felling or the effects of forest fires. Such classifications are nominal ones, in that any natural forest of either type is in a constant state of evolution, where even-aged or mixed age stands of trees may be found. A third main category, the regenerated (man seeded) forest and eucalypt plantation, was not considered in the fieldwork of the present research. A number of eucalypt species form the bulk of trees that are used for pulp and woodchip production, as well as for sawlogs. These include those known in Tasmania as blue gum *(Eucalyptus globulus)*, white gum *(E. viminalis)*, stringy gum or swamp gum *(E. regnans)*, brown top *(E. obliqua)*, white top *(E. delegatensis)*, black peppermint *(E. amygdalina)*, silver peppermint *(E. tenuiramis)*, and the mountain gum *(E. dalrympleana)*, (Boland and Johnston, 1984).

Tasmania has the highest proportion of forested land in any state in Australia and some of the finest hardwood forests in the world. The tallest known hardwood tree, a *Eucalyptus regnans*, rises over 100 metres above a grove of similar ninety metre trees in the Stynx valley of southern Tasmania. At the time the fieldwork for the current study was carried out, the estimated value of the predominantly eucalypt based industry for this state was $255.8 million, in contrast to $66.1 million for primary industry and $189.7 million for secondary industry and mining (Tasmanian Forestry Commission, 1981). There is little reason to doubt the continued importance of the timber industry to the Tasmanian economy (Tasmanian Forestry Commission, 1988). Some writers have indicated that it was the advent of the export woodchip industry in the early 1970s in Australia that dramatically changed the nature of the logging industry, even if the methods of cutting and transporting trees in these natural eucalypt forests remained basically the same as before this date (Walker, 1982).

The aim of this chapter is to describe the occupation of the Australian hardwood tree-feller and some of its idiosyncrasies, and to discuss international statistics which highlight the position of tree-fellers within the overall problem of logging worker injuries. Non-Australasian accident statistics are discussed first, followed by New Zealand and Australian data. Further sections consider the status of accident models in the logging ergonomics field, and detail research on tree-feller performance mainly by reference to Scandinavian studies. The focus of the final sections is on the particular Tasmanian forest setting of the research, as well as assumptions underlying the study. The difficulty of establishing safe work practices in such a varied and unpredictable work environment is also considered. The objectives of the research program reported in the thesis are then outlined.

1.1.2 Logging technology

Since the late sixties increasing attention has been paid in Europe, and particularly the Scandinavian countries, to full mechanization of all stages of logging. A primary objective of mechanisation was to reduce the injuries and the physical work-strain associated with motor-manual logging methods (Pettersson, 1978; Pettersson et al., 1983). Fully mechanised timber harvesting was capable of extensive development in the Scandinavian and Nordic countries because of the smaller size of the various native species in the softwood plantations and natural forests, the longer and more adverse winter climate, the more integrated, educated and unionised workforce, and a large market for "comfortable" machines (Andersson, 1979). There was also greater pressure for improvements in occupational safety and health in these countries than in Australia (Henderson, 1980). Tree felling machines were initially designed in Scandinavian countries in the early 1970s to cut defect-free trees up to 50 centimetres in butt diameter, while larger capacity softwood felling vehicles have been developed in Canada (Andersson, 1979; Legault, 1976).

Hardwood logging necessitates the use of particularly heavy machinery in terrain of varying difficulty. The major changes in technology over time have been the transition from horse or bullock teams for log hauling to the static steam engine log hauler, the bulldozer, and more recently to the larger types of rubber tyred or steel tracked skidder. For the bushman or hardwood timber feller cutting larger-sized trees, the main technological change since the 1960s has revolved around a progression of minor (and not necessarily genuinely ergonomic) changes to the hand-held chainsaw rather than any major innovation. Chainsaws used in hardwood are usually heavier, larger, and with longer cutter bars than those used in softwood tree felling (see Appendix 1).

The hardwood tree-feller remains as the first stage of the whole production process. Without this small but specialised group of workers, the multimillion dollar hardwood part of the forest industry could not exist. For those not familiar with the timber industry in Australia it is necessary to emphasise the important difference between forestry activities, which are carried out mainly by the permanently employed wages labour force of the various state forestry commissions, and logging activities, which typically are undertaken on a piecework basis by private sector sub-contractor operations. Nowadays a typical hardwood logging crew consists not only of a timber-feller but a choker setter or operator who attaches the steel hauling wires to the trees once they have fallen. The skidder or bulldozer driver is responsible for hauling one or more logs back to the landing or loading platform. The bucker, or chainsaw operator in Australia, cuts up the trees on the landing and prepares them for loading onto the logging trucks with a crane or grapple loader. There may also be high lead operators on those sites where trees are pulled in via cables slung from trees or steel spars (a practice more common in Canada and America and southern parts of Tasmania than in the rest of Australia). Two or more of these roles are taken by one man in smaller crews (for example, choker/skidder driver). For much of Australia's native eucalypt forests the larger average tree size, the problem of tree shape and defect, and the significant areas of steep terrain (26^0 or greater than 50% slope) in eastern seaboard states have all ensured that mechanised tree felling is not a feasible alternative to motor-manual method in native forests. It is thus likely that felling of native timber in Australia, as well as in North America and in many tropical rainforest areas, will be carried out by the highly-mobile, chainsaw-carrying fellers for the foreseeable future.

In discussing the social and economic context behind forest accident prevention efforts, Ager (1978) provided one scheme to describe the levels of development of working conditions for forest workers. He identified three case descriptions that could be used in assessing forestry and logging in any country. The first was termed manual techniques under unfavourable socioeconomic and climatic conditions, the second, moderately mechanized techniques under comparatively favourable socioeconomic and climatic conditions, while the third was of highly mechanized techniques under favourable socioeconomic and climatic conditions (see Appendix 2). Besides the mechanization of transport and de-limbing at the work site, mechanical timber felling machines are increasingly employed in major northern hemisphere logging regions (see Appendix 3). The third case description above finds its best example in logging operations in Sweden and Finland where major mechanisation and associated injury prevention work has taken place (Pettersson et al., 1983). Through the initiatives of one large paper manufacturing company in particular, Australian softwood plantation logging is partly following the Northern European trend to full mechanisation, including mechanical tree felling (Brotoft, 1983).

The environment and working conditions of the hardwood logging industry in Australia, rather than in Scandinavian countries, for example, are more likely to be in Ager's second case description above. The injury statistics reported in this chapter are consistent with such a classification. As in other Australian logging states the logging workforce in Tasmania is more widely scattered and isolated for hardwood operations than for softwood. Further, hardwood logging is more likely to be organised on an independent sub-contractor rather than company employee basis. In Tasmania, logging and tree felling environments range between the lush and rugged temperate rainforests of the western rainfall area and the dry schlerophyll and more open forest types of the eastern parts of the state (see Appendix 4). Given the major decline of the traditional work skills of the axe and crosscut bushman (Beckett, 1983), this thesis is concerned with the work of a modern chainsaw timber-feller in Australia's native hardwood forests.

1.1.3 Professional felling

At the practical level, models of accidents attempt to explain why workers are injured or killed to a significantly greater extent in certain occupations than in others. In the case of tree felling it might appear unusual that so many men are seriously injured while carrying out the seemingly straightforward job of "cutting down a tree". In rudimentary terms, tree felling involves the cutting of a wedge shape "scarf" out of the front of the tree to a depth of one quarter to one third the diameter, and subsequently cutting into the back of the tree at a slightly higher level than the scarf cut until the tree begins to fall in the desired direction. However, it is important to emphasise the difference between cutting down a single tree in a garden or similar location as a once-in-a-lifetime exercise and the felling of mature hardwood timber as a full time occupation. The domestic scene of cutting down one tree (where fatalities still are regularly reported) is distinctly different from the activities of a professional feller cutting up to 600 and sometimes as much as 1000 tonnes of timber in a week. An insightful description of the work of a modern lumberjack working in big timber and steep terrain is given by one American writer, Hager (1980), who was himself a lumberjack (see Appendix 5). This description is indicative of the more difficult working conditions and challenges that confront Australian hardwood timber-fellers. This picture can be compared with a description of the chainsaw operator's work in a Swedish felling operation given by Pettersson (1978) and the difficulties of working in snow and below zero temperatures for part of the year. In Australia it is the age and size of the trees, the surrounding undergrowth and forest, adverse wind and weather, the closeness of other similarly decayed or damaged trees, and the proximity of heavy logging machinery that makes the hardwood situation qualitatively different from the occasional use of smaller domestic chainsaws. The hazards of using large professional chainsaws for eight hours a day is a subject in its own right (ISO, 1982; Haynes, Webb, and Fenno, 1980: Hunt, 1979; Pykko et al., 1986).

1.2 Logger injuries in Pacific basin forests

1.2.1 Introduction

The problem of logging injuries and fatalities has only begun to be properly documented in the last fifteen years or so (FAO/ILO, 1971; United States Department Labour, 1973). A number of Scandinavian and European reports have clearly confirmed that tree fellers and chainsaw operators are the highest risk group in their particular softwood forest industries (Broberg, 1986; Hoffle and Butura, 1980; Pettersson et al., 1983; Strut, 1972).

In assessing health risks for loggers, Edlin and Granstam (1980) made a comparison of causes of death in a Swedish sample of timber-fellers against the general working population (see Table 1.1.). Although the focus in this research was on certain types of cancers, the analysis confirmed the high risk of timber-fellers meeting a "violent death".

The standardised proportionate mortality ratio (SPMR) for violent death was higher than that for the other causes shown in the table. This study also noted significant excess mortality for violent deaths for lumberjacks over the age of 50. The SPMR for violent deaths was 1.79, while fatalities from all other causes had an SPMR of 0.53 when compared with the general population at or above the age of 50. Even though the information on the death certificates used in the study did not allow a complete sub-division according to work accidents, Edling and Granstam were confident that the general results plus the findings of increased risk of violent death with those over 50 years of age "should probably be interpreted as a high mortality being due to accident rather than suicide" (p.405).

Table 1.1 Distribution of observed and expected causes of death amongst a sample of Swedish lumberjacks: Standardised Proportionate Mortality Ratios (SPMR)* (Derived from Edling & Granstam, 1980).

	Cause of death (Age 25-69)									
	Ischemic Heart Diseases		Cerebrovas. Diseases		Other Circulat'y Diseases		All Cancers		Violent Death	
	Obs	Exp	Obs	Exp	Obs	Exp	Obs	Exp	Obs	Exp
	123	114	26	21	23	21	75	85	94	65
SPMR	1.08		1.24		1.10		0.88		1.45	
95% Conf. limits	0.90-1.29		0.81-1.81		0.69-1.64		0.69-1.11		1.17-1.70	

* Standardised Proportionate Mortality Ratio - The percentage ratio of the number of deaths observed from a particular cause in the age-occupation-sex group studied to the number expected from the same cause for a reference or standard population.

1.2.2 The overseas statistics

Due to the difference between the Scandinavian countries and Australia in terms of trees, environmental conditions, the chainsaws used, and the organization of the workforce, the most appropriate data on the likely risk for the Australian native eucalypt fellers are probably best given-by non-EEC or non Scandinavian-Nordic reports (e.g., Frazier and Coleman, 1983; Macfarlane, 1980; Milham, 1976; Peterson and Milham, 1980). Paulozzi (1987) and Holman et al., (1987) have attempted to look more strictly at the epidemiology of fatal logging injuries in large timber logging in North American forests.

In 1983 the American National Institute of Occupational Safety and Health selected logging as the subject of its first report on the series of NIOSH Surveillance Reports (Frazier and Coleman, 1983). Earlier general occupational mortality studies of NIOSH by Milham (1976) and Peterson and Milham (1980) had focussed attention on the logging injury problem. In the 1983 paper, four major data bases from previous investigations were used to cross compare past logging injury statistics in the three main lumber regions of the country (see Appendix 6). In the study, estimates of the total American logging workforce were found to vary widely due to the seasonal nature of the work, the isolated nature of many of the operations, and the varying definitions of "logger" in different states. Using figures from the 1970 census 73,192 males were characterised as the population at risk, even though a NIOSH survey in 1976 had concluded that as many as 300,000 workers possibly were employed throughout the industry. Analysis of the National Health Interview Survey (HIS) data base covering non-disabling injuries over a four year period (1969-1974) showed that males engaged in the manufacture of wood and wood products had an injury rate 38 % higher than the figure for all other workers combined. The study also found that the injuries sustained by loggers in the Western lumber region, where timber is larger and the logging conditions more rugged and difficult, were significantly higher than the other regions.

Analysis of the Social Security Administrator's Continuous Disability History (SSA) sample for the same 1969-74 period indicated that loggers were responsible for 79% of disability awards. In over 1000 cases of logger injury, 350 involved fractures to the lower limbs of one type or another, while 218 entailed fractures of the skull, spine, or torso.

Table 1.2 Percent distribution of disability award among American logging workers by age.

		Age			
Data base	Injury %	<40	40-49	50-59	60-64
(HIS) Age 1970 Census	100	51.3	22.8	17.9	5.2
(SAA) Awarded Disability	100	26.5	17.6	35.1	19.1
Award Incidence	1.00	0.52	0.77	1.96	3.67

As with the (HIS) survey data base, the Western lumber region were found to experience a disproportionate share of these serious injuries even though this region constituted little more than one fifth of the total estimated American logging workforce. The combined data analysis also revealed that older workers have a greater risk of disabling injuries than younger workers (see Table 1.2.).

The above results led Frazier and Coleman to conclude that a high risk group could be identified in terms of personal characteristics, geographic location, and the broad nature of injury:

> "White male cutters (including buckers, fellers, timber markers and wood boss) in the age group fifty and over working in the Western lumber region are at greatest risk of disabling injuries caused by fractures of lower limbs, skull, spine and trunk."

Two earlier general NIOSH mortality studies in two states had included loggers as one of the occupational groups. The 1983 NIOSH study combined the data for these two states, in each of which logging conditions are similar to Australian hardwood logging. In both Washington State and California, loggers had excess mortality from injuries caused by falling trees and branches. Unfortunately data from Oregon (another premier logging state like Washington) were not available. Table 1.3, which is taken from the Petersson and Milham (1980) report, gives the proportionate mortality ratios (PMR) for their sample of American loggers in a similar manner to the study of Swedish lumberjacks by Edling and Granstam (1980).

Table 1.3 Proportionate Mortality Ratios for loggers in Washington State (1950-71) from Petersson and Milham, 1980.

ICD 7th Revision *	Deaths		
	Observed	Expected	PMR
Tuberculosis (001-008)	74	57	130
Cancer of the stomach (151)	223	186	120
Lymphatic Leukemia (204)	18	14	128
Bronchiectasis (526)	31	16	199
Chronic interstitial pneumonia (525)	24	26	94
Blow from falling object (910)	368	34	1075

* International Classification of Diseases.

In the period 1950-1971 for the state of Washington, 368 fatalities out of a total of 738 logger deaths were due to blows from falling objects and trees. The difference between PMR's for cancer of the stomach, for example, and the falling objects fatalities is very noticeable. The figure of 368 fatalities for this cause of death based on the overall working population constituted approximately one quarter of all accidental deaths for this sample of loggers. Though blows from falling objects were the major cause of death (as is found in Swedish, New Zealand, and Australian data), cuts, lacerations, and fractures were predominant in non-fatal injuries. A single year analysis for Washington state loggers in 1979 showed cuts and lacerations were predominant in non-disabling injuries in 27-28 % of cases, with strains and sprains a close second.

Though 60% of disabling injuries were fractures, in the non-disabling case fractures accounted for only 5% of injuries. Some of the questions posed at the end of the NIOSH-Frazier and Coleman (1983) report which are relevant to Australian loggers include:

1. What environmental conditions may contribute to the apparent increased risk of injury for the loggers (in the Western lumber region)?

2. What characteristics of older loggers may be contributing to increased risk of injury?

3. To what extent could training programs or retraining contribute to a reduction in logging accidents.?

4. What behaviours differ between older and younger fallers as regards controlling hazards and for that matter between one region and another?

Auxiliary questions which are not the concern of the present study considered the problem of chainsaw cuts and the differing use of items of protective equipment.

1.2.3 Australia and New Zealand

Although the softwood industry predominates, New Zealand has a high proportion of some of the largest old crop *Pinus radiata* to be found in the world. These trees, which are comparable in height and dimension to those found in many Australian hardwood areas, often have uneven shapes due to frost damage during early growth. In a significant number of areas logging conditions include steep terrain and heavy undergrowth. In a comprehensive study of injuries and fatalities on the main logging area of the North Island of New Zealand, Macfarlane (1980) found that the majority of injuries in some 90 long term cases of hospitalization were caused by a falling tree or log. Of 110 fractures studied, the majority were to a lower limb and 66 required reduction of the limb.

Nearly half of all fractures had significant complications. For example, there were 12 cases of chronic infections, nine entailing bone shortening or amputation, and seven non-union of the fracture. The causes of death for 143 logger fatalities during the period 1970-78, as detailed in the same report, are given in Table 1.4. No estimates of the annual workforce or calculation of PMR rates were possible. These data emphasise that the use of the term softwood or hardwood is somewhat irrelevant in the case of injury. All wood with a minimum of weight and velocity acts like steel when it impacts the human body.

Table 1.4 Cause of death New Zealand North Island loggers 1970-78 (Macfarlane, 1980).

Cause	No	% Tot
Falling tree	64	
Falling branch	17	>57%
Logs falling off truck etc	24	17%
Crushed by machinery	11	8%
Falling from a height	4	--
Blow from flying objects, steel hooks etc	4	--
Drowning	2	--
Insufficient detail	17	--

Total	143	

The concern with accidents in the Australian hardwood logging industry is not new (Waters, 1959). However, Crowe (1986) was the first investigator to look in some detail at accident statistics for mainland hardwood forest conditions. He analysed accident statistics over a three year period (1979-1982) for five of the largest pulpwood and woodchip companies in the south eastern eucalypt forests of Victoria and New South Wales, and the southern karri and jarrah forests of Western Australia. The five companies for which statistics were available were responsible for approximately 40% of Australia's annual hardwood cut. Crowe cautioned that since his analysis concentrated on the larger mainland companies with more resources and usually some sort of safety program in place, the actual picture for the remaining predominantly small logging contractor operations would be worse. Crowe reported a total of 445 lost time accidents during the three years for an average estimated seasonal full-time workforce in the five companies of 1500 men. No details were given of the seven fatalities. Some 42% of the injuries involved at least 100 days off work and a further 18% of the accidents involved between 51-100 days lost. The majority of these serious accidents (some 60% of those surveyed) occurred in association with falling trees, falling limbs and rolling logs. Injuries incurred in the falling of trees involved a mean lost time of 49 days compared with a mean lost time of 28 days for falls, slips and musculoskeletal injuries. Fellers and other men operating chainsaws had some 61% of the total accidents and represented over 66% of the total lost time even though they formed only 34% of the surveyed workforce. Crowe's conclusion in this Australian study was that a tree-feller was three times more likely to have an accident than a logging machine operator. Over-representation of accidents in the above 50 years of age classification was also found in this analysis.

In studies undertaken outside Australia, Pettersson et al., (1983) and Paulozzi (1987), found an inverse relation between size of logging organization and injury rates. If the same situation applies in Australia we can assume the above statistics represent a best case scenario for Australian hardwood logging. A partial confirmation of this best case conclusion comes from unpublished data on serious injuries for Tasmanian hardwood logging where the smaller sub-contractor operations predominate (Tasmanian Department Labour, 1981). In the 21 month period that was sampled seven timber-feller deaths involving falling trees occurred within an estimated hardwood timber feller workforce of no more than 310 men. Seven very severe injuries, which could easily have been fatalities, ranging from serious head and spinal injuries to crushed legs and a severed foot were also reported. In addition there were 28 injuries involving the impact of the tree or limbs on a tree feller which resulted in minor lost-time injury, but could easily have had fatal consequences. Overall there was a probable serious injury/fatality rate of between 5 to 12% over a period of nearly two years. These particular results probably represent the worst case scenario for Australian hardwood logging.

1.2.4 An optimistic viewpoint

In a recent investigation that followed the North American ones previously described, Paulozzi (1987) examined the epidemiology of fatal logging injuries using Washington State data for the years 1977-1983. The analysis, which was restricted to timber felling and the pulling and loading of logs, excluded lower risk jobs (such as those of log truck driver) which have tended to confound the denominator in other PMR studies. In such a sample of logging workers there were 132 fatalities over a five year period. Forty five of these deaths or 34% were caused by the man being struck by a tree brought down by the deceased or, to a lesser extent, by a tree felled by another person. A further 20 men (15%) had been killed by trees that had rolled or toppled when disturbed, while 13 (10%), most of them tree-fellers, were struck or run over by heavy mobile equipment. Surprisingly, no chainsaw associated fatalities had occurred.

Table 1.5 Logging fatalities, Washington State 1977-1983 timber fellers and machine operators only (total n unspecified).

	No	%	
Struck by tree brought down by deceased	34	25.8	
Struck by tree felled by another	11	8.3	>34%
Struck by rolling log	20	15.2	
Struck by log being dragged	18	13.6	>29%
Struck by heavy equipment	13	9.8	
Equipment rollover	12	9.1	
Struck by machine boom	7	5.3	
Struck by log during loading	3	2.3	
Electrocution felling near power lines	2	1.5	
Other	9	6.8	
Unknown	3	2.3	

TOTAL	132		

Table 1.5 summarises results from the study, and clearly demonstrates the kinetics of injury in modern large timber harvesting. Paulozzi's calculation of the annual logger mortality rate for the state varied between 1.8-2.4 per 1000 according to whether the census count or the estimated hours worked was used in the denominator. Paulozzi noted a significant trend ($p < .01$) toward lower PMR with increased organization size, a result that has been found in other industries (e.g., Kjellen and Baneryd, 1983). Paulozzi pointed out that if all logging operations had experienced the same mortality rates of the largest companies in his survey, deaths would have been reduced by 75% during this period and 81 lives would have been saved. In addition, Paulozzi reported that safety inspectors from the Washington State Department of Labour had estimated that 90% of the 129 fatalities they had investigated were preventable, while nearly 50% had involved a clear violation of official safety codes. While the previous NIOHS reports and his own study led Paulozzi to conclude that logging was not simply a dangerous occupation but "an extremely dangerous occupation", he also felt that:

> "This study demonstrates that logging fatalities are not inevitable or random events. A great deal more can be learned about their causes, but clearly many fatalities can be prevented as evidenced by the record of larger companies in the study." (Paulozzi, 1987 p.107).

Confidence in external regulations and general safety programs bringing about such a reduction in injury rather than increases in the worker's skills in dealing with job risks could possibly be too optimistic. A questionnaire study by Lindstrom and Sundstrom-Frisk (1976) on risky behaviour in Swedish timber cutting work (to be reported in later sections) clearly demonstrated that ignoring safety regulations was perfectly "rational behaviour" from the timber feller's point of view, particularly under piecework conditions.

A smaller analysis of severe rather than fatal logging injuries is reported by Holman et al., (1987) in a cohort study of 51 loggers admitted to a Level-1 trauma centre in Washington state. Sixty seven percent of the injuries resulted from being struck by falling or rolling trees and logs, with chainsaw cuts as the next highest source of injury (16%). Two deaths within 24 hours of injury yielded a mortality rate of 4%. Twenty five of the men or some half of the cohort had permanent disabilities. The investigators concluded that there would be little possibility for improvement in the logging injury position until the mechanism, type and severity of injuries were more clearly understood, and until the magnitude of the logging injury problem had been fully appreciated in the community and the logging workforce itself.

To assert, as Paulozzi (1987) has, that greater regulation and increased fines for safety violations will significantly reduce injury is possibly too simplified an approach. Such a point of view could be counter productive in the cause of injury prevention because, as one example, there is no clear understanding at this stage as to why logging company size is generally associated with reduced injury. Even "reduced" injury rates are not necessarily satisfactory when compared with currently "acceptable" mortality rates in other high-risk industries. The western forests of the north American continent bear greater resemblance to Australian hardwood forests than other logging regions in America because of the diverse and often steep terrain and the greater tree size. The consistency of severe injury rates that are reported in those regions and for Australian hardwood logging seems to question the optimistic point of view.

1.3 Theories of forest accidents

1.3.1 Accidents and research orientation

In the accident prevention literature the term "accident" can refer to a completely random and unpredictable event causing injury which some workers will refer to as "pure chance" or "a twist of fate". Accident can also refer to the mechanical event immediately preceding injury, to human error preceding injury, or to all events, human and otherwise, which contribute to the injury process (Surrey, 1969).

In the present thesis the use of the word accident is limited strictly to that of an unpredictable randomly occurring event leading to injury. Thus, in logging, the prime example of an accident is injury resulting from the collapse of branches or even a tree on to a worker as a result of the natural process of ageing and decay of the tree in an undisturbed forest. This definition of a so called "real accident" is similar to that used by many bushmen themselves. Events where mechanical failures of machinery are implicated, or those involving mechanical failure of the wood fibres in a tree as it is cut, or where a failure of human performance can be clearly shown to have occurred are termed exactly this - mechanical, tree, and human performance failures, and not accidents.

When discussing accident models in relation to timber worker injury in particular, Lagerlof (1974) suggests the term "model" is perhaps misleading. In the literature there are in fact three orientations to accident phenomena, linked particularly to the disciplines of epidemiology (medicine), systems engineering (engineering), and behavioural-ergonomics and skill psychology (the behavioural sciences). Other researchers suggest that there is no one "theory of industrial injury" any more than there is one theory of human behaviour or human error (Singleton, 1984a p.113; Benner, 1983 p.127-8). Leplat (1984) emphasised that "an accident is a phenomenon resulting from the interaction of a set of variables for which there is no simple model" (p.87). He suggested the study of accidents often requires the combination of several models, and for this reason systems theory offers a suitable perspective. As demonstrated by the Paulozzi (1987) study previously described, the medical epidemiology of industrial injuries constitutes a fruitful approach to the study of accidents. However, the literature relating to this approach falls outside the scope of the thesis and is not considered further.

The so called cognitive (and systems) framework for describing an accident in process industries attempts to identify and chart the network of human performance and decision failures; that is, errors and "mechanical or material failures" which lead up to the actual injury event itself, or the point where the person can no longer regain control of the system (Leplat and Rasmussen, 1984). In such systems engineering or multi-disciplinary orientations to work injury, two basic thrusts can often be found (Chapanis, 1980; Rasmussen, 1985). The first perspective emphasises the fact that errors are an absolutely inherent component in all human performance and should therefore be accepted in setting up any production system. Thus, the systems engineer and equipment manufacturer should in theory accept responsibility for any recurring patterns of injury that will occur, despite following a total error reduction strategy wherever possible (see Appendix 7). A second position, with a much older heritage in common law (see Appendix 8), suggests that the worker is, in legal theory as well as working practice, totally responsible for acceptance of risk, and that the most a responsible industry

Factors

The individual	Workplace	Situational
Age	Characteristic of	Physical work
Experience in job	the machines, and	environment: heat
Personality	tools	cold, humidity,
Motivation	Problems with	available light,
Intelligence	materials i.e.,	weather.
Special skills	trees demanding:	.Work hours/rest
Strength/stamina	*Perception	.Shiftwork
Adherence to:	*Decision making	.Organisationwork
social norms of	*Hazard perception	.Job instruction
production or	*Speed & accuracy	.Super. support
safe working.	Problems with chain	.Payment & reward
	-saw	systems.

Figure 1.1 Interacting factors in forest accident "models" (after Lagerlof, 1974 , 1979).

management should aim to do is eliminate those factors that greatly influence the worker's decision to accept high levels of risk. The middle ground adopts as much of the total error reduction strategy as possible to prevent the technical provocation of error, but at the same time recognises that factors within the work setting may elicit high-risk behaviour. Timber felling binds these important system issues together. The outdoor forest setting prohibits introduction of a total error reduction strategy in spite of the continuing high levels of injury. The organisation of the industry (in Australia in particular) makes it difficult to remove all the factors (Lindstrom and Sundstrom-Frisk, 1976) thought to be supporting high-risk actions. Indeed, some observers of the hardwood industry might suggest that, contrary to modern occupational safety and health ideology, the hardwood feller is still in the final analysis responsible for any injury that befalls him because of the essentially direct personal control of job risk at the tree stump and the skilled trade-craft nature of the job.

The human and environmental factors considered to be involved in forest accidents are typically represented in generic models as in Figure 1.1. Such a rudimentary systems listing of factors likely to be involved in accidents could be couched in the more descriptive terms as follows: "beside the characteristics and skills the operator brings to the job his behaviour and choices are influenced by the surrounding work group, the task characteristics, the nature of the tree he is felling, job information and instruction, physical condition, organisation of the work process and the methods of management, as well as the system of payment." Agren (1981) is an example of those researchers who have warned against the dangers of complex models and flow diagrams when considering a systems approach. Agren suggested, "it is all too easy to, on paper, put down some boxes and connect them with arrows and then make some "reasonable" guesses about the values of these arrows ... There is an urge to make the model as "realistic" as possible by including all factors thought to be important ... it is then very difficult to relate the behaviour of the model to any particular formulation (p.16)." The system orientation might therefore be best suited in many instances for establishing the context of the research study of performance relating to accidents rather than specific content.

A third orientation in accident research and human performance studies is of particular importance because of the inherently uncontrolled nature of native forest timber felling. The behavioural-ergonomics approach is exemplified by Singleton (1984), who argued that there was "increased interest in behavioural approaches to safety as distinct from the engineering approach which relies on physical separation of the person from the hazard ... the objective of behavioural [ergonomics] approaches is to reduce the probability of human error" (p.107). Singleton also emphasised the need to determine the relative importance of the same sociological and background system factors discussed by the other researchers, as listed in Figure 1.1, in discovering the origins of human errors within injury processes. The behavioural-ergonomics stance underlying the tree assessment fieldwork will be further defined in chapter 3. However, the difficulty in following Singleton's pragmatic recommendation is emphasised by the fact that in many industries so called risk-taking or unsafe behaviour is rarely followed by an accident, and even less so by injury. The "unsafe" way of tackling some tasks is often experienced to be easier, quicker, and less strenuous so that choosing the higher risk option can be associated with reward rather than a cost for the worker. Sundstrom-Frisk (1983) suggests risk-taking should be regarded as "an intentional choice of behaviour which is known from accident statistics to increase the chances of having an accident." The choice is made although there is time and opportunity, at least in an observer's eyes, to choose a safer way of acting. "How then", asks Sundstom-Frisk "can you convince a person, who has been applying "unsafe" methods for 20 years without having an accident, to change to "safer" but less rewarding work habits?" (p.49). The promise of no injury at some indeterminate point in the future is not an inducement to change behaviour if experience has demonstrated to a worker that he should not expect an accident from his "unsafe" behaviour.

In an earlier article on the relation of the various psychological schools of the time to the problem of human error, Singleton (1973, p.730) suggested the field type theories in psychology at least made us realise that:

> "almost any accident involving a man-machine system can with equal validity be traced to inadequate machine design, inadequate training, inadequate instruction, inadequate attention, an unfortunate coincidence of relatively rare events, or just to human error".

It is therefore of some importance to decide what aspects of human performance and accident phenomena one is attempting to research. While the accident and human performance models relating to the high-risk work of tree-fellers are at a rudimentary stage of development, this thesis concentrates on the physiological and behavioural aspects of error and performance failures in tree felling within three important facets of the job, and within the broader systems framework of factors supporting so called high-risk behaviour.

1.3.2 Previous research on factors in feller injury

Productivity and accident prevention have been studied with reference to logging in the European and Scandinavian countries over a long period (e.g., Samset, 1963, 1969; Harstela, 1971; FAO/ILO 1971; Pettersson, 1978; Vik et al., 1980). However, few forest ergonomics studies which are directly relevant to the problem of the tree feller's skilled and safe performance have been undertaken. In contrast, there have been many studies of the work physiology of tree fellers. This latter literature is considered to have particular implications for safe felling and is discussed in detail in Chapter 2.

Dunn (1972a), one of the first investigators to consider the question of the 'subjective risk model' of the tree-feller, obtained estimates of the frequency of the particular problem of chainsaw injuries to different parts of the tree feller's body from 25 English forestry workers. There was a consistency amongst the men on assumed injury patterns. However, the estimate of the frequency of injury to the different parts of the body did not correspond to injury statistics. Though the perceptions of the group were inaccurate, Dunn made the point that even having accurate knowledge of injury probabilities was unlikely to prevent many fellers from being injured in the real felling situation. A well informed worker might experience injury whenever cues to danger were difficult to perceive, if he did not have the requisite skills for that particular type of tree, or when equipment was not up to the task. These points are taken up in chapter 3.

As part of a larger study of risk-factors with Swedish forest workers (Lindstrom and Sundstrom-Frisk, 1976), Ostberg (1980) reported data on the perceived risk in pictorial representations of commonly accepted dangerous felling situations in Sweden (see Appendix 9). Employing a booklet of illustrations of 10 dangerous felling situations and a neutral but hazardous work-related situation (walking home from work along a dark forest highway without reflection strips on clothing), a paired comparison analysis tended to show tree fellers had lower perception of risk in felling than most other personnel groups within Swedish forestry (see Figure 1.2.). Ostberg reported a consensus across all groups on the ranking of the felling situations from the least to the most unsafe work behaviour; the felling of lodged trees or being in close proximity to another working tree-feller were seen as the most hazardous situations (see Appendix 9). A lack of accident statistics for the 10 specific felling scenarios used in the study did not allow comparison between the subjective and objective rank order of the risk situations. Although Ostberg's emphasis was that the tree-feller supervisors had lower overall assessments of risk than the tree fellers themselves, the relatively low overall rating in Figure 1.2 by

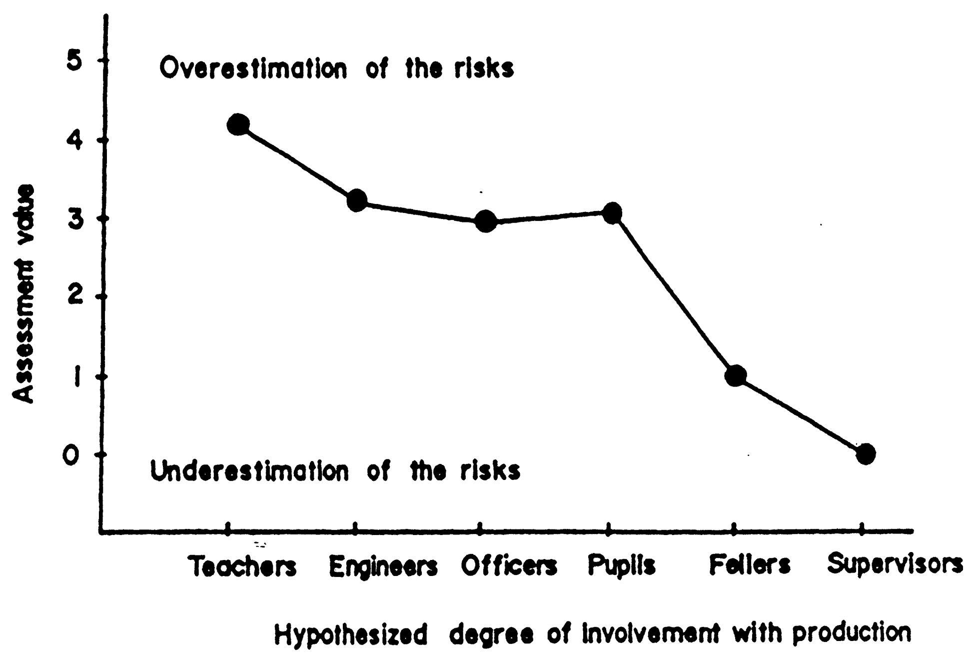


Figure 1.2 Mean risk assessment values of 10 felling situations for six Swedish forest personnel groups (Ostberg, 1980) (Range of values O `not very unsafe' to 5 `extremely unsafe').

those workers at actual risk should be noted.

Important findings on the broader systems aspects surrounding tree felling injuries were also reported in a second major part of the study by Lindstrom and Sundstrom-Frisk (1976). Some two thirds of the 600 workers taking part in a questionnaire survey reported that they occasionally used methods forbidden by the Swedish forest safety legislation. Furthermore, those men using forbidden work methods often did not consider that this involved "taking [real] risks". The major reasons given for using the banned methods were to increase piecework earnings, to save energy, or simply because there were no other practicable methods to solve the problem available. Surprisingly, the investigators reported a distinct lack of consensus among these Swedish workers in terms of the regulations and recommended procedures for making the felling cuts. There tended to be a difference of opinion about work technique between those workers who had and those who had not recently suffered accidents. It was also reported that older workers generally earned less and were less willing to trade their safety against higher production or convenience. In relation to the size of the logging enterprise, supervisors in smaller companies were seen as more lenient in safety matters, while "safety minded workers" (sic) were more likely to have "safety minded" supervisors. The types of tools and chainsaws used by the men were found to be much more dependent on the type of company than on the type of logging operation. Many of the men believed that piecework led to an irregular work pace and hence unsafe working behaviour.

In summary, this large questionnaire survey showed that the average Swedish forestry worker sometimes did not follow the prescribed safe working methods. This did not seem to be due to his ignorance of the safety regulations and the risks they were meant to avoid, but rather to the fact that (a) the production system often inevitably created the risks; (b) too many supervisors had a lenient attitude toward unsafe work behaviour; (c) the higher risk methods were regarded as more economic in terms of energy, time and earnings, especially by the younger worker; (d) the equipment, tools, and work procedures were not designed entirely from the point of view of safety; and (e) the piecework system, by and large, acted against safe behaviour.

Piecework is the prevalent method of payment in the Australian logging industry. The simple idea behind the flat-rate piece rate system in logging is that the faster the man works the greater his productivity and pay. Payment is one of the "background" factors that has received consideration in accident models for many years, and had featured in the conclusions of the previous Swedish surveys just described. A major field study of the issue of payment methods in Swedish logging was made possible in 1975 (following the Lindstrom and Sundstrom-Frisk risk factors study), when several thousand forestry workers went on strike, with the primary goal of getting rid of a thirty year old flat rate piecework system. Systems of payment were subsequently changed for forestry workers throughout the country. Pettersson et al., (1980) and Sundstrom-Frisk (1981; 1984) reported strong evidence that the subsequent 29% reduction in injury frequency, with a 50% drop in the severity index, was due mainly to the change in payment to a salary (85%) and incentive (15%) method. However, according to Sundstrom-Frisk (1980), the established use by this time of other system factors such as ergonomic saws, protective leggings and felling aids, and the training of different personnel groups also contributed simultaneously to the decrease in accidents. Although reduced productivity occurred, interviews with workers and supervisors showed quite clearly that Swedish chainsaw cutters on a salary system were less likely to use the shortcut methods to maintain or increase earnings, particularly in very hazardous situations such as bringing down lodged trees. Both supervisors and the workmen reported workers as more willing to help each other in difficult phases of the work once they were freed from the potential for loss of earnings for doing so (Sundstrom-Frisk, 1984).

The role of payment methods was also the subject of a Canadian study (Mason, 1977). Data for compensation claims by fellers and buckers on the BC Workers Compensation Board for 1972 revealed that the nature of the injury and fatalities was not associated with the logger being on piecework or salary. However, piecework tree fellers were found to have been struck by falling trees and limbs to a significantly greater extent than salaried loggers. Mason also reported that a more "direct" method of analysis indicated that the age of the worker, the size of the company and its geographic location had stronger links with accidents rates than the type of payment. Contrary to other findings Mason found that men under 25 years of age had the highest accident rates, and those over 49 the lowest. It is hard to directly compare the conclusions of these two logging payment studies because their execution was so different, as were the environments in which they were undertaken. With major differences of forest types and operations management, it is far from certain that simple changes to the payment schemes in the Australian hardwood industry (as opposed to the comprehensive program of technical and work organisation changes that occurred in Sweden in the late 1979s) would influence injury patterns to a large degree.

Finally, Lagerlof (1979) provides a description of a single fictional accident to a man felling a softwood tree into the wind, which is based on her own experiences in the field and is an example which applies to her own model of felling accidents. Her causal factors include the condition of the man, the outdoor environment and wind conditions, and lack of proper equipment. Work organization and piecework payment were given as background reasons for the worker to be "taking-a-risk" (see p.18, previously). The precipitating error leading to the blow from the tree and the man's broken arm was poor execution of the cut in the hinge wood of the tree. In the article Lagerlof gave priority to four factors in the case.

> *1. The worker was not sufficiently aware of the actual accident statistics nor convinced of the danger of felling this class of tree against a strong wind. A question of information and conviction.*
>
> *2. Even knowing of the uncertainty of success and the risk involved, the man's attitude that "this won't happen to me" based on his successes in several similar falls against the wind. A question of past experience and rare events, the major problem in injury prevention that near-accident reporting attempts to combat.*
>
> *3. The time of day and his unwillingness to walk back and get the proper felling aid for this particular tree. A question of time pressure and possibly physical work strain.*
>
> *4. The reward for taking the quickest and least physically demanding option that is represented by the piecework method of payment. A question of the broader organization of high-risk work.*

The previously described studies are good examples of the particular attention logging ergonomics and occupational health and safety has received in the Scandinavian - Nordic sphere for some two decades (see Henderson, 1980; Pettersson et al., 1983). Many of the conclusions from these large overseas studies might well apply to hardwood tree fellers working in Tasmania, and it is these background or system factors to logging injuries which are the context for the more direct studies of skill and error such as those reported in this thesis.

In graphs of injury prevention success, like that for the Swedish Forestry Service reported in Pettersson et al. (1983) (see Appendix 10), the injury rate may reach a baseline level. It is at this point, where all "common sense" accident prevention measures have been used, that the issue of human performance and error may need to be re-considered for the higher risk groups. Some eight years after a national forestry (and logging) accident prevention program was initiated in Sweden by Pettersson and his colleagues, Broberg (1986) reported almost 4000 injuries over one year in the forestry and logging sector. The most important point in relation to the present research was that some 64% of injuries occurred during manual logging operations and felling. Of the 14 fatalities in the industry that year, ten occurred during tree felling operations. At the time of writing no detailed testing of parts of the logging "accident" models described in previous pages had been undertaken in the actual field situation of logging. Such research is necessary to establish the importance of the various proposed factors under real working conditions, and this is especially so in large-tree native forests like those in Australia.

1.4 A study in Tasmanian forests

1.4.1 Assumptions

Tree feller injury rates in the Australian hardwood logging industry remain a largely unknown quantity. There is however sufficient evidence from the research so far reported to suggest that Australian hardwood loggers are no better off in terms of fatality and injury than their counterparts in North America, and to a lesser extent the Scandinavian countries. The injury data of the American Western forest region are particularly relevant because they come from an area where big timber felling operations have the reputation of being the most professional in the world (Dent, 1974; Williams, 1976; Workers Compensation Board, 1977). With a history of extensive logging for well over 150 years, these red cedar forests are where the term "professional lumberjack" originated. The skill in the logging past of Australia, and Tasmania in particular, is probably equal to that of North America and Canada (Beckett, 1983). Small pockets of the Australian hardwood logging industry that have adopted normal industrial accident prevention strategies still have significant problems in the area of tree feller injuries (Crowe, 1986).

A familiar opinion about the nature of felling work that can be found in the hardwood industry is that the tree feller is a specially skilled and somewhat unique individual when compared with the rural working population in general. An alternative point of view in the ranks of logging workers and management alike is that hardwood felling is a semi-skilled job for which little selection and minimal training and experience are really necessary. There also appears to be an implicit belief in the forest ergonomics literature, and on the part of many people in the logging industry itself (see Dent, 1974; FAO, 1980; Pettersson, 1983), that timber fellers would be fully able to cope with the demands of the job if the industry introduced changes such as (a) selection of men, (b) basic chainsaw skills training, and (c) further ergonomic improvements to protective equipment and chainsaws. Initial observations in Tasmania and New South Wales suggested that such a "classic ergonomics" solution to the problem of feller injuries might not be totally valid. The existence of this underlying assumption thus had some influence on the focus and direction of the thesis.

1.4.2 Practical limits to "safe working"

When the weights, size, velocities and ground conditions often involved in the work of hardwood felling are given proper consideration, one is left wondering why so few injuries are reported rather than why so many. Keeping injuries in felling to a minimum is not simply a case of adopting "safe felling practices" taken from standards or work manuals, but of working to the lowest risk possible commensurate with frequently hazardous conditions. On numerous occasions there may be no alternative but to accept a considerable level of risk in order to get an awkward tree to the ground. As Dent (1974) describes the issue in dealing with the particular problem of old and decayed trees:

> "Snags [stags] present a special problem for the faller because they may fall at any time and in any direction. A snag by, definition, is a dead or dying tree which is still standing. To some degree or another a snag is comprised of rotten wood. Many times the supporting root systems have decayed to the point that virtually any vibration will result in the snag toppling to the ground. Vibrations from a falling tree, gusts of wind will cause a snag to come crashing down (p.44).

In such cases, suggesting with hindsight that the accident was "caused" by a violation of safety regulations is of little use in explaining the incident. Such simple assertions take little note of the detailed circumstances surrounding injury to a tree feller. If a man cuts between 10 to 60 trees per day for much of his working life in a totally uncontrolled and physically demanding work setting, there will be ample opportunity for the occurrence of random failures of human performance of a physical or mental nature. These failures might in turn interact with defect and rot or mechanical failures in the tree, and sudden changes in the physical environment such as wind direction, weather and conditions underfoot. Thus, even on superficial observation, it can be suggested that some of the information demands on the tree fellers may be beyond the abilities of even the most able and experienced man simply because of the inherent unreliability of the raw material and the normal error-prone nature of human performance. Figure 1.3 lists the major groups of factors which have the potential to lead to human or mechanical failure and create excessive hazard in the job.

It may not always be possible to perceive and predict a threat like a sudden wind change, or it may not be feasible to check for defect and obstructions in trees many metres away. One typical example is the case when some 30 metres or more above

Source		Hazard factor
Tree being felled		*Decay & fire damage in the tree*
		Clarity of cues to lean etc
		Felling charac. of partic. species
		Previous damage to tree
		Poor cuts in tree
Man		*Poor physical co-ordination & strength*
		Fluctuating attention
	Chapter 2 >	*Low PWC &/or physical skill*
	Chapter 3 >>	*Poor judgement of lean & hazards*
	>	*Poor prediction of direction of fall*
	>	*Scarf choice & cutting*
	>	*Misplaced or low certainty*
	>>	*regarding fall*
	Chapter 4 >>	*Speed in detecting abnormal fall*
	>	*Choice & preparation of escape path*
Environment		*Density of scrub & undergrowth*
		Heat & humidity
		Rain & snow
		Severity of slope & surface
		Wind-direction & strength
Other trees		*Distance-(within one tree length)*
		Decay & fire damage
		Stags
Tools and machinery		*Carrying tools, axe & wedges, chainsaw and fuel*
		Logging machinery too close
		Axe/Chainsaw blade
		Chainsaw kickbacks

Figure 1.3 Factors contributing to potential failure (mechanical or human) in hardwood tree felling.

the man a tree has a branch which is partially obscured by foliage and, though appearing healthy, is actually rotten. Such limbs can fall if the tree lurches away from the stump too quickly, or it can be thrown back forcibly when the tree hits the ground. Another familiar example is where a young healthy looking tree some distance away is defective on the side away from the bushman, and though only hit a glancing blow at its base during the main fall the weakened tree "comes back" unexpectedly on to the man. Ground debris and stumps obscured in undergrowth can lead to injury, while wind changes might sometimes cause a tree to topple over backwards when it is finely balanced during a fall. Examples of these and other types of almost unpredictable incidents were observed during the research. They are part and parcel of the practical limits to complete "safe-working" for the professional tree feller. Finally, production pressures within the man himself, as well as external pressure from the logging crew because of piecework, may serve to exacerbate the problem.

1.4.3 The overriding goal of felling accuracy

Because there are numerous hazards in the job that the professional timber feller cannot fully control it should be emphasised that a proportion of hardwood feller injuries will not involve inaccuracy in tree felling (e.g., chainsaw cuts, being hit by logs on the ground or by machinery). The feller's basic aim, however, is to maintain accurate directional control of the tree he is felling, and thereby obtain the all important outcome of a predictable fall (Dent, 1974, p.48-68; Workers Compensation Board, 1977, p.13-20).

Target accuracy of the fall is one of the central tests in the National Scandinavian Forest Worker Skill Competition (SAKA, 1979 - 1987). In this annual event a straight 16.5 metre spar must be felled with pin-point accuracy on a 5 centimetre target peg 16 metres from its base. Though the conditions for this simulation test are a far cry from the working conditions of a hardwood feller, a similar need for accuracy applies to the Tasmanian working situation in many instances. In the continually changing conditions of the forest, the tree feller will regularly be presented with trees that need to be fallen with precision. He may be trying to avoid hitting a tree in the line of the natural lean, felling between two trees, or simply felling into a position with less ground debris. He may need to pull a tree away from its natural lean to avoid breaking it over a recent stump, an old log, or rocks. A particular direction of fall requiring more mental as well as physical effort may make things a lot easier for the skidder driver to extract the tree.

> "A professional faller always puts his best face forward ... The face is comparable to the sights on a rifle in that both determine direction. Therefore, the proper use of the face is the key to professional falling" (Dent, 1974, p.54).

A similar view can be found amongst the bushmen of Tasmania with the terse adage that "you must do your homework in the front". An accurate fall is not a total solution for there may still be those occasions when, in spite of the tree falling accurately, a chance of injury remains from broken branches or difficult escape paths. However, the accuracy of the fall is the final and ultimate performance measure which encapsulates all previous judgements and actions. The question of good directional felling therefore appears to remain of the utmost importance for both productivity and injury prevention in natural forest logging.

1.4.4 Potential research methods

The investigation of performance in relation to injury at work has been dealt with in a number of ways. Descriptive material and self reports are useful in identifying areas for more objective investigation. Participant-observer articles like that published by Hager (1980) demonstrate the value of personal insights into job demands (see Appendix 5). Detailed investigation of individual fatality cases has been used in logging to decide on accident prevention measures (Preen, 1981). The analysis of general accident statistics, which took such prominence in the earlier literature review (e.g., Petersson and Milham, 1980), demonstrates the benefits of such a method for problem clarification. A drawback in such studies is their post hoc nature and the assumptions that must be made in building up a picture of causation of "the accident" or classes of injury. Accident statistics are usually the logical starting point for an assessment of issues and drawing up regulations and legislation.

The questionnaire and survey approach is ably demonstrated in the structured surveys of workers at risk like that of Lindstrom and Sundstrom-Frisk (1976). The questionnaire survey approach can also be used in the study of circumstances and factors associated with near-accidents which are reported some time after the event (Gustafsson, 1973). Studies of near-accidents using self report methods attempt to bridge the gap between the accident statistic approach and the direct performance study. Ergonomic performance studies in the actual job try to determine how much is demanded by the task in terms of perception, judgement, decision, output and control; that is, how close the operator is required to work to his individual limit of performance, and to a lesser extent, the general limits of human performance. These empirical facts can be used to correct whichever model of "the accident" has been derived from accident statistic or near-accident studies.

In the final analysis, work injury results from a person's inability to recover from error and retrieve control of the system. If sufficient fieldwork observations are made of the men in the real risk environment, a critical part of the job can sometimes be simulated or tested in a more controlled setting or laboratory. This can allow more careful selection of subjects for particular characteristics or levels of skill. It may also enable a measure of error that is not swamped by the noise of other interacting factors. A simulation enables failures of performance, and "the accident", to be studied in safety. For dangerous occupations in particular, simulators enable study of the subject's failure to perceive accurately and quickly enough, to make the appropriate decision for the specific demands of the situation, and to make the exactly appropriate response with speed and accuracy (Davis and Behan, 1962). It is conceivable that some form of partial-simulation could be used in the training of hardwood timber fellers in the 1990s.

In planning the research it was accepted that analogues of the real task of hardwood production felling would need to be developed. The goal was to make these analogues as close as possible to the real task so that conclusions about performance and error, but not accidents *per se*, could be drawn. The strategy was that of two analogues of the job linking actual forest observations and a more controlled testing of part of the job. The first test was as close as possible to normal felling in the forest, while allowing opportunity to interview the men on tree assessments and risk and monitor behaviour under realistic conditions. The second test was an analogue that focussed on a critical escape aspect of the job under more controlled conditions. In this way it was hoped that this second "laboratory" measure might then be validated against the initial fieldwork results, although they were both still analogues of the real production task. At the less theoretical level the study could also be seen as assessing three critical sets of behaviours within the felling cycle, and allowing possible identification of where the failures might actually occur with a representative sample of workers, as well as how such performance failures might be related to each other and to the various "antecedent" variables employed in the study.

A short pilot study was carried out to test the feasibility of work physiology measurements in these particular forests, and the level of interview cooperation likely from this type of worker in the field. Using some of the research methods outlined above, the investigation was planned with relatively separate assessments of various component parts of skilled (and thus relatively safe) performance. The men were studied from three perspectives in chapters 2 to 4 in the sense of:

(a) In chapter 2 the medical and work physiology perspective of energy expenditure and heart rate was the principal concern, with psychological factors receiving less emphasis.

(b) In chapter 3 the behavioural ergonomics and skill perspective focussed on the decisions and risk evaluation as the subjects attempted to produce an accurate and controlled fall.

(c) In chapter 4 an experimental psychology rationale was employed to investigate the detection of abnormally falling trees, using subjects selected from the field work phase and a matched group, in a film simulation of the escape phase of the felling cycle.

1.5 Aims of the research

Study of men drawn from a proven high-risk work environment, and reputed to have special skills for dealing with risk and error recovery, offers a unique opportunity to investigate behaviour at the upper limit of human performance. This research was the first of its kind to be undertaken with this particular type of rural high-risk worker, and one of only a small number of combined field plus laboratory studies in the area of blue-collar job performance (e.g., Blignaut, 1979b; Caille et al., 1972; Rognum et al., 1986; Ursin, Baade, and Levine, 1978). It was also the first time an attempt has been made to test parts of a model of tree feller performance and error actually in the forest. The study was one of operator performance and error rather than of actual accidents. Since there are at present only rudimentary models concerned with timber feller "accidents" and errors, the research was not based on a broad overall model of felling performance. The concern instead is with selected aspects of men at their work. The studies reported in this thesis represent an initial approach to assessment of key ergonomic demands of felling in a hardwood forest. Without such baseline studies, more advanced theoretical work with this high-risk occupation, and others like it, might be considered premature. A subsidiary goal of the research is to establish the proportion of workers who are working beyond their particular physical capabilities. A final aim is to lay the foundation for a prospective study of the longer term health and survival of hardwood tree-fellers.

Chapter 2

Characteristics of the men and physiological workload

CHAPTER 2

Characteristics of the men and physiological workload

2.1 Physical and biographical details of the sample

2.1.1 Introduction

The occupational image and historical stereotype of the lumberjack were introduced in the initial chapter along with present day injury patterns. In Australian writing of an earlier era, the bushman is depicted as a large, heavily built and fit man, skilled though sometimes reckless, with a certain degree of stoicism shaped by hard work and difficult working conditions (e.g., Calder, 1980, p.48-57; O'Reilly 1958, p.99-105). By describing the physical characteristics, work physiology, and part of the personal profiles of the men tested in the present study, it is possible to determine how far felling workers in Tasmania conformed to the Australian version of the lumberjack stereotype.

As the literature review of the present chapter will show, timber felling with the chainsaw still relies heavily on the man's physical capacity for work. If the man's working skills and physical capacities are not equal to the demands of this outdoor job, it is usually suggested that the subsequent overload and strain might lead to poor job performance, error, and finally injury. The fit between the physical working capacities of the person and the demands of the job would seem more critical in timber felling than in many occupations because, as chapter 1 demonstrated, the consequences of performance failure can be so severe. The main focus of the present chapter is thus on the work physiology of the job. Four psychological or personality characteristics said to be of importance in successful hardwood felling were also tested, though this forms a minor part of the chapter.

Modern descriptions of the job, such as those found in the article by Hager (1980), serve the important purpose of reminding us that the forest working environment has not changed, and that many of the work hazards for the natural forest faller of today remain much as they were 50 or 100 years ago. The advent of the modern high capacity chainsaw has significantly increased the cutting speed and the productivity of the single worker, without necessarily increasing the basic safety for the worker.

The chapter is in three major parts. The first sections describe some basic physical and biographical details of the men in the sample. The central section of the chapter is concerned with the physiological cost of the job and the men's responses in terms of oxygen consumption and heart rate. The last part of the chapter deals more briefly with some of the psychological attributes of the men.

2.1.2 The sample

No centralised register of full-time logging workers exists for Tasmania. Estimates by logging safety officers and Labour Department Inspectors of the number of full-time hardwood timber fellers working in Tasmania ranged between 180 to 420 persons. Data from the four major pulp, paper, and woodchip companies cooperating in the study gave 217 full time hardwood tree fellers at the time of the research, but this did not include men working for small back-block mills and the major sawmills, or the day-wages tree fellers of the Forestry Commission.

A sample of 42 men was selected at random from the lists of tree fellers supplied by the four major companies. This constituted a 10% sample of the maximum estimated population of hardwood fellers assumed to be working in the state at that time. One subject withdrew from the study after initial contact because he was leaving the industry, while heavy rain prevented fieldwork with two of the subjects. Medical, biographical and questionnaire information, as well as work physiology and field data, were obtained from 39 men. Minor exceptions due to missing data for some subjects are detailed in the text.

2.1.2.1 Stages of data collection

The research incorporated three main data collection stages (see Figure 2.1). The first stage was a medical examination and interview. This was carried out in each forest district by a doctor who was familiar with examination of forestry and logging workers.

The second stage of data collection was a day of fieldwork with measurements including assessments of work physiology, risk judgements and decision making, and measures of the worker's tree felling accuracy. The work physiology data are reported in the present chapter, while those on tree judgements and felling accuracy are reported in chapter 3. At the end of the day of field measurement the subject was interviewed for approximately one hour and completed questionnaires covering biographical details, a fatalism and work involvement measure, and questions on the recall of near-accidents. The third stage of data collection, reported in chapter 4, was the simulation signal-detection tests conducted with a sub-group of 18 men. These tests were made in the tree feller's own home some weeks after fieldwork. At the start of the project the principal investigator visited

	Stage	Data	Chapter & Section
1.	Medical Exam. & interview	HR rest,systolic/diastolic blood pressure. Height/weight, eyesight Previous L/motor system, trunk flexibility. J A S questionnaire	Chapter 2 sect. 2.1.7
	PWC test	Oxygen uptake (ml/min) Minute ventilation (l) Energy output (kJ/min) Predicted VO_2 max (l/min)	chapter 2 sect 2.1.7 2.2.4
2.	Field (Work physiol.)	Heart rate (absolute & nett), oxygen consumption, ventilation, energy output.	Chapter 2 section 4.4
	Field (Tree assess)	Risk & awkwardness of cutting, certainty of fall, choice of fall & felling accuracy, retreat distance, judgement of perf. by S's and instructor. Fatalism/Locus control & biographical questionnaires	Chapter 3
3.	Simulation of signal detection	P (A) Sensitivity B Bias	Chapter 4

Figure 2.1 Stages of data collection, data collected and chapter in which it appears.

each of the five regional doctors to explain the nature of the overall study and the medical examination requirements of the project. Administration procedures for the Jenkins Activity Survey (JAS) were also explained and this test was subsequently completed by each subject at the time of the medical examination.

Each subject was visited at home or on the worksite prior to the study. One of the subjects chosen for study declined to participate on the grounds that he was soon leaving the industry. The remainder volunteered after full explanation of the investigation and the risks in their involvement. The anonymous nature of the individual's research results was emphasised, as was the right to leave the project at any time. On the allotted day subjects signed an informed consent form before fieldwork commenced.

The field study consisted of one day and occasionally two days of measurements with the subjects at their normal worksite. Heavy rain and high winds prevented fieldwork with two subjects, while one other man completed fieldwork but was unable to complete the physical work capacity test because of a recent knee injury. Complete sets of data consisting of results from medical tests, questionnaires, and fieldwork were obtained for 39 men.

Field measurements took place over a 17 month period in five major blocks. Field trip sequence and average values for temperature and humidity according to the season are given below. The summer temperatures are less than the low thirties that can be encountered on high fire danger days in Tasmanian forests. The men worked under their normal piece-rate conditions with a guarantee of normal daily earnings and a small additional payment for research co-operation.

			Average @ Noon	
			Dry bulb	Humidity
Period	Field trip	Subjects (n=39)	C^{o}	%
October	(Spring)1	10	17.6	68
December	(Summer)2	5	15.0[a]	89
January	(Summer)3	5	23.5	67
June	(Winter)4	11	14.5	83
November	(Spring)5	8	20.8	72

[a] Unseasonal weather - west coast rainshadow area.

2.1.2.2 Age, physique and experience

The average age of the group was 34.4 years, with a standard deviation (SD, hereafter: $^+/_-$) of 9.4 years. Ages ranged from 19 to 54 years. The number of men in different age groups is shown in Table 2.1. The average height of the group was 177.0$^+/_-$7.8 cms, range 162 to 196 cms. Average weight was 73.4$^+/_-$12.6 kilograms, range 45 to 102 kilograms. The mean height for a national sample of Australian males age 25-64 years is 175 cm (5th percentile 163 cm, 95th percentile 186 cm, present study 177.0 cms not significantly different) (National Heart Foundation, 1980). The mean weight of the Australian male population for the same age range is 79 kilograms (5th percentile 61 kg, 95 percentile 99 kg), and the present study value of 73.38 kg was significantly different, t (40) = 3.00, $p < .005$).

Table 2.1 Frequency of fieldwork subjects by age group in the overall sample (N=41)

Range (Yrs)	N	Mean age group (Yrs)
16-20	2	19.5
21-30	13	25.1
31-40	13	35.1
41-50	12	44.6
50+	1	54.3

The physical heterogeneity of the group is emphasised by a 25 year old man at one end of the spectrum who was 167 cm in height, weighing 45 kilograms (5 feet 6 inches tall, at 99.2 lb). At the other extreme, there was an athletic 29 year old worker, 196 cm in height weighing 102 kilograms (6 feet 5 inches, at 224.9 lb). Such differences are striking since one might expect homogeneity through natural attrition of those men less physically suited to the job.

Over three quarters of the group were married, with 65% of these marriages having at least one child. Out of the 41 men, 32 or approximately 78% were from a rural or logging family background. Seven of the older men had sons working in a logging operation, with two of these men working as tree fellers.

Experience in full time tree felling ranged from four subjects with less than a years experience to three men with over 25 years full-time experience in hardwood felling. The average for experience was 9.44 years with one third of the men having 2 years or less in the work. There was a significant correlation between age and years of experience ($r = .70$, $n=39$, $p < .01$) (Figure 2.2).

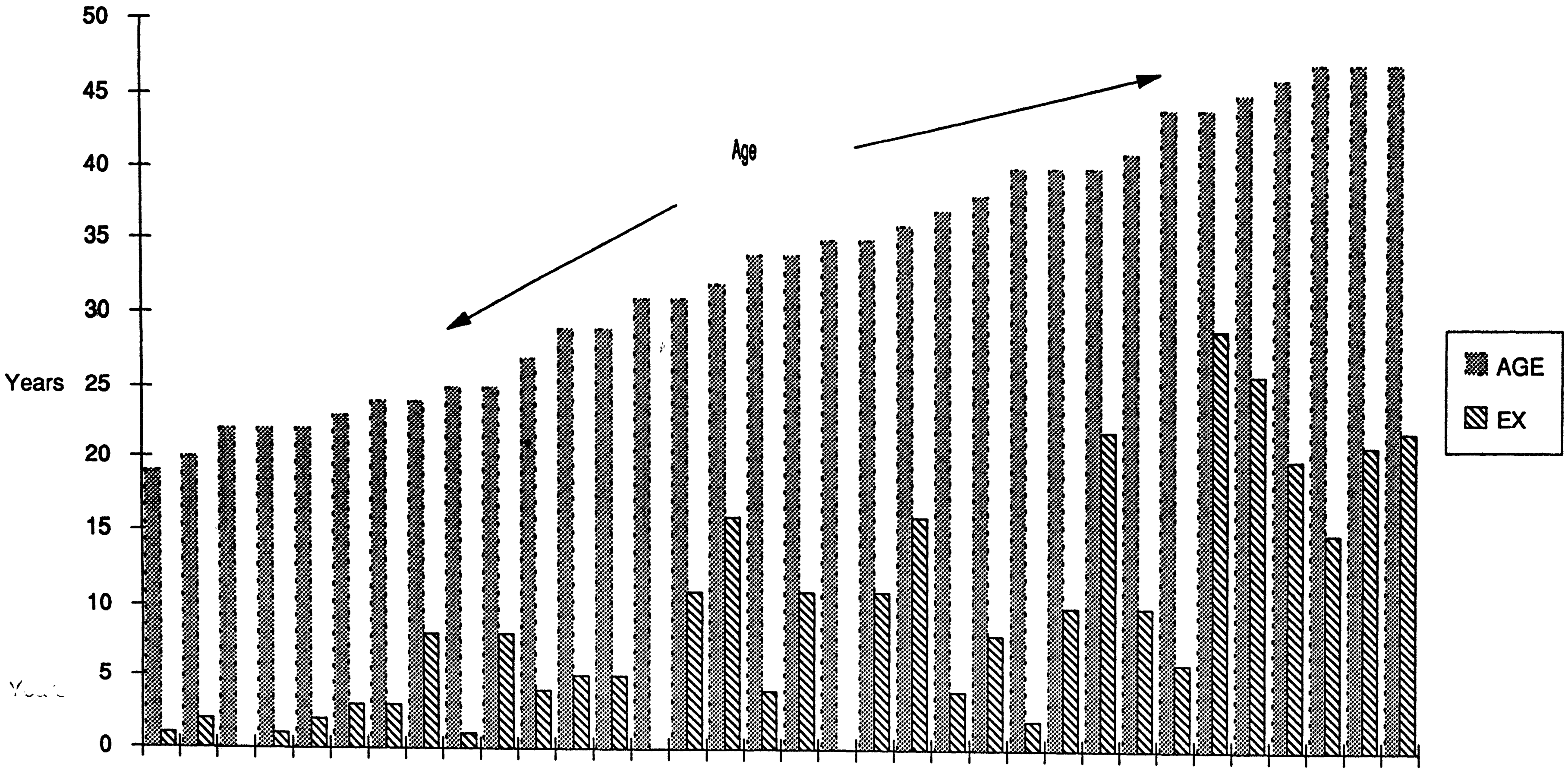


Figure 2.2 Ascending values of age and differing years of experience showing the diverse pattern of full-time felling experience relative to age (n=34).

Approximately half of the group (20) had always worked in logging operations as tree fellers, while the remainder had alternated tree felling work with periods in commercial fishing, farming, or factory work. Five of the men had previously qualified as mechanical or building industry tradesmen, while six were owners of commercial farms. One man was still active as an officer in the Australian Army Reserve. Thirty seven percent of the group had left school at or below 14 years of age and overall 88% had left school at or before 16 years of age. One man had completed full time education at 18 years of age, while four had been at school until 17 years of age.

2.1.3 Medical examination and PWC test

The medical examination and interview included the basic measures reported in Table 2.2. This Table also lists the baseline parameters related to the field work physiology measurements. The medical examination included testing for eyesight, a clinical test of hearing with audiometry in some cases, and examination of previous injuries. Subjective assessment of respiratory function, spinal flexibility and upper body mobility was made to identify any gross abnormality that may have excluded the person from the project (see Appendix 11). The three classifications for the men's medical status were:

1. Fully fit.
2. Capable of work in this occupation relative to normal ageing and past injury.
3. Doubt as to suitability for this occupation and the research project.

Twenty nine men (74%) were placed in the first category by their respective medical examiners, with the remaining 12 (26%) in the second category. None of the men was excluded from the research on the basis of results from the medical examination. Eighty percent had 6/5 vision or better in both eyes, and the remainder wore glasses during work. One man was totally colour blind. Sixteen of the men smoked, with 14 smoking more than 20 cigarettes a day. National data on blood pressure of Australian males are available for the period covered by the present study (National Heart Foundation, 1980). Average systolic blood pressure for the national adult male population (all age groups) was 134 mm/Hg, while the value for the men in the present study was 129 mm/Hg. National mean diastolic pressure was 86 mm/Hg, and for the present study 79 mm/Hg. In the national study, values for diastolic blood pressure above 95 mm/Hg were taken as one of the indicators of hypertension. Eighteen percent of men in the national sample were above that level. Only two subjects in the present study had diastolic blood pressure above the 95 mm/Hg level (i.e., 108 and 100 mm/Hg).

Table 2.2 Basic medical characteristics of the subjects

	X	SD	Range
Basic:			
Age years n=41	34.39	9.35	19-54
Height cm n=41	177.02	7.79	162-196
Weight kg n=41	73.22	12.34	45-103
parameters at rest n=38:			
Heart rate rest (beats/min)	64.6	8.3	49-80
Blood pressure (mm/Hg)			
systolic	128.76	14.15	106-170
diastolic	78.78	10.59	54-108
oxygen uptake (ml/min) n=37	345.80.	76.79	200-560
minute ventilation (l) n=37	10.06	1.97	6-16
energy output (kJ/min) n=37	6.78	1.17	4-9
Predicted maximum oxygen uptake (PWC) VO2 max (l/min):			
Absolute measure	4.20	0.86	3-6
Corrected for age (VO2 max)[a]	3.77	0.80	2-6

[a] Correcting predicted VO_2 max for age Astrand & Rodahl 1977, p.352-353.

The specification of maximum aerobic capacity (VO_2 max), or physical working capacity (PWC) as it is sometimes known, can be derived either from direct measurement in maximal tests or by prediction of VO_2 max from heart rate in sub-maximum tests, as was the case in the present study. Predictions of maximum oxygen uptake (hereafter: VO_2 max) (Astrand-Rhyming test, see Astrand and Rodahl, 1977 p.334-361), were made from steady state heart rate at 1200 Kilopound/metres (kpm) on a bicycle ergometer (Repco Ergometer HP5209, Australia). Steady state readings at 600 and 900 kpm for a minimum of two minutes preceded the final two minutes workload at 1200 kpm. The test was completed at the worksite prior to the day's field measurements. The range in predicted VO_2 max was much greater than anticipated, from a figure of 2.10 litres/minute (hereafter: l/min) for one 47 year old subject in a non-quota operation to the highest value of 6.00 l/min for a 29 year old man cutting 1000 tonnes of timber per week. The measurement procedures for predicting VO_2 max and the individual subjects field results are discussed in more detail in section 2.2.1.2 and 2.3.3 respectively.

During medical interview 19 men indicated past injury sites or scars that had required medical treatment and significant time off work (> 2 weeks). These injuries included 15 fractures; one hand, two arm , three legs, two feet (with the amputation of three toes in one of the cases by the tree jumping back over the stump), four trunk-shoulder, and three lower back-pelvis. Extensive contusions were associated with many of these injuries. Seven men reported chainsaw lacerations requiring hospitalisation. Five were to the leg, one to the shoulder, and one to the forearm. The most severe injury history was a man having a fractured leg, fractured ribs, and a severe chainsaw cut to the thigh in three separate incidents over a period of three years. One of the arm fracture men and one with a previously fractured shoulder had reduced flexibility in the joint, while a significant reduction in forearm strength and hand grip was reported and confirmed in the case of the man with the major forearm laceration. The subject with the amputated toes felt he was still learning to cope with the disability even though the injury had occurred more than 12 months before. These subjective data on injuries mirror the accident statistics of chapter 1. None of these past injuries were thought by the doctor, the subject themselves, or the investigator to prevent the men participating in the study.

2.1.4 Summary

Discussion of group results requires the unavoidable simplification of the individual case. This relatively small sample of men displayed a wide range in the physical attributes of weight and height, with only a minority of men fitting the larged-framed lumberjack stereotype. The group mean height did not deviate a great deal from the mean value in a national Australian survey of the same period, while over 70% of the men were below the mean body weight of Australian men in general. Hypertension as indexed by elevated diastolic blood pressure was less than in the national study . Basic physical working capacity showed wide variation and is discussed in more detail in section 2.2.3. Other than minor injuries regarded as a normal part of the job, nearly one third of the group had suffered major fractures during their careers, while five out of the 41 men (12%) had suffered chainsaw injuries requiring hospitalisation. Felling experience showed a wide range irrespective of the man's current working conditions. The majority of the men had a farming or logging family background. Over three quarters of the men were married with children. The formal education level was low, with a small number of exceptions.

2.2 Physiological working capacity and job demand

2.2.1 Literature and measurement rationale

2.2.1.1 Capacity and demand

This central part of the chapter now turns to the question of the men's physiological suitability for the demands of hardwood felling work. It has been proposed that a tree-feller who works beyond the medically recommended limits for his physical working capacity is more likely to look for short cuts and the least demanding work methods (Gustafson, 1973; Lindstrom and Sundstrom-Frisk, 1976). A mis-match between capacity and demand would seem one of the strong candidates in the explanation of the injury statistics reviewed in the first chapter. In the tree felling situation, for example, the man may compromise by not making the full depth of front cut needed to control accurately the fall of a larger tree, or in steep terrain and heavy undergrowth he may be tempted not to retreat to the full safe distance as the tree falls. Following sections explore the physiological work capacity (PWC) and the reactions of the men to the physical demands actually on the job.

The best measure of aerobic fitness to undertake prolonged arduous work is still that of maximal oxygen uptake (Astrand and Rodahl, 1977; Malchaire et al., 1984; Taylor, Buskirk, and Henschel, 1955). In any given individual there is an approximately linear relationship between oxygen uptake and heart rate under standardised test conditions (Astrand and Rodahl, 1977, p.357, 344-349, 455). Using the nomograms of Astrand (1960), the heart rate at predetermined sub-maximal workloads in the test situation can be used to predict maximum oxygen consumption (VO_2 max). If the same large muscle groups are involved in the working situation, under similar environmental temperatures and levels of emotional arousal, the field heart rate can be used to estimate the oxygen consumption or workload (Astrand and Rodahl, 1977). At the same time, estimation of oxygen consumption from heart rate in field situations has been questioned. Gilbert and Auchincloss (1971), for example, found the correlation between heart rate and oxygen consumption to be significantly lower under unsteady-state work than under steady-state work. More recently Neilsen and Meyer (1987) found that the calculation of oxygen consumption from heart rates in eight different working situations significantly overestimated the actual measured oxygen consumption. Their conclusion was that static load and tasks such as lifting and carrying (as opposed to fully dynamic activity such as walking) were the main source of the over-estimation of oxygen consumption from heart rate measurements.

If similar conditions between VO_2 max tests and the field conditions are not thought to apply, the alternative to attempting to infer oxygen consumption from heart rate is to look at oxygen consumption and heart rate measurement as separate issues. This stance was adopted in the present study. A relatively large number of oxygen consumption measurements were made on site. While field measurements of oxygen consumption are of an intermittent or spot measurement nature, heart rate allows assessments of the haemodynamic part of work load over the whole workday, as well as the closer evaluation of the workload for particular stages in the work. To measure respiratory function and energy cost of work, the first parameter employed is oxygen consumption and the respective energy output value. The second parameter is the percentage (%) utilisation of the maximal aerobic capacity (VO_2 max). Overall ventilation of the subject is also usually included in the measurements taken. Along with continual heart rate measurement these respiratory indices allow a comprehensive analysis of the cardio-respiratory reaction of the subject.

For all practical purposes the maximal oxygen uptake is approximately the same while running on a horizontal tread mill, cross country skiing, or pedalling a cycle ergometer (Astrand and Saltin, 1961; Bergh et al., 1976; McArdle, 1973). In a comparison of five submaximal methods for the prediction of maximum oxygen uptake the bicycle ergometer method was found to have the highest association with the actual VO_2 max value from running to fatigue state on an inclined treadmill (Robertshaw et al., 1984). The intrinsic difficulty for naive or untrained subjects of running on a treadmill can preclude its use in some testing situations, and this was the case in the present study. If the working position in bicycle ergometry is carefully monitored (i.e., seat at the correct height for each subject and almost directly over the pedals), the proper protocol of progressive workload for a sub-maximal test is adhered to (Astrand and Ryhming, 1954) and sufficient motivation is created in the subject, results from the bicycle ergometer are considered the best sub-maximal indicator for maximum oxygen consumption predictions (Astrand and Rodahl, 1977 p.355-360).

Lehman (1953), Astrand (1960) and Bink (1962) were among the first researchers to propose upper limits of physical strain in terms of oxygen consumption for work over extended periods. Though there is not complete agreement on a precise cut-off point, it is recommended that workers of moderate working capacity or less should not exert more than 35% of their maximal aerobic capacity as measured on a bicycle or treadmill ergometer (Astrand and Rodahl, 1977, p.445, 462-466). Myles et al. (1979) reported Canadian and French army males using 30-40% of their VO_2 max when working at their own pace in sustained, repetitive exercise (6.5 hours per day over 6 days). Evans et al. (1980) found energy expenditure close to 45% of their VO_2 max with soldiers of "average physical working" capacity. These subjects were carrying different loads across four types of simulated battle terrain at their own pace, but the tests were only over a two hour period of this "hard physical work".

Research and experience over several decades have thus confirmed that the reasonable upper limit for physical work performed over a 7-8 hour day is between 30 to 40% of the workers maximal aerobic power. Beyond these levels the "average" worker can be expected to exhibit objective as well as subjective symptoms of fatigue (Astrand and Rodahl, 1977 p.462-466).

Trained workers of high working capacity are considered by some researchers to be capable of using up to 50% of their maximum oxygen uptake value over a normal working day with appropriate rest periods without any long term deleterious effects (Astrand and Rodahl, 1977, p.302-304; Bink, 1962). At intensities of work above 50% VO_2 max some anaerobic metabolism and lactic acid production can be anticipated, and it is speculated that this forms the barrier for subjects attempting to work as close as possible to their aerobic limit (Evans et al., 1980).

The definition of low, moderate and high categories of physical work capacity (PWC) centre on the notion of the fit, average worker between 20 and 30 years of age (Astrand and Rodahl, 1977, p.462) Such descriptive categories for a person's physical working capacity should only be used as a general guide because of the very wide individual variations in the ability to perform different types of physical work. For such descriptive purposes, this thesis employs the scheme based on Astrand (1960) and Astrand and Rodahl (1977, p.466) (see Appendix 12).

2.2.1.2 Oxygen consumption measurement

Oxygen consumption during fieldwork was measured in the present study with the portable Oxylog (P K Morgan, England) which employs the polygraphic principle and provides minute ventilation of oxygen (VO_2/min) and overall ventilation volume (BTS). The Oxylog is approximately 20x22x8 cm in size and 2.6 kg in weight. It is supplied with a oro-nasal mask held by a two-strap head harness. The manufacturers give a reliability range of 0.25-3.0 l/min for oxygen and 6 to 80 l/min for volume ventilation. Oxygen consumption per minute or total oxygen, and ventilation per minute or total volume ventilation can be displayed as digital readout in an LED display on the top of the instrument. The Oxylog corrects the volume of inspired air to 0^{o} dry at the barometric pressure of the experimental site, and this must be set before sampling takes place. The correction is achieved by the instrument automatically measuring temperature at the flow meter with a thermistor assuming a relative humidity of 50%. Inspired air passes through a turbine flow meter in the face mask while expired air passes to the measuring electrode through a flexible hose usually passing over the subjects shoulder to the top of the unit. The ambient (inspired) and the expired air is dried by passing through a filter of anhydrous calcium sulphate and the partial pressure of oxygen (PO_2) measured separately with two polargraphic oxygen electrodes.

Volume of oxygen consumed (VO_2) per minute is calculated by the Oxylog using the formula:

$$VO_2(L) = (PO_2 \text{ inspirate} - PO_2 \text{ expirate}) \times V1/760$$

Before each field trip the instrument was calibrated with nitrogen as the inert gas and samples of known oxygen concentration according to the designer's recommendation (Humphrey and Wolff, 1977). In the field the subject wore the Oxylog for five minutes while seated during the subject preparation phase to obtain a value for rest and familiarise them with the feel of the instrument. Harrison, Brown, and Belyavin (1982) recommend a pause of between two to five minutes to allow the oxygen concentration of the arriving expirate air to equalise with that surrounding the oxygen electrode. At the tree a minimum of three minutes at rest was taken before measurement under working conditions commenced. Thirty seven subjects had oxygen consumption measured in a maximum of three and usually two work cycles which covered main elements requiring chainsaw work. Measurement time per Oxylog sample averaged 4.37 centi-minutes, range 1.08 - 13.71 centi-minutes. Energy output in kilojoules per minute (hereafter: kJ/min) was calculated by the Douglas formula from oxygen consumption measurements (see Appendix 13).

2.2.1.3 Physical working capacity (VO_2 max)

Prior to the field research, subjects had been medically examined, weighed, and had completed the sub-maximal bicycle ergometer test. As shown in Table 2.2, the mean oxygen uptake of the men was 345.8+/-77 ml/min, with a range of 200-560 ml/min giving an energy output at rest of 6.78+/-1.2 kJ/min, range 4-9 kJ/min. Predicted maximum oxygen uptake (VO_2 max, corrected for age) was 3.77+/-0.80 l/min with a range of 2 to 6 l/min. The correlations of the predicted VO_2 max with basic physical parameters of the men and their timber cutting quota at the time of the research are given in Table 2.3.

Table 2.3 Correlations between the predicted VO_2 max, basic physical parameters, and current timber cutting quota (M^2).

	VO_2 max	Age	Wt	Ht	Quota
VO_2 max	-	-.23	.57**	.37	.24
Age		-	.00	.30	.00
Wt			-	.51**	.00
Ht				-	-.27
Quota					-

* $p < .05$ ** $p < .01$ *** $p < .001$

Astrand (1960) recommended broad ranges of VO_2 max for five categories of physical working capacity in five age groups (see Appendix 12). Using this descriptive framework the approximate distribution of the men's predicted VO_2 max, or levels of physical working capacity, are shown in Table 2.4. Based on the work physiology literature so far discussed, the expectation would be to find all subjects in the high or very high categories of physical working capacity, as defined by Astrand, irrespective of their age. Approximately 36% of the sample had a moderate or lower working capacity according to Astrand's classification. In the group of older subjects, 11 of the 13 men (85%) were in the highest two categories, whereas only seven of the younger men (fewer than 50%) were in the highest two categories. The proportion of men in the low or unsatisfactory working capacity categories decreased with age group suggesting the possibility of a selective attrition effect dependent on years of survival in the work.

2.2.1.4 Heart rate measurements

Heart rate was the measure chosen for evaluating physiological cost of a job over the whole working day. Within the context of blood pressure and stroke volume, heart rate indexes the cost of a job to the heart and haemodynamic system. Both

Table 2.4 Physical working capacity against age as in the categories suggested by Astrand (1960).

	Physical working capacity category [a]				
	V low	Low	Moderate	High	V high
	Moderate or below (36 Percent of total) (group of men) (n=14)			High and above (64 Percent) (of group) (n=25)	
	V low	Low	Moderate	High	V high
Age:					
20-29 (n=15)	1 7%	1 7%	6 40%	1 7%	6 40%
30-39 (n=10)	-	-	4 36%	3 28%	4 36%
40-49 [b] (n=13)	1 8%	- -	1 8%	4 23%	7 67%
50-59 [c] (n=1)	No PWC test taken	-	-	-	
Total	2 5%	1 2.5%	11 28%	8 20%	17 43%

a Appendix 12 for the limits of each PWC category
b One subject age 49 did not complete PWC test
c One subject age 54 did not take the PWC test

absolute heart rate (hr) and heart rate nett (hereafter: hr nett) as proposed by Muller (1942) can be employed.

Specifying work limits on the basis of absolute heart rate levels, Christensen (1953) proposed that chronic heart rates of 125-150 beats per minute (hereafter: beats/min) reflected a high daily cost for the normally fit worker. The 150 beats/min limit is a commonly accepted view in the literature, and Astrand and Rodahl (1977, p.462) include absolute heart rate levels in their general guide-lines for prolonged physical work. Heavy work is defined as between 110-130 beats/min, and very heavy as 130-150 beats/min (see Appendix 14). Heart rate nett, as the term implies, is the working heart rate minus the resting value for that individual. Karrasch and Muller (1951) and Hunting et al. (1974), as also cited in Grandjean (1986), recommend a continuous hr nett of not more than 30 beats/min over the a normal work day to avoid any risk of overload and to maintain long term productivity . On the other hand Hettinger (1970) and Hollmann et al. (1963, 1976) suggest a limit of 40 beats/min for hr nett over a day of continuous hard physical activity.

Law of initial value

Heart rate nett enables the cardiac measure to be in relative rather than absolute terms but does not completely solve the problem of interpreting baseline to working level differences. The use of unadjusted raw score differences in psycho-physiological measurement was first questioned by Wilder (1958) when he proposed the Law of Initial Value (LIV). This was said to apply for those phenomena where the magnitude of change is systematically related to the initial value of that variable. In a subsequent paper the problem was described as follows:

> Given a standard stimulus and a standard period of time, the extent and direction of a physiological function at rest depends to a large measure on its initial (pre-experimental) level. The relations are as follows: the higher the initial value, the smaller the response to function raising, the larger the response to function-depressing stimuli" (Wilder 1967, p.viii).

In the case of heart rate while there is some evidence that LIV is applicable (Graham and Jackson, 1970; Oken and Heath, 1963), there are also studies which show that LIV does not apply (Hutt and Hutt, 1970; Stratton, 1970). When a relationship exists between initial level of a response and the operating level other interpretations are possible besides the Law of Initial Value. Any particular situation could, for example, be a case of regression toward the mean or an unknown homoeostatic mechanism operating.

One index of LIV is the correlation between the baseline level and the difference score. If the correlation is negative then the individuals with the high baseline level for heart rate have a relatively smaller response than their lower baseline counterparts. Benjamin maintains that this is the best single index for LIV (Benjamin, 1963).

Beside the actual workload itself, factors having an effect on heart rate include climatic conditions, the proportion of dynamic versus static load, emotional arousal, and basic characteristics such as age, dexterity, special skills, and the general state of health of the worker (Astrand and Rodahl, 1977; Green et al., 1986). One concern of particular interest in the present work was the anticipation period just prior to the tree falling and the possibility of elevated heart rate at this point in the fall (e.g., Bateman et al., 1970; Becker et al., 1983).

Field measurement

In the present study heart rate was measured telemetrically with an FM transmitter and receiver built for the particular forest conditions of the project (H. Riddle, Melbourne). The subject's transmitter was a nine volt unit weighing 245 grams designed for R-wave polarity, with each heart beat giving a 50% reduction in amplitude for 5-20 milliseconds. The unit was carried in a pouch on the belt of the subject with a 45 cm aerial hanging away from the body in the vertical position. Beckman Micro-telemetry electrodes from the unit (Beckman NNP-9) were placed above the sternum and on the fifth left hand intercostal space in a modified V5 position, with the indifferent electrode unused in the majority of cases.

The heart rate receiver was a 10-15 DC unit of proprietary circuitry (as above) with a 80 cm coaxial aerial. A two metre half wave dipole aerial was also tested but not found to be necessary over the transmission range encountered in the field i.e., usually less than 40 metres. An LED range control included in the unit allowed adjustment during monitoring to compensate for interference and as a warning of out of range conditions. A 10 second sampling interval for the receiver was chosen (i.e., unit range 10-60 seconds in 10 second steps), although heart rate was recorded by the forest technician every 30 seconds. The heart rate data were recorded by the forestry technician from a digital display on the receiver as he observed and timed the various work elements employing normal time study procedures (ILO, 1969). The technician had an auditory signal through an earphone in one ear as well as a flashing LED signal for each 30 second interval between heart rate records. Later coding and computer data entry allocated heart rate response to the particular work activities of the subject.

2.2.2 Previous research

2.2.2.1 Related "blue collar" studies

It is a popular misconception that automation and mechanization have removed the need for hard physical effort from most occupations in industrialised countries. The literature demonstrates that many working situations, of which timber felling is only one example, still require significant energy expenditure. In determining the physical cost of outdoor work, peak loads in the job can be as important, if not more so, than average levels of energy expenditure. Awkward working positions and static load will also have a strong influence on the man's willingness to work even at energy demands within recommended limits (Astrand and Rodahl, 1977, p.463-466). A worker's subjective rating of a particular work load is more closely related to heart rate than oxygen uptake (Borg, 1970; Skoldstrom, 1987).

Deep sea fishing is one well known example of high physiological cost job. Rodahl et al. (1974) found that oxygen consumption of older commercial fishermen was close to the permissible limit of 50% VO_2 max for much of the work shift, and highest not while at sea but when unloading the catch at the pier. In a study of the handling of gas cylinders on stairs and building sites, Westerling and Kilbom (1981) found peaks in heart rate often approaching maximum values in the heaviest tasks, in spite of mean heart rate over the whole work day being 99 beats/min. Subsequent biomechanical analysis was used to reduce stresses on the upper torso during dragging of the cylinders, but no significant reduction in physiological workload was achieved. In another example, the delivery of milk products by lorry the average heart rate reached 122 beats/min, while mean oxygen consumption was 1.5 l/min (Ilmarinen and Nygard, 1982). Some of the least fit workers in this study were also found to be using up to 50% of their maximal oxygen consumption capacity at different parts of the day. A related study of work allowances for different types of manual postal delivery (Ilmarinen, Louhevaara, and Oja, 1984) found the utilisation of maximal aerobic capacity varied between 31 and 54%, with the hardest mode of delivery averaging 1.7 l/min oxygen uptake when carrying a mail bag up and down stairways. This study also showed that with freely chosen pace and rest breaks, energy expenditure was at or above 50% of VO_2 max in three out of the five modes of postal delivery.

2.2.2.2 Studies of tree fellers

The work of the tree feller in cold and temperate climates has been studied by numerous work physiologists and foresters for several decades (e.g., Bink, 1962;

Hansson, 1964; Harstela, 1975; Kukkonen-Harjula and Rauramaa, 1984; Samset, 1963; Samset, Stromnes and Vik, 1963; van Loon and Spoelstra, 1973; Vik 1973; Vik, Kristianden and Nyland, 1980). Many of the studies, especially in more recent years, have included measurement of heart rate and oxygen consumption. Those studies most relevant to the present research are discussed below.

Hansson (1964) was one of the first investigators to relate heart rate to worker characteristics and productive output. He found that the high production worker in felling tended to be in a higher oxygen uptake group. Hansson suggested the more fit worker achieved his higher productivity due to less need for long rest breaks. He also found that these higher capacity men tended to take less time per unit of production than the "average" men. Most studies of tree fellers have used 10 or fewer subjects, although Samset (1969) employed 25 subjects over an extended period to study the effect of field and tree conditions on productive output and heart rate in felling and bunching. The study investigated the effects of tree species, snow, work methods, tools, and general working conditions. Oxygen consumption was found to vary between 1.03 to 1.85 l/min. Average heart rate for felling and cross-cutting varied between 106-133 beats/min. Durnin and Passmore (1967) in the British Isles reported that the activity of felling required an average energy output of 23 kJ/min (1.13 l/min).

More recent studies have shown that in spite of technical improvements and lighter and more ergonomic chainsaws the workload of the softwood timber feller has remained very high. In Poland, Fibiger (1976) reported felling, trimming, and stacking having a range between 22 and 43 kJ/min across widely differing terrain and tree characteristics. More recently, Fibiger and Henderson (1982), working with a small group of Australian softwood fellers in summer ($21^{+}/_{-}4$ °C), found an average energy demand of 36 kJ/min, with the stacking part of the job requiring up to 49 kJ/min in one subject. The elements of felling and trimming were found to require an average of 30.4 kJ/min. The mean percentage utilisation of maximal aerobic capacity (VO_2 max) was 55.5%, but this value was considered atypical due to the small sample size. In a Norwegian study of tree felling and trimming steep terrain was shown not to increase the workload so much as to increase the energy consumption per unit of wood produced (Vik, Kristianden, and Nyland, 1980). Energy expenditure was found to vary between 27 to 35% of the subjects predicted maximal working capacity.

Kukkonen-Harjula and Rauramaa (1984), who studied a group of 15 experienced Finnish lumberjacks between 30 and 39 years of age, found average energy expenditure in felling, trimming, and cross-cutting of 36.6 kJ/min (or 1.8 l/min), combining winter (snow depth $62^{+}/_{-}12$ cm, temperature $5^{+}/_{-}5$ ^{0}C) and autumn measurements (no snow, $10^{+}/_{-}4$ ^{0}C). Separate figures for snow conditions were not provided. For felling alone the average energy expenditure was 32.5 kJ/min (or $1.6^{+}/_{-}.31$ l/min). Maximum oxygen consumption (VO_2 max) for this select group was $3.94^{+}/_{-}.52$ l/min using a symptom-limited maximal exercise test on a treadmill. Utilisation of the VO_2 max for felling was 41% and 46% for trimming and cross-cutting. The average heart rate for the felling part of the work cycle was $126^{+}/_{-}$ 6 beats/min, while cross cutting and trimming was $125^{+}/$-6 beats/min. Thus, although felling had a similar heart rate to cross-cutting and trimming, it had a lower level of oxygen consumption (1.6 vs 1.8 l/min). Bunching of timber after felling and trimming was the most demanding part of the job from the work physiology point of view, at 44.7 kJ/min (or $2.2^{+}/_{-}0.2$ l/min), and was the major influence on the average cost of the all work phases combined of 38.6 kJ/min.

Smith, Wilson, and Sirois (1985), in a study of forest workers in the southern states of America, concentrated on the effect of summer working conditions on heart rate in different types of jobs. In felling work the heart rate was rarely found to exceed 130 beats/min, with heart rates exceeding 120 beats/min up to 34% of the time. No direct measures of oxygen consumption were undertaken.

Upper body work

A number of papers have reported that upper body exercise alone (usually in the form of arm cranking) elicits approximately 70% of the peak oxygen uptake obtained during bicycle ergometer or running work (Astrand and Saltin, 1961; Bergh et al., 1976; Petrofsky and Lind, 1978; Sawka et al., 1982). This phenomena has some importance for field measurement if tests for predicting maximum aerobic capacity have of necessity been conducted with bicycle ergometry, or any method concentrating on the main muscle mass of the legs. As Kukkonen-Harjula and Rauramaa (1984) suggested, quoting Petrofsky and Lind (1978), "... For work such as logging which involves a lot of upper body effort the standard maximal capacity tests tend to underestimate the relative oxygen consumption at work" (p.63).

Chainsaws used in hardwood felling are several kilograms heavier than those used in softwood, for example, Stihl 035 (softwood) 8.5 kg versus Stihl 075 (hardwood) 12.9 kg, with longer guide bars and heavier cutting chain. Chainsaw weight within the present study also varied by as much as 4.3 kilograms according to the man's preference for a saw suited to the felling conditions of the research day i.e., 12.85 kg to 17.15 kg with fuel and oil. However, there was no correlation between chainsaw weight and the direct measures of oxygen consumption with the Oxylog. Much of the work in all types of felling is done with the arms and upper body but in hardwood felling, in particular, energy expenditure will be partly dependent on the cutting efficiency of the man's chain, and on how he uses the supporting dogs (spikes) on the front of the saw to take the weight of the chainsaw while cutting. His skill in the balancing and placement of the saw when cutting the larger trees is also an important factor to take into account. Thus in the present study under-estimation of oxygen consumption in some parts of the job might have been anticipated, especially for those men who - though having a good aerobic capacity - were less skilful, and had relatively light upper body development.

2.3 Work physiology in the field

2.3.1 Goals for the work physiology

All of the forestry studies discussed so far have been ones concentrating on productivity rather than on safety and skill ergonomics. All but one of the tree feller studies (i.e., Fibiger and Henderson, 1982) also relate to softwood felling in the northern hemisphere. In mature eucalypt forests tree size is greater and the extent of defect more widespread than in the forest setting of the studies so far cited. Terrain can also be very steep and heavily overgrown. Factors in the trees themselves, and in the equipment used to cut them, point to the possibility of different work technique and energy consumption patterns in eucalypt felling work when compared with the other studies.

Generally, and particularly in the last decade, studies of timber feller work physiology have used specially selected samples of workers. The sample sizes of these studies have been small compared with the present study although the duration of measurement may have been for more than one day. Even the few non-European/Nordic studies have been restricted to softwood fellers using a lighter weight chainsaw than is commonly found in our own native eucalypt forests (e.g., Fibiger and Henderson, 1982, 1983; Smith, Wilson, and Sirois, 1985). The present study sought to use a large heterogeneous sample of timber fellers where a sizeable proportion of the group were of limited experience; i.e., 30% having less than two years experience in felling work. The objectives and aims for the study of work physiology were to determine: first, whether the physiological functioning of a tree feller in the hardwood environment is above generally recommended standards for physical work, and second, to compare these research results with those of previous studies of this type of worker, both in terms of aerobic work capacity (VO_2 max) and energy cost of the job. An issue of further interest was to assess what proportion of men currently working as hardwood tree fellers might be physiologically unsuited for this type of work. Finally, in a strenuous job such as hardwood felling there were additional considerations in terms of the often proposed work physiology implications for felling error. It was thus necessary to hypothesize that a man working close to the recommended limit of his physical capacity might experience physical strain and fatigue which might in turn affect perceptions, judgements, and reactions. These fatigue effects in one or more job elements could then eventually lead to felling error in combination with other environmental factors. For example, an excessive utilisation of heart rate reserve might influence the man's ability to execute the proper scarf cuts as the day progressed, or hinder his persistence in identifying hazards in the heads of trees past which he must fall the working tree. These matters are considered in both chapters 3 and chapter 5.

2.3.2 Field-work conditions

Work physiology measurements were taken across a wide range of microclimate, terrain, and environmental conditions (Appendix 23). As previously described, tree size averaged $9.73^{+}/_{-}7.34$ tonnes, and varied from 0.31 tonne to a number of trees estimated at over 65 tonnes. The quotas of wood cut by the men in the week preceding their field trial varied between 200 and 1000 tonnes per week, with a mean of $450^{+}/_{-}196$ tonnes (work study details for each man are given in Appendix 15). Although interruption of the flow of work occurred throughout the day because of tree evaluation interviews that were part of the overall study, the separate work cycles *per se* could be regarded as uninterrupted.

Microclimate was recorded once every hour from 0900 hours, the approximate starting time for field measurement, until the man stopped work. Ambient temperature during actual work measurement ranged from 7°C at 0900 hours on some winter mornings to 31°C at 1400 hours on one of the warmest days of the study. Humidity varied from 36% in open woodlands in summer to almost 100% in rainforest in winter. Micro-climate varied considerably according to the velocity and direction of the wind, as well as exposure of the work area to direct sunlight.

2.3.3 Energy output

2.3.3.1 Basic levels of energy expenditure

The overall results for oxygen consumption, minute ventilation, and energy expenditure while working in the field on the oxylog test trees are given in Table 2.5. Measurements with the oxylog were made either on the whole work cycle including cutting and trimming, or only on the front and back cuts in the case of larger trees. The highest energy expenditure figure in the field calculated for a whole work cycle was 40.61 kJ/min, equivalent to 2.00 l/min, while the lowest measurement on a man of medium physical working capacity was 17.06 kJ/min or 0.84 l/min. The average energy expenditure for the whole group of 34 men where measurement was successful was $27.42^{+}/_{-}5.19$ kJ/min, while average energy output at rest was 6.78 kJ/min.

Table 2.5 Energy output and respiratory parameters for field measurements - 73 readings N=34.

	Mean	SD	Range
Oxygen uptake VO_2 (ml/min)	1.35	0.29	0.84-2.00
Minute ventilation (l/min)	33.30	6.70	18-52
Energy output/min (kJ)	27.42	5.19	17-41
Utilisation VO_2 max (%)	37%	9%	20-68%

Estimated energy output/hour over 7 hour Standardised day 1150 kJ/hour)

The older age group of 40-49 year men had the higher average group energy expenditure of $30.34^{+}/_{-}3.7$ kJ/min. Energy cost for activities during productive delays such as saw maintenance and chain sharpening was estimated at 12 kJ/min on the basis of the literature. The average proportion of time for productive delays of the whole group was 17% of total production time. Assuming a seven hour standard workday (seven hours of productive time and productive delays), the average daily nett energy output calculated from observed values and time study was 1150 kJ/hour (see Appendix 15). This figure is within the "heavy level of effort" for a 7-hour day according to the recommendations of the British Medical Association, and just within the "very heavy" classification of Lehman (1953) (see Appendix 14 - Physical Effort Standards). The correlation between energy output in the field and VO_2 max was positive and significant ($r = .31$, $n=34$, $p < .05$), while the strongest correlates of energy output were height and weight ($r = .56$, $n=34$, $p < .001$, and $r = .44$, $n=34$, $p < .01$) respectively.

2.3.3.2 Utilisation of VO_2 max

The average level of percentage utilisation of VO_2 max (%-utilisation) across all subjects was $37^{+}/_{-}9\%$, with a range between 24-68%. Sixteen of the men (47% of those where field VO_2 measures were obtained) had average utilisation levels at or less than 35% (mean $29^{+}/_{-}4\%$) of their predicted VO_2 max (Table 2.6 & Figure 2.3). The average %-utilisation of VO_2 max for a further 15 men was between 36% and 49% (mean $.40^{+}/_{-}3\%$). Only three men had utilisation levels above 50% (mean $58^{+}/_{-}9\%$), two of them with a "very high" class of physical working capacity and one with only a "moderate" classification of working capacity . As might be expected there was a negative correlation between the men's predicted VO_2 max and the %-utilisation of VO_2 max. As the man's capacity increased, utilisation of capacity generally decreased ($r = -.47$, $n=34$, $p < .005$). Even though there was no statistical association between age and the man's potential in the form of predicted VO_2 max (Table 2.3), the correlation between utilisation of VO_2 max and age was positive and significant ($r = .41$, $n=34$, $p < .05$). Thus in the main age groups of the sample adopted for the chapter (PWC categorisation-Table 2.4), the level of utilisation of VO_2 max consistently increased (being $33^{+}/_{-}8\%$ for the 19-29 year group, $35^{+}/_{-}8\%$ for 30-39 years, and $40^{+}/_{-}5\%$ for the 40-49 year group). The difference between the youngest and the oldest group was significant ($\underline{t}$ (26) = -2.89, $p < .01$). These group trends are illustrated in Figure 2.4.

Table 2.6 Levels of utilisation in the group above and below the medically recommended lower 35% limits (Individual predicted VO_2 max not withstanding) N=34.

	Class % utilisation				
	20-35%	36-40%	41-45%	46-50%	50%+
No.	16	6	8	1	3
of Men	v	v	v	v	v
		v	v	v	
Overall	v		v		v
	16		15		3

Large differences in energy expenditure as well as utilisation of VO_2 max could be found not only between subjects with the same category of physical working capacity, but between different trees dealt with by the same subject during the tests. Examples of such cases indicating the potential range of physiological costs

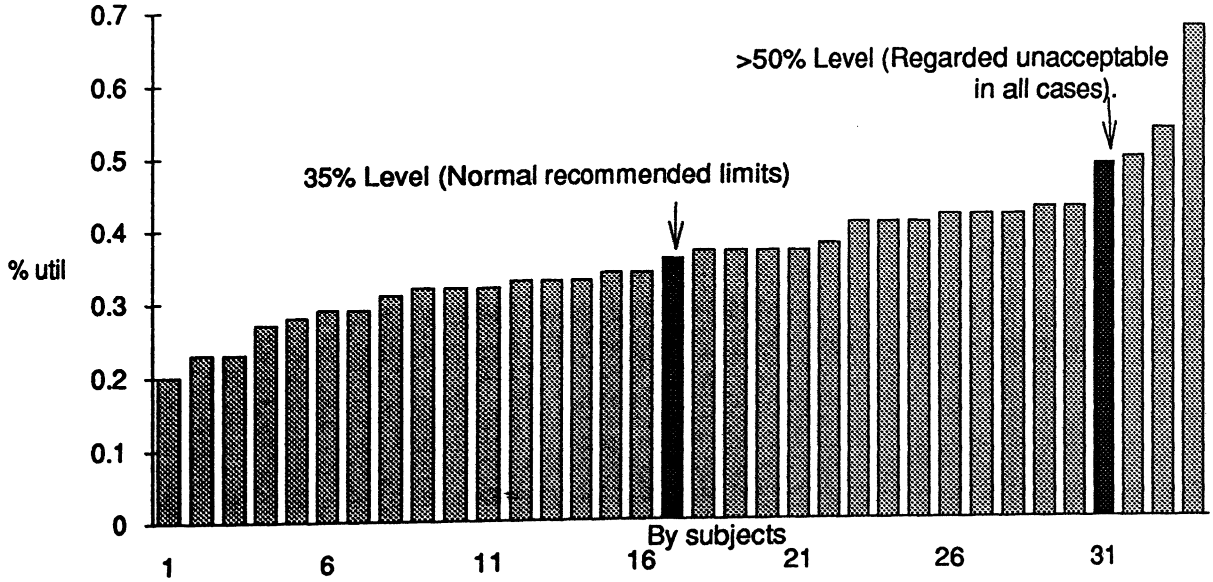


Figure 2.3 Distribution % utilisation V02 max by subjects, relative to the commonly accepted limits (n=34).

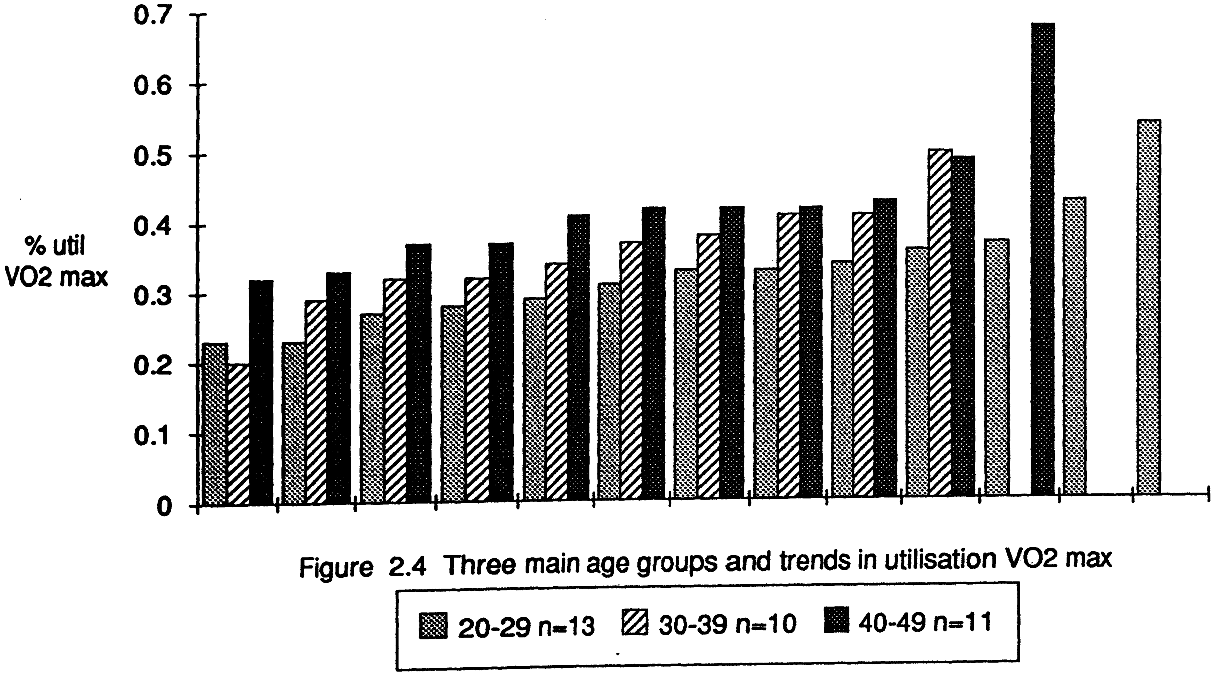


Figure 2.4 Three main age groups and trends in utilisation VO2 max

involved in the job are given in Table 2.7. A single case worthy of mention was that of a 47 year old subject with a very low VO_2 max of 2.11 l/min, who had a level of utilisation of 68% in his field oxygen consumption test. This specialist or cull tree-feller was working on some of the largest and most defective timber of the study (average volume 54 tonnes) necessitating large saws and the longest cutter bars. The example gives some indication of the importance of annual work capacity testing and alternative forest employment opportunities for the older worker.

Table 2.7 The possible range in energy expenditure and percentage utilisation of VO_2 max for Australian hardwood felling.

Range between diverse subjects			Range within two high PWC subjects		
	(s5 age 47)			(s25 age 36)	
VO_2 max l/min	kJ/min field	% util	VO_2 max l/min	kJ/min field	% util
2.7	29.4	54%	6.0 Tr1	28.8	24%
			Tr2	38.3	31%
	(s18 age 47)			(s16 age 24)	
5.2	26.4	25%	5.3 Tr1	18.2	17%
			Tr2	31.7	29%

2.3.4 Heart rate

2.3.4.1 Absolute heart rate

The average heart rate per tree across all subjects was $126.9^{+}/_{-}12.4$ beats/min, with a mean resting heart rate in the field prior to testing of 64.6 beats/min. While the highest single recorded heart rate was 183 beats/min, the highest mean heart rate for any one tree was 179 beats/min (hr nett 115 bpm), and the lowest was 97 beats/min (hr nett 29 bpm). The mean heart rate per subject with different sets of trees, varied between a subject with an average of 105 beats/min over 25 trees to an average of 155 beats/min over three large trees for the subject with the highest average heart rate in the study.

Typical patterns of absolute heart rates during the field testing period (excluding the periods of tree assessment interviewing) are shown in Figures 2.5-2.9 for three subjects drawn at random for descriptive purposes from the overall data (Examples of average heart rate/tree for different subjects are given in Appendix 16). In the example of Figure 2.5 the predominant trend in the 110-130 range for the subject is quite clear, while a more erratic pattern can be discerned in Figure 2.6 for a subject who had a higher average heart rate. As indicated in the figures, the first set of readings come from an experienced tree-feller of 40 years of age, while the second set of results are those of a younger entrant to the industry. Though the resting heart rates of these particular two men were in fact at quite similar levels (58, 54 bpm), any direct comparisons between subjects would be spurious when the set of trees cut by each man was always unique. Figure 2.7 combines the charts of the first two examples to highlight variation over the sampling period. Figure 2.8 shows a typical record of a further subject with a higher resting heart rate than the preceding subjects (78 bpm) and relative consistency in the 110-130 range after approximately the first hour of testing.

The heart rate cost of the different work elements remained at similar levels (Table 2.8), being attributed in part to the flow-on nature of heart rate between elements and to the contribution of the continual effort of walking and working with a heavy chainsaw.

Table 2.8 Physiological cost of the different elements in an Australian hardwood tree feller's job expressed by heart rate/min (n=38).

Work element	Number records	Heart rate Mean	Heart rate Mean [a]
(1) Walk to tree	750	124.6+/_15	-----
(2) Prepare fell	757	124.8+/_15	-----
(3) Felling	2701	128.7+/_14	126+/_6
(4) Trimming	1026	128.1+/_14	125+/_6
(5) Dock/cross cut	887	128.6+/_13	-----
(6) Prod delays	950	114.6+/_15**	91+/_4
Overall product. mean (1-5)	126.9		

* $p < .05$ ** $p < .01$ *** $p < .001$

[a] Kukkonen-Harjula and Rauramaa (1984) Finnish sample n=15

Multivariate analysis of variance of heart rate with the six work elements as repeated measures (Kerlinger, 1986) gave a significant difference between the heart rate in the five major work elements and the productive delays such as using the axe, and chain and saw maintenance, mult. $\underline{F}$ (5, 185) = 48.86, p < .001. The

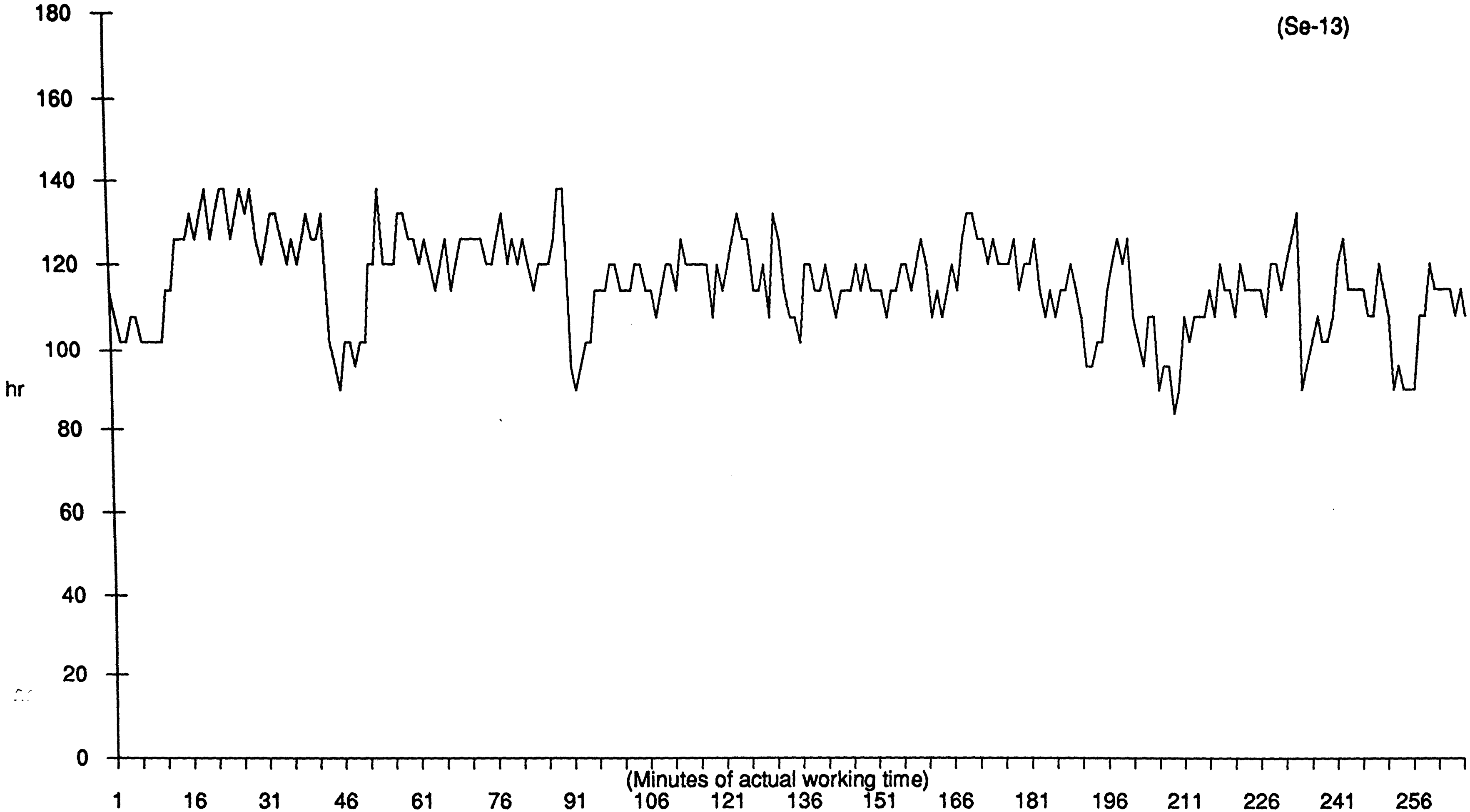


Figure 2.5 Example of hr pattern - 40 year old experienced subject .

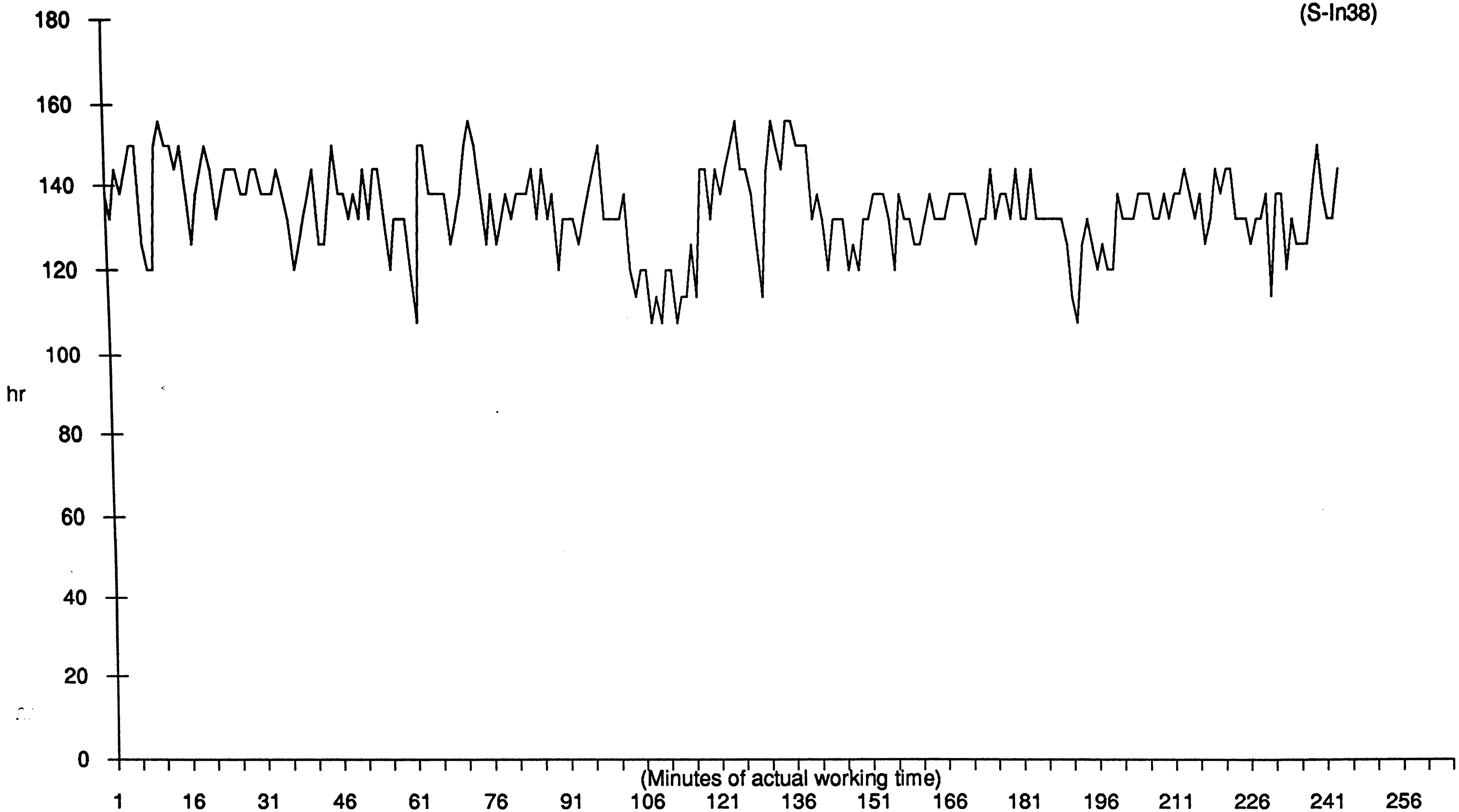


Figure 2.6 Example of hr pattern - 22 year old inexperienced subject .

2T-H02.XLC

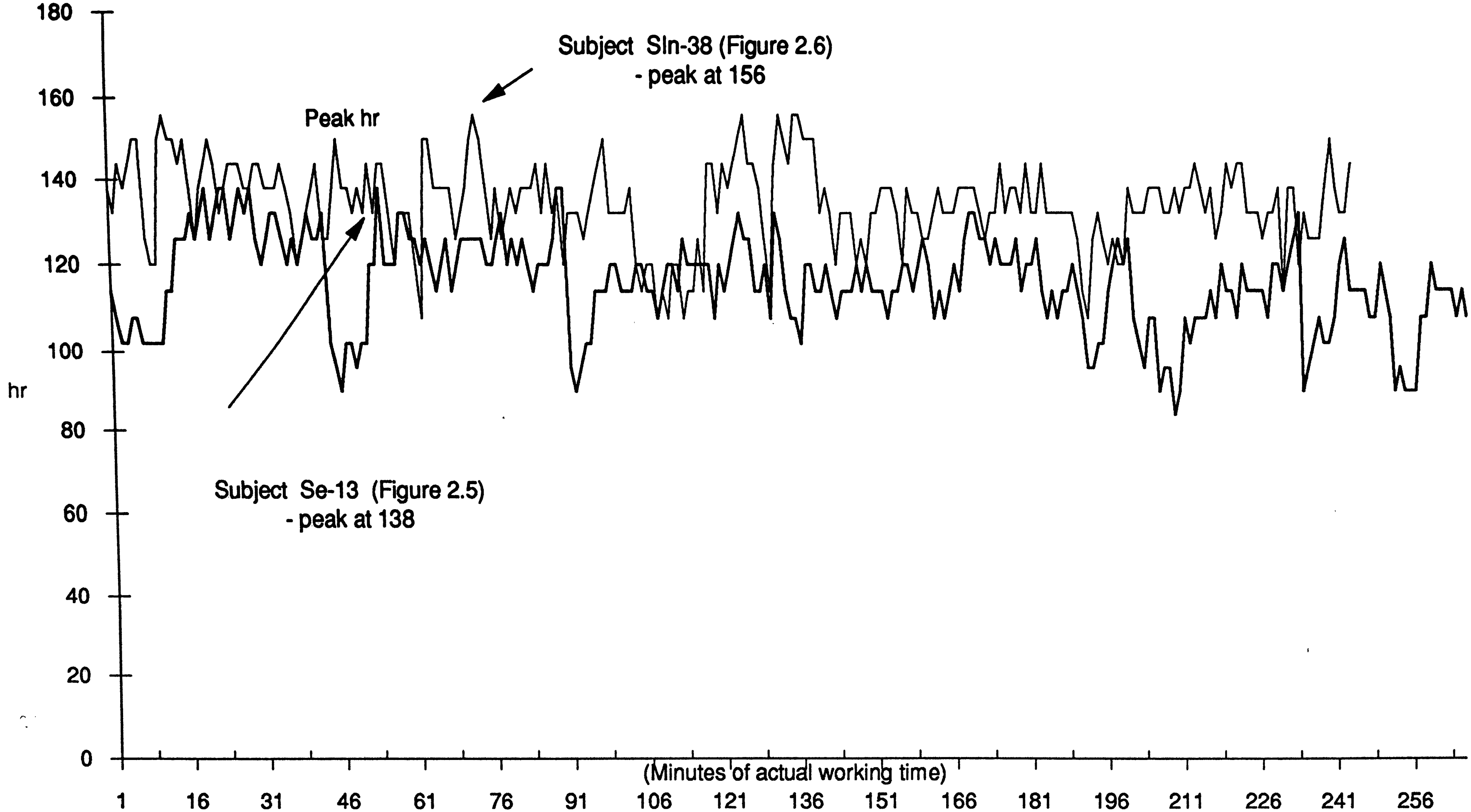


Figure 2.7 Trends in hr for two subjects with similar resting heart rates

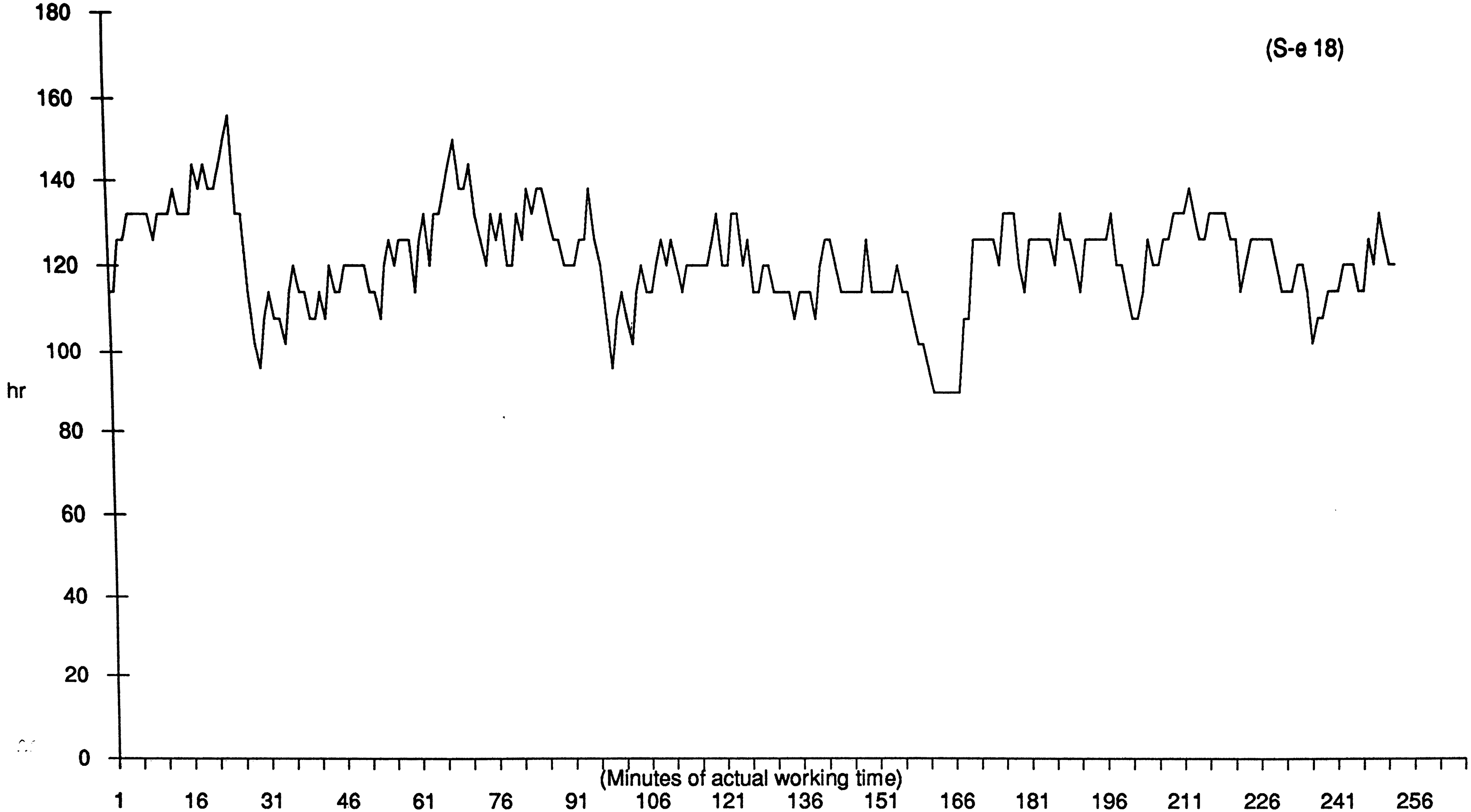


Figure 2.8 Example of hr pattern - 46 year old subject, (resting hr 78 bpm)

heart rate in productive delays remained distinctly above heart rate at rest. Multivariate analysis of the heart rate for the five production elements alone indicated that felling, trimming and cross cutting were significantly different from the elements of walking to the tree and preparing to fell, F (4, 48) = 6.36, $p < .001$. The difference between heart rate in the least demanding productive element of walking to the tree and the productive delays element was significant, t (37) = 11.5, $p < .001$. There is close similarity between the mean heart rates of the hardwood study to the mean heart rate of the two matching work elements in the Kukkonen-Harjula and Rauramaa (1984) study of Finnish timber fellers (Table 2.8).

2.3.4.2 Heart rate nett

The average heart rate at rest in the field was $64.6^{+}/_{-}8$ beats/min (range 49-80), which was slightly lower than the mean resting heart rate in the medical examinations reported previously. The average hr nett over all subjects was thus 62.3 beats/min (tree mean minus resting heart rate). The value of average hr nett, or the relative heart rate cost per tree, ranged between 29 and 115 beats/min over the 636 trees that were cut down. The overall hr nett for an individual's set of trees varied between 43 to 90 beats/min nett (see also Appendix 16). Most subjects had average hr nett values which were considerably higher than Hollmann's recommended limit of 40 beats/min for heavy manual work over an 8-hour day. The distribution of average hr nett across subjects is given in Table 2.9 where it can be seen that the greatest number of subjects were at the 50-59, and 60-69 beats/min nett level. There was a significant negative correlation between the base-line resting heart rate and the hr nett, or difference score ($r = -.48$, $n=39$, $p < .001$), confirming that in terms of the "law of initial value", the individuals with the higher resting heart rates exhibited a relatively smaller increase in heart rate response to the work.

Using the data for the two previous absolute heart rate examples with similar resting heart rate (Figure 2.7), the clear difference in hr nett levels between the two men is shown in Figure 2.9. The more experienced man rarely drops below the 60 hr nett value, and while peaking at 100 or more beats/min shows a consistent high effort over almost the whole measurement period. The second younger and less experienced subject remains in the (still excessive) 60-70 range for most of the time with significant episodes in the 40 beats/min range. The lower graph suggests a downward trend in the man's reaction to the work, while in the upper graph of the

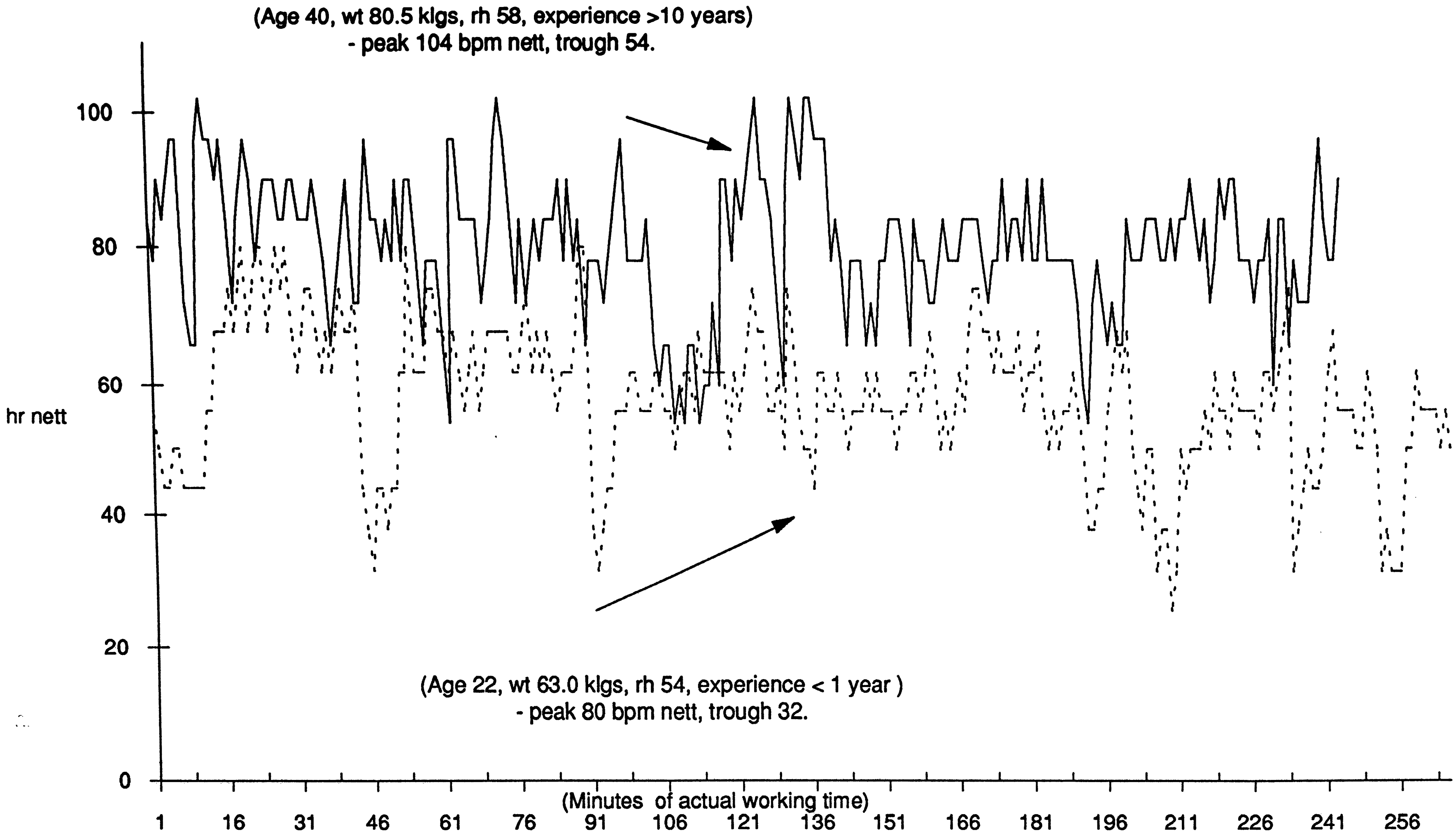


Figure 2.9 Example of patterns of hr nett (relative physical effort) for two distinctly different subjects.

more experienced man the peaks in hr nett decrease, and the cost in the region of 80 beats/min remains.

The trend in absolute heart rate over time was assessed by a repeated measures analysis of variance with subject as the factor, and tree series as covariate, where the sign of the regression coefficient of the covariate indicates the trend or slope of the grouped data (Norusis, 1986b). Data up to the tenth tree were analysed in the group of 27 subjects who had cut down 10 or more work study trees. A significant difference in heart rate over the series of trees was evident F (1, 242) = 18.31, $p <$ .001 with a negative raw regression coefficient (-. 60) indicating a slight downward trend in heart rate over the day. An analysis with a group of 18 subjects who had cut down 15 or more trees also produced a similar result, F (1, 251) = 26.18, $p <$ .001, and the same indication of a small decrease in heart rate. The difference in heart rate between the normal trees that were cut down as the day progressed and the one or two oxylog test trees for each subject was significant, F (1, 595) = 4.36, $p < .05$, (normal trees 127.0$^{+}/_{-}$12 (n=561) vs oxylog trees 125.4$^{+}/_{-}$11 (n=71). However, this difference in heart rate is small in practical terms and is not in agreement with Malchaire et al., (1984) who reported significant increases in working heart rate during oxygen consumption measurement in a factory setting.

Table 2.9 Distribution of average hr nett within the group of tree fellers (n=38).

Hr nett beats/min.	N	percentage %	Mean beats/min	Range beats/min
<40		0	-	-
40-49	5	12	43	41-46
50-59	12	32	56	52-59
60-69	12	32	68	65-69
70-79	5	12	74	71-79
80-89	3	1	86	84-89
90>	1	-	91	-

2.3.5 Conclusions

2.3.5.1 Energy expenditure

The percentage utilisation VO_2 max and average heart rate for each subject were the two measures chosen for assessing physical work effort and energy cost. The correlation between these two indices was $r = .55$, n=34, $p < .01$, and the plot of the relationship of average heart rate to percentage utilisation of (PWC-VO_2 max) is given in Figure 2.10. On initial inspection, with the mean value of 27.4 kJ/min (1.35 l/min) for energy expenditure, the group seems to have demonstrated a lower level of aerobic demand than that experienced by similar logging workers in other countries. Astrand and Rodahl's general guide-lines for absolute or basic oxygen uptake still places hardwood tree felling in the "heavy physical work" category (see Appendix 14). The mean %-utilisation values for the whole group was just above the 35% limit advocated for those with a moderate to high PWC. The utilisation of physical working capacity varied considerably between individuals and seemed most closely linked to the age of the worker, which in many instances was a positive covariate for height and weight. The group of older men had the highest average level of utilisation at 40% of VO_2 max, but this could not be seen as excessive in view of their generally higher physical working capacity and probably skill level.

2.3.5.2 Heart rate

The average heart rate for all the subjects and all the job elements (126.9 beats/min) is just inside the very heavy class of physical workload according to Christensen's classification of 125-150 beats/min (see Appendix 14), while some 19 subjects or half the group had average heart rate in this very heavy category, and two subjects were over the 150 beats/min level (see Figure 2.10). The average value of the study of 62.3 beats/min is approximately 22 beats/min above the level recommended by Hollmann et al. (1976), while the 30 beats/min limit (Hunting et al., 1974 or Grandjean, 1986) sets the findings well above that recommended for regular hard physical work (see Appendix 14). During work all subjects therefore had average hr nett values above the recommended limit. However, the ameliorating effect of production delays and rest during tree evaluation on such findings needs to be taken into account. Analysis of variance on the mean individual tree heart rate over time showed no consistent fatigue effect, though this possibility would have been masked by the non-productive delays involved in tree assessment interviews of the study. Astrand and Rodahl (1977, p.359-60), describe a number of situations that may cause an marked increase in the pulse rate under sub-maximal workloads. These include dehydration due to the heavy nature of the work or working conditions (Saltin, 1964), the length of the exercise (Rowell, 1974), as well as the familiar reference to emotional arousal which has special relevance in tree felling. However, the heavier the workload the less pronounced the nervous effect on heart rate. Astrand and Rodahl also suggest that under circumstances such as those detailed above, the "excessive" heart rate is still a better criterion for reduced work capacity than oxygen uptake . This is possibly the conclusion to be

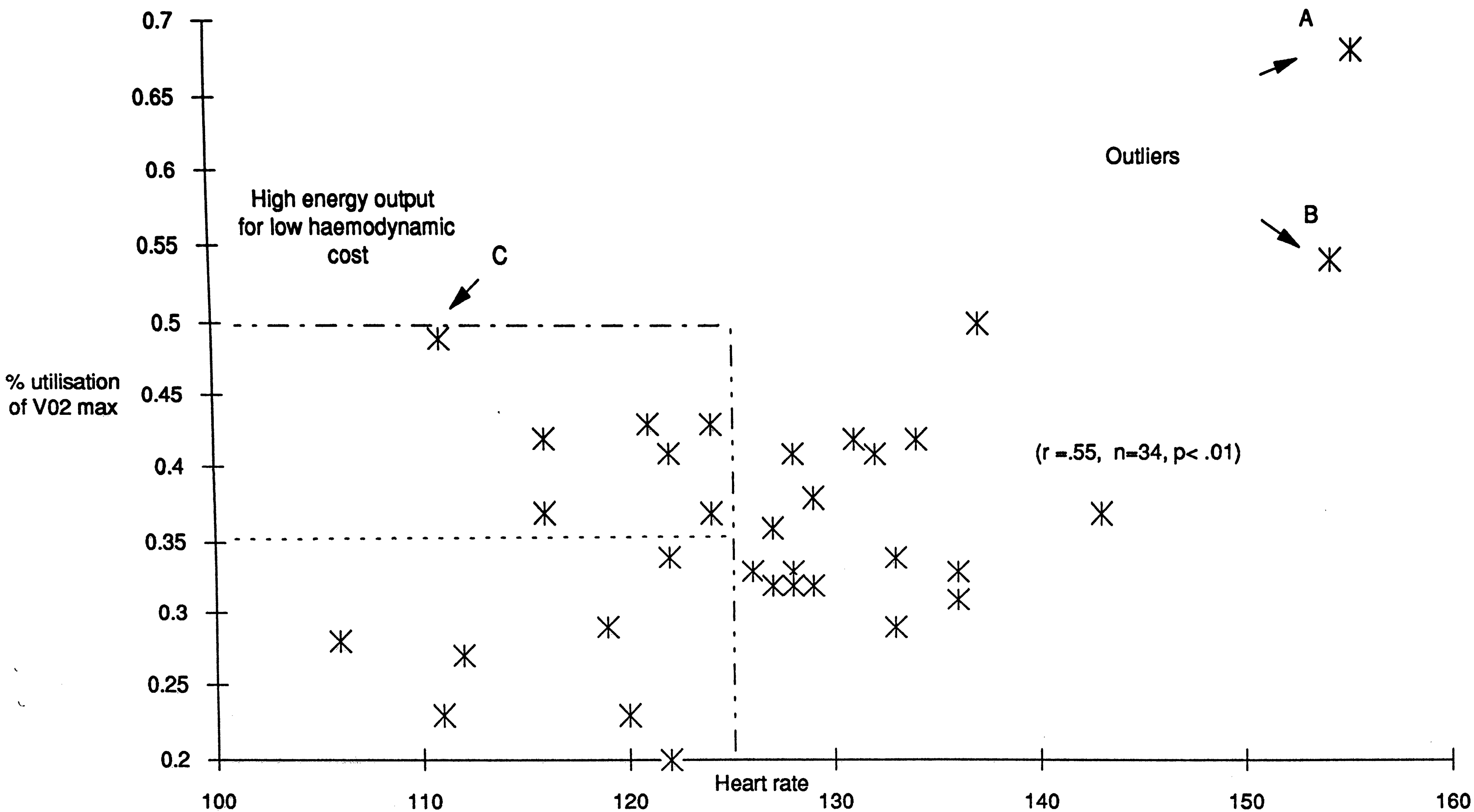


Figure 2.10 Relationship of utilisation of V02 and average heart rate

drawn in the present study, since the heart rate measure has more validity than the spot measures of oxygen uptake that were carried out in less than ideal conditions.

The data in Figure 2.10 show that some of the individuals could be clearly identified as risk outliers of the group in terms of the physical effort they required for the job. It is quite apparent that subjects A and B cannot match the job in terms of the work physiology, while C is an example of a high PWC subject who is operating well within capacity on both parameters. Thus, there appears to be some possibility of identifying workers who may not suit the job on basic work physiological grounds, without any reference to their level of skill.

2.4 Some psychological attributes in the group

2.4.1 The rationale for psychological assessment

In addition to the issue of physical working capacity and the man's success in dealing with the actual physiological demands of the job, there is also the question of the stable psychological attributes of the productive and low-risk tree feller. The earlier literature review emphasised how some investigators felt that productivity and safety were often mutually exclusive states in many felling situations, and especially under piece work conditions. The accident diagram based on Lagerlof (1974, 1979) and discussed in chapter 1 (p.17) was chosen as describing the potential factors leading to failures in felling performance. There has been considerable focus on mechanical - ergonomics improvements and on work organisation factors that are thought to decrease the acceptance of risk and promote a general climate for safe behaviour (Pettersson et al., 1983; Sundstrom-Frisk, 1981, 1984). Though Lagerlof described "personality" as a factor in accident causation she did not specify any particular psychological variables for study. To date there have been no tests of the association between psychological attributes of tree fellers and safer behaviours in the job.

Preliminary discussions with the older experienced bushmen and with instructors during pilot work revealed implicit stereotypes of the attitudes and work habits of the successful hardwood tree-feller. These attributes of the men were considered by instructors to be a separate issue from levels of technical skill in cutting a tree. Whether the attributes were considered essential or desirable was difficult to ascertain. These comments by highly experienced people familiar with the work and workforce were linked to some degree with the psychological concerns in the literature to be described. Important psychological attributes were reputed to be as follows. First, a fatalistic or accepting approach to the hazards and difficulties of the job if one was to have the necessary "peace of mind" while working in the forest. Second, the ability to remain patient and unperturbed even if the felling of a particular tree became increasingly difficult. Third, a steady productive workpace irrespective of forest or weather conditions with, paradoxically, the ability to work speedily under maximum pressure when there was catching up to do because of machinery breakdown or bad weather. Fourth, the drive and determination to improve personal standards of workmanship, irrespective of pressures to reduce standards or to cut corners from people who were not actually felling the trees.

Surveys of accidents and their antecedents in occupational groups other than tree-fellers have sometimes included assessment of psychological attributes. For example, in the rural sphere, Harrell (1980) conducted a questionnaire survey of the accident histories of 450 Canadian male farmers using masculinity items derived from previous research. Factor analysis of 15 items resulted in five short scales: men in charge, unemotional masculinity, strength and persistence, reckless driving, and aggression. Frequency of exposure to hazards (e.g., heavy machinery and livestock) as well as age were found to be significantly related to average yearly accident rate, $r = .14$ and 0.13 respectively $p < .05$, as had been shown in previous farm accident studies (Pfister and Hofmeister, 1969). Though other questionnaire variables assessed in the survey had significant but low correlations with the farmers' accident rate, e.g., conservative farming practices, $r = -.25$, $p < .001$, and taking health risk to make a profit, $r = .17$, $p < .01$, none of the masculinity scales Harrell had constructed was associated with the farmers' reported accident rate. Arguments were offered in the paper for the indirect influence of the masculinity dimensions. However, multiple regression analysis, showed that masculinity yielded negligible increase in varianee accounted for. No other studies of masculinity as an important psychological factor in farming accidents or similar outdoor work have since been reported.

2.4.2 Scales

2.4.2.1 Fatalism and locus-of-control

Many working situations, including tree felling, may be divided into those where outcomes are dependent to a large extent upon the man's skill and the way he organises his work, and those where outcomes appear dependent mainly upon chance or uncontrollable factors no matter what safety precautions or rules are applied. This dilemma is captured in the Australian working man's phrase "she'll be right, mate". An important psychological consideration regarding tree fellers was the way they felt about the "skill versus chance" accident realities of their work; that is, the fatalism they exhibit about being in control of the dangerous outcomes in the job. Some tree fellers maintain that a fatalistic attitude to eventual injury in the bush is the only realistic stance to take in the job.

The Locus of Control scale of Rotter (1966) has been widely used as a measure of perceived control in research in educational and clinical settings (e.g., Rotter, 1975, Watson, 1981). In the original Internal-External (I-E) scale, the 23 core items were considered to sample reported behaviour from areas ranging from friendship and affection to general life philosophy. Rotter (1966) postulated that individuals who had an internal locus-of-control generally believed that rewards followed from their own actions, and that these actions would affect the course of their lives. Internal subjects are thus those who report greater confidence in their ability to influence task performance. Conversely, individuals with an external locus-of-control orientation are more likely to believe that rewards and failures are largely controlled by forces outside themselves, with the state of their life more determined by chance, luck or fate.

Mirels (1970) was the first to attempt to isolate separate factors with the I-E scale and he described two prominent factors as "a belief concerning mastery over events in one's life", and a factor which related to control over "political processes and institutions". Subsequent factor analytic studies arrived at similar conclusions to Mirels and several versions of the locus of control scale were produced (e.g., Dixon, McKee, and McRae, 1976; Cherlin and Bourque, 1974). A study by Reid and Ware (1973) found two clear factors with close similarities and item content to Mirels' factors. They termed the first factor Fatalism, "the belief that luck, fate or fortune versus hard work, ability and personal responsibility determined one's outcomes". The second factor, which was similar to that found in other studies, was termed "social control."

Lange and Tiggemann (1981) administered a 23 item I-E scale to a sample of Australian students and found a "general control" factor consisting of nine items and a second factor of control over political institutions. Cronbach alphas for the general control (or Fatalism) items and the political control items were 0.69 and 0.70 respectively, while the inter-scale correlation of 0.23 was not significant. As in the Mirels (1970) study, the general control factor contained similar items to that of the Fatalism factor found in the Reid and Ware (1973) study. In discussion of the dimensionality of the locus of control scale, Watson (1981) argued that an interpretation of more than two factors should be made with considerable reluctance. She considered that it would be more desirable to develop smaller situation specific scales for use in different contexts than to use the original 23 item locus of control scale.

The I-E scale or variations has been included in several studies of blue collar workers. Chiappone and Kroes (1979) assessed the validity of the idea of fatalism in miners by comparing 33 male miners with 33 male industrial workers on a variety of measures. In using a variation of the I-E scale and a questionnaire to tap fatalistic attitudes, they reported no significant differences between the two groups and concluded that miners were not fatalistic as the "term is commonly used". In a similar study involving a large sample of British coal miners Sims, Graves, and Simpson (1984) administered the original Rotter I-E scale to men in three major regions. No regional differences were found. Nor were there differences between locus of control measures in two of the collieries that had significantly different accident records. However, the miners demonstrated a more external orientation than is found in studies with undergraduates.

In a simulation of driving military cross-country vehicles, locus of control was used as a personality measure in a study of performance and physiological cost of driving under whole body vibration (Webb et al., 1981). The two performance measures were tracking accuracy and reaction time. Subjects with a more "internal" locus of control had significantly less tracking error, with a correlation between locus of control and tracking error of $r = .73$, $p < .01$. This laboratory study showed that internal subjects (those who report greater belief in their ability to influence events) have a significantly smaller decrement in tracking accuracy during simulated cross-country driving. Because the effect was stable across all vibration conditions the investigators suggested that "the personality measure defined by the locus of control score" (p.253) becomes increasingly influential with the severity of the stressor, in this case whole-body vibration.

Montag and Comrey (1987) investigated the relationship between the internality-externality construct and a person's involvement in driving accidents which included a fatality. These authors developed separate specialised scales termed driving internality and driving externality. Internality was negatively related and externality was positively related to involvement in fatal accidents, though neither relationship was statistically significant. Montag and Comrey felt their results were consistent with previous work showing generalised internality rather than externality is related to cautious behaviour.

These occupational studies incorporating various locus of control measures, in conjunction to the fatalism comments of the tree felling instructors, led to assessment of locus of control in the present study. A Fatalism scale of 12 items was constructed from those fatalism items described and evaluated in the Lange and Tiggemann (1981) and Watson (1981) studies. Since a number of these items were originally intended for an educational setting, the wording was slightly changed to provide face validity for timber fellers. A further set of 10 job involvement items was based on the involvement scale of Lodahl and Kejner (1965), or adaptations of this measure by Saleh and Hosek (1976) and Saleh (1981). The primary interest was in the fatalism scale, and the work involvement items were included as buffer items to counteract response bias. The 10 work involvement items were randomly combined with the 12 fatalism items to form a single questionnaire (Appendix 17 Work and Life questionnaire). The questionnaire containing the full 22 items used the Likert scoring format ranging from strongly disagree to strongly agree as recommended by Duffy, Shiflett and Downey (1977).

2.4.2.2 Type A behaviours

Since tree felling can be self-paced or forced paced, the question of self-direction and work rate is a critical one in this type of work. It might be expected that the way a man views the job, the expectations he feels the logging crew have of him, the pressure he feels from the supervisor or contractor would influence how much the workpace and quality of workmanship are genuinely under the tree feller's control. The particular need for the tree feller to overcome work difficulties consistently and maintain high personal work standards has already been discussed.

The Jenkins Activity Survey is the most established measure of what has been termed the Type-A behaviour pattern. From laboratory, clinical and epidemiological studies two cardiologists defined a coronary-prone behaviour pattern - also called Type-A behaviour (Rosenman et al., 1964). These investigators defined Type-A as:

> "overt behavioral syndrome or style of living characterised by extreme competitiveness, striving for achievement, impatience, haste, restlessness, and feeling of being challenged by responsibility and under time pressure."

A corollary is that the behaviour pattern is often associated with persons so deeply committed to their job or vocation that other parts of their lives are relatively neglected. Not every aspect of the pattern needs to be present for a person to be classified as possessing it. Type B behaviour was defined by Rosenman (1978) as:

> "a relaxed, mellow, satisfied style where the Type-B person may be interested in progress and achievement, but tends to flow with the stream of life rather than constantly struggling against it."

Subsequent research produced a structured self report questionnaire, known as the Jenkins Activity Survey (JAS), which is used in the present study (Jenkins, Zyzanski and Rosenman, 1979). Based on a number of extensive factor analytic studies the Jenkins Activity Survey incorporates 3 sub-scales of some 20 items each assessing: Speed and impatience (S), Job involvement (J), and a Competitive hard-driving factor (C) (Rosenman et al., 1964; Zyzanski and Jenkins, 1970). The JAS measures have demonstrated internal consistency, test-retest reliability, and discriminant validity with a range of different occupational and health status groups (Jenkins, Zyzanski and Rosenman, 1979).

In a prospective questionnaire-based study of health changes and injuries in 416 air traffic controllers, Neimcryk et al.(1987) employed the JAS as a predictive personality measure, along with life and work change measures and levels of dissatisfaction with operations management. The Type A measure was significantly related to the future incidence of physician-diagnosed acute illness and to injury. When the Type A measure was split into three percentile groups (Type A, Mixed Type, and Type B) those air traffic controllers with scores in the highest third on the Type A measure (Type A) had more than 3.5 times the injury rate of those in the lowest third (Type B) over a 27 month period. A (C) factor sub-scale of the Type A measure, speed and impatience, was also shown to be a slightly less powerful predictor of injury experience. Subsequent regression analysis attempting to deal with multi-collinearity between the predictor variables indicated that "the Type A behaviour pattern was by far the best predictor of 27-month risk for injury" (p. 649).

Cooper and Sutherland (1987) investigated the job stress and mental health of a sample of 194 oil rig men. A subsidiary goal of the research was to compare accident and non-accident workers on some of these questionnaire measures. Personality measures included the Framington Type A scale (Hayes, Levine, and Scotch, 1978), and the Locus of control measure (Rotter, 1966). Type A behaviour was heavily implicated in injury experience when the scores were divided at the median into Type A and Type B classes. Those 24 percent of the sample composing the accident group were significantly less satisfied at work and had lower overall mental health rating than the accident free majority. Though the authors emphasised that the causal order between Type A, satisfaction, mental health measures, and accident experience could not be tested with the data, they maintained that, " Type A behaviour seems to be a very important predictor of off-shore accidents, and must, therefore, be investigated further" (p.124).

The major use of the JAS measure has been in relation to occupational stress and the search for reliable predictors of cardiac heart disease (CHD) (e.g., Davidson and Cooper, 1980; House, 1974; Kalimo, El-Batawi, and Cooper, 1987; Levi, 1981). Critics of the A-B personality type dichotomy consider that the coronary prone behaviour pattern is more a product of the environmental conditions than of stable personality traits of the individual, and point out that the allocation to Type-A or Type-B classification is to some extent arbitrary (e.g., Ray and Bozek, 1980). It would seem unrealistic to assume that the two extreme descriptions of the Type A and B predisposition, as described above, would outweigh genetic, lifestyle and environmental factors in the causation of CHD. The use of the instrument in the present study was not concerned with reference to the CHD outcome, but in order to provide a reliable and comparable self report measure of how the individual reacted to their work tasks and general environmental demands. Few studies relating a measure like Type A to actual working performance have been made (Damos, 1985).

In the JAS, scores on the (A) sub-scale give a position on the Type A - Type B dimension described above. The (S) sub-scale provides a score for speed and impatience of the man, while the (C) scale indicates how far the man can be seen as competitive and hard driving. These three psychological measures relate quite closely to those tree feller attributes described by instructors and experienced men (see section 2.4.1.). The following psychological factors or characteristics were thus measured by questionnaire:

- Fatalism and Locus of Control
- JAS Type-A/Type-B predisposition
- Speed and impatience
- Competitive and hard-driving nature

2.4.2.3 Possible outcomes

The first goal was to obtain descriptive statistics on the psychological measures that had been selected. The second goal was to compare results for the sample with normative data. From the literature and the anecdotal evidence, there were some grounds for making predictions about relationships between these variables.

There was also some basis for saying what might be expected if the group was to fulfil the instructor's stereotype or image of the professional hardwood timber feller using these measures.

Inter-correlations in the three JAS scales would be predicted from previous studies, while the fatalism and work involvement measures in particular were expected to be unrelated. In terms of the Type-A behaviour, meeting the men in the sample in a forest or in the distinctly rural settings at their homes rarely gave the impression of being with a person of the previously defined Type-A disposition. The expectation was a wide distribution of scores on the Type-A scale, with a tendency towards the Type-B pattern of reported behaviour for the group as a whole. Scores on the speed and impatience scale were expected to be lower than the normal population for similar reasons. Conversely, for hard-driving competitiveness the expectation was for higher scores, mainly because determination and need for the pursuit of improvement seemed an essential predisposition in such a demanding work setting. It might also be expected that the speed and impatience and hard-driving competitiveness scores would gradually decrease with age, along with physical strength and work capacity, as the man saw the need for the steady, consistent, and as some instructors described it a "more cunning" approach to the job.

Predictions about the fatalism scores were not clear cut. Two previous studies using the locus of control measure found no significant differences between coal miner samples and fatalism responses in the workforce in general. On the other hand, there was the consistent suggestion from highly experienced instructors that a fatalistic attitude was needed if a man was to remain calm while felling, and in dealing with the everyday frustrations of logging work. On this basis the expectation was for a skewed distribution of fatalism towards low scores. A positive correlation between increasing years of experience and the fatalism measure, as well as a large range in the differences between the men, was also expected.

2.4.3 Results

2.4.3.1 Fatalism and locus of control

The Fatalism (and work involvement) scales contained within the work and life questionnaire were subjected to the same principal components factor analysis (Norusis, 1986b) to form new versions of the original raw score measure on the 12 items in the fatalism measure, and the 10 items for work involvement. Neither scale gave the simple or short factor structure anticipated from results of previous studies. The fatalism scale produced four factors, with the first factor accounting for 24% of variance (see Appendix 18 for analysis details and item loadings). Analysis with the solution constrained to one factor gave the same nine highest loading items. The similarity and face validity of the fatalism items overall defied any simple interpretation as to why the nine items had high loading on factor one while the other three items did not. The restricted number of items was used to produce two versions of a Fatalism measure. The first was simply the summation of scores of the nine highest loading items (Fatalism 2). The second was the summation of scores of the same nine items weighted by their respective coefficient score as recommended by Norusis (1986b) (Fatalism 3). The inter-correlation between the two versions of the fatalism scale was high ($r = .96$, $n=38$, $p < .001$). The reduced fatalism measure (Fatalism 2) was thus chosen for use in later analysis. Scores on this scale could range from a minimum of 9 to a possible score of 45.

The work involvement scale produced a three factor solution, with the first factor accounting for 37% of the variance (Appendix 18). Using the same rationale and procedure as above, an eight item scale was produced in a reduced raw score form (Work-involvement 2) and in a factor score weighted form (Work-involvement 3). The correlation between the two versions was $r = .98$, $n=34$, $p < .001$, and the Work-involvement 2 scale was chosen for later analyses. Table 2.10 contains the detail for score distribution and group means for both fatality and work involvement scales using the reduced raw score version in both cases.

Table 2.10 Properties of the Fatalism and Work Involvement measures (Fat.2 & WI.2)

	Mean	Standard Deviation	Range in study	Max possible
Fatalism (9 items)	25.61 (24.53)[a]	5.11	16-34	9-45 (X=27)[b]
Work Involve (8 items)	24.81 (25)[a]	6.58	15-38	8-40 (x=24)[b]

[a] Median value for study group
[b] Mean of full possible range

A relatively even distribution of scores was found for the sample on both scales, although the range of scores on the fatalism measure was noticeably smaller than for the "buffer" set of work involvement items (Appendix 18). The fatalism scores covered approximately half the potential range, while the work involvement scale covered approximately 70% of the potential range. Dividing the scores at the 25th and 75th percentile gave close to 60% of the subjects in the middle group for both measures.

2.4.3.2 Type-A, impatience, competitiveness

The scores of the tree fellers on the Type-A (A), Speed and impatience (S) and Competitive hard-driving (C) scales are presented in Table 2.11. Comparison of standardised scores on each sub-scale can be made against the results obtained in the original instrument development studies (Rosenman et al., 1964, 1975), where the standardised scores on all three scales have mean of 0.0 and a standard deviation of 10. Reference can also be made to a large predominantly blue collar group such as that reported by Waldron et al. (1977). In this study the reported mean and standard deviation relative to the standardised mean and standard deviation for Type-A was (-2.2 SD 9.3), Speed and impatience (-2.9 SD 9.6), and Hard-driving and competitive (1.5 SD 9.9).

Table 2.11 Properties of the three JAS sub-scales used in the tree-feller study compared with the standardised scoring range of Jenkins et al., (1979)[a] (Maximum possible range in parentheses)[b].

	Mean	Standard Deviation	Range[b]
Type A Factor (A)	-0.96	10.65	-19 to 22.4 (-25 to 25)
Speed & impatience Factor (S)	1.02	10.57	-13.6 to 26.2 (-23 to 32)
Competitive hard-driving Factor (C)	6.06	10.87	- 8.6 to 30.8 (-28 to 40.8)

[a] All JAS scales standardised to have mean of zero and sd's of 10.

In the present study the men had a mean of -.96 and a standard deviation of 10.65 on the Type-A scale. These scores were not significantly different from the standardised scores for a normal population reported by Jenkins et al. (1979). On the speed and impatience scale, the sample had a mean of 1.02 and a standard deviation of 10.57. This difference was again close to the normative data provided by Jenkins et al., and was not significant ($t(34) = .57$, $p > .01$). On the competitive and hard-driving scale, however, the men had a mean of 6.06 and a standard deviation of 10.87. These data were significantly different from the normative values for this scale, t (34) = 3.30, $p < .005$, and in the predicted direction.

Type-A behaviour is indicated by positive scores on the Type-A standardised scale, while type-B behaviour is indicated by negative scores (Jenkins, Zyzanski and Rosenman, 1979). Caution is necessary in individual cases when interpreting scores close to the zero point between the two different types of self-reported behaviour patterns. Advice in the test manual of the Jenkins Activity Survey suggests that "Type-A scores are thus an added piece of the puzzle" when used in studies of the factors associated with CHD (Jenkins, Zyzanski and Rosenman, 1979, p.11). Other researchers have adopted the strategy of using the third percentile of scores at either end of the distribution as cutoffs for definite Type A or Type B cases (e.g. Niemcryk et al., 1987).

Of the 14 men in the group with Type-A scores greater than the standardised mean, seven were within one standard deviation of the mean and only one man had a score greater than two standard deviations from the mean. Of the men with negative Type-A scores, 33% were within one standard deviation from the mean. Out of the three scales, the competitive and hard-driving measure had the largest proportion of scores above the eightieth percentile, with 12 men or approximately 30% of the sample above this level.

2.4.3.3 Relationships between measures.

There was a significant association between age and experience as a tree feller ($r = .70$, $p < .001$), whereas years as a tree-feller and level of education were not related. Table 2.12 shows the correlation of the scores on the five psychological scales with age, experience and education level (year of leaving school). The only statistically significant finding within the set of scales was the negative correlation of work involvement with educational level.

No correlation was found between the Fatalism and Work involvement measures. These two measures were not associated with any of the three JAS sub-scales. Fatalism was slightly correlated with experience, but not work involvement. This argues against the suggestion that a fatalistic attitude in tree fellers increases with experience or age. The unexpected significant correlation of work involvement with educational level suggests that work involvement might decrease with educational level if it enabled greater insight into the potentially costly nature of the job.

Table 2.12 Relationship of scores on the psychological scales to age and background factors and to each other.

	Age	Exp	Ed	Fat'sm	W Involv	JAS (A)	JAS (S)	JAS (C)
Age	-	.70***	.00	.00	-.02	.24	.23	.00
Experience		-	.12	-.16	.00	.17	.08	.00
Edu. level			-	-.20	-.40**	.13	-.13	.13
Fatalism				-	.00	.00	.17	-.20
Work Involve.					-	.13	.00	.27
JAS								
Factor A						-	.68***	.34
Factor S							-	.14
Factor C								-

* $p < .05$ ** $p < .01$ *** $p < .001$

Correlations between the three sub-scales of the JAS questionnaire matched findings from previous studies (Jenkins et al., 1979). There was a substantial correlation between Factor (A) and Factor (S),(r =.68, n=35, p < .001), and a lower correlation between factors (A) and (C), (r =.34, n=35, p < .05). There was no a priori reason to expect the three sub-scales of the Jenkins Activity Survey questionnaire (JAS) to be significantly associated with age, educational level, or even years of experience. None of these correlations was significant.

From these analyses the two measures of fatalism and work involvement used in the study appear independent of each other, and neither was related in any statistically significant way to the three scales chosen from the JAS. These selected measures of the individual's psychological attributes are thus separate and distinct candidate factors for association with levels of physical effort, or with the performance measures used in the field.

2.5 Discussion

2.5.1 Work physiology

Compared with softwood tree fellers during felling and trimming under Australian conditions (Fibiger and Henderson, 1982), the present subjects appeared under a slightly lower level of average load (30.4 vs 27.4 kJ/min). However, the hardwood men had more production delays than in the Australian softwood felling study. These delays can act as recovery time, particular for those workers with lower capacity. Compared with overseas studies such as that by Kukkonen-Harjula and Rauramaa (1984) the energy expenditure cost for the same job elements of felling and trimming were distinctly lower (36.6 vs 27.4 kJ/min), with the heavier chainsaws of the Australia possibly having to be balanced in this case against the snow conditions in part of the Norwegian study. Further, the research delays occurring during the hardwood study when interviewing the subject about trees might have acted as recovery time over and above normal opportunities. However, the haemodynamic cost in terms of absolute heart rate while felling, trimming, and cross-cutting was very close to that of the Norwegian study, while the most demanding work element of bunching was not involved. The sample in the present study was more representative, with younger, smaller, and less experienced men, than most previous forest ergonomics studies such as that of Kukkonen-Harjula and Rauramaa with a smaller sample of highly skilled workers.

From the energy expenditure results of the present study it would appear appropriate to conclude overall that hardwood felling and trimming does not necessitate more energy expenditure than several types of felling and trimming work in other industrialised countries. While energy demand in VO_2 terms was within the recommended 35% limit in almost half of subjects under these research conditions, the hr nett cost was significantly above recommended medical standards in all cases. Provisos in the interpretation of the work physiology results are now discussed under the headings of: (a) Oxygen consumption, upper body effort, and reliability, (b) Work pace, interview interruption, and external validity.

(a) Oxygen consumption, upper body effort, and reliability.

The physiological effects of any given level of demand for effort and energy output are determined not only by the individual's maximal aerobic power, but also by environmental conditions, the working position, size of engaged muscle mass, and whether the work is intermittent and at a high rate or continuous and at a lower intensity (Astrand and Rodahl, 1977, p.462). The question of using the bicycle ergometer for the prediction of VO_2 max in jobs where there are major components of upper body work was discussed earlier (see section 2.2.1.2).

Some of the oxygen consumption measurements in the present study included unavoidable delays, such as re-inspection of a tree after putting down the chainsaw. Some of the men also appeared to work more tentatively during Oxylog sampling, especially during the end of the work cycle near the start of the actual fall. Since there was no significant difference in average heart rate between Oxylog trees and normal trees, it seemed unlikely that use of the Oxylog produced the underestimate of energy expenditure one might anticipate because of the subject being encumbered with the measuring device and mask. Although there was also the possibility that the complete sample of trees in the field work had been cut at an easier pace than the normal level of exertion, the average heart rates for felling and cross-cutting were very similar to other studies of tree fellers in different countries. These results increase the possibility that over-estimation of VO_2 max in some of the subjects was the basis for an underestimation of their %-utilisation in the field (see 2.2.1.2).

In comparison with the most closely related study (Kukkonen-Harjula and Rauramaa, 1984), the current research provided contradictory findings. There were similar levels of average heart rate yet a distinctly lower average oxygen consumption/energy expenditure (9 kJ/min) as measured by Oxylog. Correcting individual cases of energy expenditure data might appear feasible. One might, for example, take those subjects below the national mean for weight and height and make correction of VO_2 max utilisation using a conservative 20% decrease of their predicted VO_2 max figure from a bicycle ergometer test. However, currently there is no established methodology for determining post hoc how much of the potential underestimation of VO_2 max may have taken place.

In a job that is accepted world-wide as a "heavy" to "very heavy" one it might be anticipated that there would be a high attrition rate in the first few months in the job due to strain and injury, or that subjects would have self selected to have a capacity, size and physique to match the demands of the job. The job might also have a physiological training effect on those medium capacity men who remain in the work. The sample was heterogeneous in physical terms with a significant spread of height and weight, and of the capacity for work and the utilisation of that capacity. A number of the younger men in the 20-29 age group appeared relatively disadvantaged mainly because of their lower height and weight, and this suggestion is supported by the strong correlation of both height and weight to energy expenditure in the field tests. For example, using 30 years and the median height and weight in the national health survey as a criterion point (Age <30, Height <175cms, Weight <77 kilograms (National Heart Foundation, 1980), a group of eight young men of average age 23.5 years, average height 168.9 cms and weight 63.6 kilograms was created. Their average energy expenditure was 22.9 kJ/min, with a %-utilisation of VO_2 max 32%. For a group of five older men in the sample (> 30 years, >77 kgs. >175 cms), the average age was 43.2 years, average height 184.6 cms, and average weight 82.5 kgs. Their average energy expenditure was 36.3 kJ/min, and utilisation of VO_2 max 42%. In a study involving Brazilian industrial workers Chaffin and Couto (1986) found an effect similar in part to the present study, where there was little decrement in workers' aerobic capacity with age in jobs requiring high levels of energy expenditure (i.e., >21 kJ/min in their terms). The question of smaller, less fit, younger men entering the hardwood industry as tree fellers is an important area for future research.

(b) Work pace, interview interruption and external validity

At the time the research took place the average weekly quota of the men was 450 tonnes, and nearly 56% of the subjects were on a quota of less than 500 tonnes/week. Aman's weekly or monthly quota could fluctuate in many cases due to mill demand, seasonal variations, machinery breakdowns, etc. The effect of the then current quotas on effort during fieldwork was difficult to assess, although no association existed, for example, between %-utilisation VO_2 max and a man's weekly quota ($r = -.13$ $p > .05$). The men above a quota of 500 tonnes also showed no consistent difference from the men on average quota or below in %-utilisation of their working capacity. The influence of production pressure and the habit of working at high quota pace can be explored in cases where high quotas prevailed. In a group of five subjects whose average quota was 700 tonnes, range 550-1000 tonnes, the energy expenditure did not differ significantly from the main group, t = 1.10, $p > .05$, (high quota group $29.35^{+}/_{-}8.4$ kJ/min, overall group $27.42^{+}/_{-}5.9$ kJ/min). The %-utilisation figure for this small high quota group was also below 40%. Thus, those with the habit of high quota did not exhibit unusually high levels of utilisation during the research day compared with the overall value for the whole group of 37% of VO_2 max.

The significant negative correlation between the predicted VO_2 max for each man and %-utilisation of that VO_2 max ($r = -.47$, $p < .005$) argues against any form of pacing based on capacity. However, unlike softwood fellers, hardwood fellers can find themselves working to an impatient skidder driver or under the production pressure of the whole logging crew waiting for logs. With a similar proportion of medium capacity men in the overall feller workforce, it is possible that maximal work capacity would become more important in the types of peak workload conditions referred to above.

The data of the present study give an indication of the levels of utilisation of VO_2 max potentially involved in the job, particularly for the worker with low to moderate physical working capacity. In spite of the provisos on measurement some degree of extrapolation is warranted. With the under-estimation problems that were raised in the study at least one third of this sample of hardwood tree fellers could be considered to be in the unsatisfactory range of medium physical working capacity or below. They had lower energy output and %-utilisation levels.

During normal production, or particularly adverse conditions, it is quite feasible that the high levels of energy output and utilisation observed with the high PWC workers in the present study would occur to a greater extent than was found in our field tests. Using the slightly higher average field energy cost of 30.3 kJ/min found in the 40-49 year group, 25 of the men in the research sample (64%) would have been working at over 35% of their VO_2 max, with 18 (46%) at over 40% of their VO_2 max, and six men in the group (15%) working at over 50% of their VO_2 max. Average energy costs up to 35 kJ/min have been observed in softwood productivity studies (e.g., Kukkonen-Harjula and Rauramaa, 1984). For a group of five older and larger men in the present sample (average age 43.2 years, average height 184.6 cms, and average weight 82.5 kgs), their average energy expenditure was 36.3 kJ/min with a utilisation of VO_2 max of 42%. Though this can be seen as the upper level of job demand in hardwood felling, a 35 kJ/min level of energy expenditure in all the men of the present sample, would have had seventeen or 44% of the men working above 40% of their VO_2 max, and 30% trying to work above 50% of their VO_2 max. Thus even in the results of the present study, a case can be made regarding the main workforce of the dangerous combination of wide differences in capacities in the men and widely differing physiological job demand. In spite of the "normality" of the results compared with other relevant work physiology studies in forestry, it was still the case that too many of this physically heterogeneous sample of men did not completely fit the job and work environment from the work physiology point of view.

2.5.2 Conclusions

The data on energy expenditure and utilisation of VO_2 max revealed a wide range in physiological workload with very high levels of demand in only a small number of cases. These higher energy demand values would be more prevalent under high production conditions across all subjects. The haemodynamic cost of the job in heart rate terms was too high in absolute and hr nett terms and similar to studies of tree-fellers in other countries. The role of non-productive delays and other recovery opportunities could not be addressed with the design of the study incorporating other tree assessment and interviewing aspects. Further research is needed to determine whether the work of this particular type of tree feller has a larger upper body component than is the case for tree fellers in Scandinavia and Europe, possibly because of tree size and cutting conditions and not just chainsaw weight. There may be a need for a combined upper and lower body test in PWC assessment, as well as upper body strength and skill tests in selection. However, as a recent study by Sawka et al. (1983) has demonstrated, a sub-maximal test for

VO_2 max on a bicycle ergometer is still the most reliable predictor of upper body aerobic performance, in spite of well documented problems.

2.5.3 Psychological factors

The sample was relatively homogeneous on three of the four psychological attributes that were assessed. The fatalism measure revealed a more complex factor structure than was expected from the literature, only reaching half of the potential range of scores. Response on the Type-(A) and on the speed and impatience (S) sub-scales of the JAS are similar to those of the normative populations studied earlier by Rosenman et al. (1975) and Waldron et al. (1977). Only seven men out of 38 had what could be seen as extreme scores (>80 percentile) on the Factor (A) measure. Speed and impatience (C) also had a normal range of scores, with a mean value slightly higher than that of the blue-collar data of Waldron et al. (1977). Both these normal results were contrary to expectation. Higher JAS Type-B scores were predicted, along with lower values than normal for the speed and impatience measure. Scores on the competitive hard-driving scale (C) differed from the normative data. A substantial number of men scored above the eightieth percentile on this measure. This was the expected direction for results on this particular psychological attribute as far as the local instructors' stereotype was concerned. Only one subject had scores above the eightieth percentile on all three JAS measures. This particular bushman, having high scores on all JAS scales, had the lowest fatalism measure possible (16) and a work involvement score only four points below the maximum possible (i.e., Factor-A 98th percentile, Speed and impatience 90th percentile, Competitive hard-driving 98th percentile, Fatalism 16 points, Work involvement 34 points). The anomalies were the minimal fatalism score, diametrically opposed to popular stereotype, and the high Type-A score. This subject had been independently ranked by two instructors as the most skilful and professional worker in the study, and had the reputation of being one of the best timber fellers in the state. Thus, in terms of the psychological dimensions that were assessed, even this subject did not present a simple picture in relation to the instructors' stereotype of the effective hardwood feller.

Many of the men in the sample did not match the felling instructors' psychological stereotype of the professional hardwood feller as having high fatalism, low Type A predisposition, and low speed and impatience. The group as a whole, however, did conform more closely to stereotype on the hard-driving and competitive dimension. The relationship of some of these psychological findings to performance in the field and in the simulation will be pursued in Chapter 5.

Chapter 3

Judgements and felling behaviour in the field

Chapter 3

Judgements and felling behaviour in the field

3.1 Background

3.1.1 Introduction

The earlier review of accident statistics and epidemiological studies of the occupation of felling revealed that many injuries occur when a tree had not fallen as planned. Chapter two showed that some men in the present study did not fit the physical stereotype of the tree feller in terms of weight and height, while others had only a marginal physical working capacity for the job. Furthermore, some men did not match the psychological characteristics for a hardwood timber feller that appeared to be part of the stereotype in the industry. The connection between injury and trees often not falling as intended, as well as wide differences between the men on physical work capacity and personal characteristics, offered a basis for the fieldwork reported in the current chapter. The goal is to examine a typical sample of men and their performance in an actual field situation, rather than to investigate an elite group selected on the basis of high levels of skill, fitness, professional motivation and equipment.

The research in the present chapter is exploratory in nature primarily because the task of assessing the worker's skill in the actual job does not have the well established rationale and methods of measurement of work physiology reported in chapter 2. Nor does investigation in the field allow the use of the more experimental techniques employed in the signal detection analysis in chapter four.

3.1.2 Studying work skills

The focus of the study is on the skilled behaviour of men under practical risk conditions where it is not only a matter of skill in the task of cutting down relatively large and often defective trees, but the inter-related skill of avoiding injury if something in the felling plan does go wrong, or an unexpected problem occurs during the felling process. Some of the questions the following discussion attempts to clarify and answer are as follows. What do the words "skill" and "error" denote in the more restricted terms of skill psychology and ergonomics? How can we describe the tree feller's job in terms of skill and behavioural-ergonomics concepts? How can we measure or at least judge the levels of decision making and felling skill of the tree feller in the practical situation?

As Singleton (1978, p.1) has emphasised, skill within the blue-collar workforce was until recently defined mainly in terms of the length and type of training the person must undergo. The distinction between skilled, semi-skilled and unskilled manual work remains enshrined in national classifications of occupation (e.g., ASCO-ABS, 1986, p.7). In these broad terms the skilled blue-collar worker was the one who had served an apprenticeship with all that this entailed in terms of occupational socialisation and standards of workmanship, while the semi-skilled might have received some form of training over days, months, or even years. The term unskilled was meant to convey the fact that average person could perform the task almost as soon as they started the work, though this is often far from the case in practice. In Australia, the occupation of softwood (and hardwood) tree feller is found in the agricultural labourer minor group, Forestry Labourers 82-8203, where no particular entry requirement is specified and general on-the-job training of between 3-12 months is nominated (ASCO-ABS, 1986, p.205). At best, in these labour market terms, the job appears to be classified as semi-skilled.

Some 10 years ago it was Singleton's opinion that the ergonomic study of practical skills was still in the early stages of development in spite of the voluminous literature on the laboratory study of human performance since the early 1960s. To quote Singleton (1978), "Ideas about skill have developed gradually and very slowly throughout this century. Since about 1960 there has been little progress because of the current fashion for the laboratory measurement of human performance. Such work is not about the higher levels of skill because the typical subjects are not skilled operators ... but the healthy educated young man as the universal human operator" (p.14). It is true to say that the situation in the specific area of high-risk worker skills is little changed today.

While remaining a productive and pragmatic scientist in the broader ergonomic literature (Singleton, 1972a, 1984a), Singleton has also been one of the more notable writers on skill and human error for more than the last two decades (Singleton, 1972b, 1978, 1979). The involvement goes back to Singleton's own experiences in analysis of industrial skills in the British shoe industry in the 1950s (Singleton, 1957, 1960). A later European group at the RISO National Laboratories has had a similar interest in the problem of human error and reliability, and process industries in particular (Rasmussen and Jensen 1974, Rasmussen, 1981, 1985, 1986a). While both principals have a primary concern for research on human performance in the working situation rather than the laboratory, Rasmussen has moved more toward the problem of so-called "cognitive engineering" and error in complex high technology systems (Greene, 1985), to the exclusion of other concerns. Singleton has maintained an interest in blue-collar skills and excellence and the issues of agricultural and industrial accidents (e.g., Singleton, 1978, 1984b, 1984c). It is impossible not to quote extensively from Singleton in particular in the present chapter because he is essentially the only major researcher who has continued the tradition of the study of practical skills initiated in the Cambridge laboratories of Sir Frederic Bartlett some forty or more years ago (Bartlett, 1943; Bartlett, 1958; Bartlett and Mackworth, 1950; Dearnaley and Warr 1979; Mackworth, 1950).

How then is skill to be defined when talking about the higher level blue-collar job skills? Singleton's two companion volumes cover the topic in depth (Singleton, 1978, 1979). His first step is to define the phenomenon in terms of "skill-economy" since "usually there is no sign of wasted effort, the moving limbs and body are controlled, but not stiffened or tightened by over-active muscles; there is no haste, there is usually speed in the sense that the total achievement in a given period is impressive but nothing seems to happen suddenly or unexpectedly to the performer" (Singleton, 1978, p.2).

The second emphasis is on the three somewhat arbitrary divisions of input-decision-output, but in a way that not only captures the integrated and parallel processing aspects of skilled performance, but the way the skilled operator learns the lesson of redundancy and knowing exactly what must be attended to guide action, and what information is just redundant noise;

> There are so many things which need to be looked for, so much to be held in mind, and so many things that need to be done either simultaneously or in quick succession. All skilled activity involves these three components of selection of <u>relevant</u> data, using it to make decisions on what to do and then doing it (Singleton, 1978, p.3).

The third root of the definition of practical work skills and indeed all high order skills, is the dimension of lead: that is, the matter of anticipation and the skilled person's understanding of how much deviation from task parameters can be tolerated before there is the real need for corrective action, or as is described by Singleton:

> The overall smoothness [and error free nature of performance] is thus not achieved by speed of reaction but by anticipation of events, partly from extrapolation from preceding events and partly from the established model of the total situation (Singleton, 1978, p.13).

Descriptive studies of practical skills in a range of occupations by Singleton and his coworkers (Singleton, 1978, 1979) are different in both conceptualisation and execution from the S-R model of the human operator which underlies much of the laboratory based research on human performance and risk (Crossman, 1964; Holding, 1981).

From the perspective of the practical skill literature previously described, the individual worker's perceived risk might be regarded as an adjunct of skill in that it may constitute a conscious judgement - before taking action - on what level of skill to apply to a situation. This might be a somewhat rational decision based on previous experience, or a reaction much influenced by psycho-dynamic factors and transient states of the person. The topic of perceived risk in recreation activities, or work settings, can range from narrative treatments such as those of Klausner et al. (1968) to more technical treatments (e.g., Ross, 1974; Vlek and Stallen, 1980). Perceived risk and judgements involving uncertainty have a prominent place in the more social and technological hazard literature under the "acceptable risk" rubric, but in spite of appearances this material does not relate directly to the particular research problem of the thesis (Fischoff et al., 1981; Kahneman, Slovic, and Tversky, 1982).

3.1.3 Human reliability

The questions of skill and error or human reliability are simply two inseparable sides of the same coin of human performance. It is the potentially lethal consequence of trial-and-error learning in hardwood tree felling that makes the error scenario in this work qualitatively different from many other occupations. Whether the operator is in charge of a relatively simple system such as a falling tree or controlling a complex system such as a high-technology production plant, many of the basic skill-ergonomics issues remain the same.

The question of human reliability as a component in complex systems is not new (Adams, 1982; Davis, 1958, 1966), but according to writers such as Bell and Swain (1985), Rasmussen (1985) and Singleton (1984a), it has found a renewed emphasis in the last decade and a half because of the trend towards even larger centralised high-technology installations where unpredicted and often catastrophic malfunctions continue to occur. Adams (1982), and Singleton (1984c) are two writers who argue against it being possible to regard the reliability of the processing plant operator in the same way that reliability is determined for engineering components in a system. The increasingly catastrophic consequences of malfunction in nuclear and chemical plants since the 3-Mile Island incident (Swain and Guttman, 1983) have thus in a sense forced a return to the naturalistic study of the operator's behaviour in the real working environment.

The changes in higher-risk technologies have coincided with a further revival of the study of on-the-job mental processes and cognition of the contemporary occupational group of the so-called process controllers (Bainbridge, 1978) or "an approach to cognitive engineering" as Rasmussen (1986b) sub-titles his more recent work. This mirrors the recent trends in general psychology towards cognitive studies. The engineering fraternity may have also begun to accept that no matter what the degree of automation in a high technology plant, a process operator (and his/her technical support team) will remain as the supervisor of the system for insurance and political reasons, as well as being the final decision point in recovery from these rare equipment and system failures. The once popular engineering-component analogy of the human operator in the human factors work of the 1960s (e.g., Gagne, 1962) has been weakened, with arguments ranging from the ethical problems of determining genuine failure rates in human operators to the difficulties of mathematically synthesising human reliability data (if available) with equipment reliability data banks (Johannsen and Rouse, 1979).

With the notion of error remaining the focus of human reliability measurement, Rasmussen (1985, p.1188) suggests that human errors in the complex modern high-technology system should simply be considered to be "unsuccessful experiments in an unfriendly environment". This type of definition of error may apply equally well to the case of the "low-technology" native forest tree feller, where he also must experiment in a naturally "unfriendly" environment whenever a tree presents a felling problem he has not dealt with before. Both Singleton (1984c) and Rasmussen (1985) emphasise that the supposedly troublesome system issue of human error has an often underestimated positive aspect in that errors have the central role in maintaining a skill as well as developing it. Rasmussen (1985) further suggested that errors neither can nor should be totally removed, even in high-technology systems, and he, like Singleton, places particular emphasis on the issue of error recovery and error tolerance in the design of such production systems.

These various points of view question the layman's notion that operator error is a discrete event at one point in time, rather than a linked sequence of cognition and output where some form of recovery from the initiating error event may be possible. Error, in cognitive terms, can be considered in the context of where the blockage of information has occurred in the major cycles of information processing and response. As an example, Singleton (1972b) has taken a well known taxonomy of common human errors by Kidd (1962, p.182) and suggested:

> 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. This is usually because of an undesirable vagueness in contingency planning. He may get all of these things right and **then** go wrong because he selects the incorrect action. This is usually due to inadequate training. 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. These are the most difficult kind of errors to deal with."

With an analysis of the error phenomenon such as this it is not difficult to see how a major error like being off-target in tree felling may evolve, and how the myth of ease of recovery from such an error, as represented in the "escape path" recommendations of tree-felling manuals, might be misplaced.

The ideas on skill and human reliability outlined above enable one to see more clearly the inadequacy of the old idea of a separate episode of behaviour called "risk-taking" in investigating human performance problems, which includes those in the forest setting. Studies of so called tree feller "risk-taking" are better considered as studies of skill in controlled directional felling, and escaping falling trees and branches. The questions of skill and error are frustrating as well as fascinating ones for, as Singleton (1978, p.14) has pointed out, "it emerges that the study of skill is elusive with a frustrating quality of 'now you see it , now you don't' about it". A year later he commented (Singleton, 1979, p.6), "Unfortunately the only observable part of any human activity is the effector functions which cannot be other than sequentially ordered. Thus skills analysis always depends on creative reconstruction of what is probably happening behind the appearance of sequential outputs".

In his major work Singleton (1979, p.3) felt that "methodologically the study of human skill [and error] seems to progress by sensitive observation of the real situation supported where possible by laboratory experiments", for he felt the experiment remained the "ancillary supporting technique" rather than the pioneering one when it came to the particular problem of looking at human work performance skills. Singleton, however, was at pains to emphasise that although the skills analyst bases his studies on practical problems, this circumstance "does not diminish his interest in and respect for good theories about human behaviour"(p.315). Rasmussen (1985) made the same point a little differently when he pointed out that:

> "It also seems important to realize that the scientific basis for human reliability considerations will not be the study of human error as a separate topic, but the study of normal human behaviour in real work situations and the mechanisms involved in adaptation and learning." (Rasmussen 1985, p.1194)

Singleton (1979, p.322) describes a number of stages for the (behavioural or skill ergonomics) appraisal of the skilled operator, which start with detailed discussions with the worker and those to whom they are responsible and end with devising techniques to evaluate any work environment innovations that were possible (Appendix 19). Broadly following the rationale Singleton proposes, the following sections attempt a description of the work of the hardwood feller in relation to ideas in the skill-ergonomics and human reliability debate, and seek to propose and test a model of the skilled hardwood tree feller in terms of his daily survival at work.

3.2 Describing the job for fieldwork

3.2.1 Introduction

Evidence of the skills of the older generation of axe and crosscut bushman can be seen in the continuation of competitive woodchopping in Australia and the men in the various state organisations affiliated with the Australian Axemen's Association. Reading about the tradition of the Australian and New Zealand bushman and the history of competitive woodchopping (Beckett, 1983, Preston, 1980), as well as observations at any major Australian agricultural show, will confirm the explosive power and fine control-skills involved in using these razor shape tools at maximum speed. Such observations leave one in little doubt that the professional axemen and sawyers of the past were essentially athletes with the strength, skill and stamina to match. Competitive axemen today, though no longer always drawn from the ranks of the logging industry, train assiduously for many weeks before major events and put great care into their collection of axes. Major competitions include the standing block where the man must cut through a 40 cm block at approximately chest height with two V cuts from either side (record times of 33-40 seconds). The underhand chop is made on a horizontal log cutting between his legs within a few centimetres of his feet, which are placed on two prepared footholds. The same V cut is adopted, with the man swinging to the other side when half way through the log (record times of 26 seconds). In the tree felling competition the man ascends a trunk by cutting slots in a "tree" and placing narrow foot or springboards one above the other before cutting through a block approximately 5 metres above the ground. The springboard is some 18 centimetres wide and up to 1.8 metres long, with a special steel shoe at its end which digs into the slot the man cuts in the tree. The man must ascend one side of the tree, cut half way through the block at the top, descend by the same narrow boards, and then go up the other side by the same means to cut through his block (record times of 1 minute 55 seconds, Preston, 1980). This event requires particular agility and balance as well as speed, and imitates the demands of felling trees with large buttresses using springboards (see Appendix 1 and O'Reilly, 1958, p.99-105). The Australian racing axe is considerably larger, heavier and sharper than the domestic tool most people are familiar with. The secret of a good axe is in the grinding and polishing of the original factory made article, which is often a jealously guarded secret. Most axemen have a collection of axes prepared for the various types of wood and their differing hardness or moisture content. Many will replace and set the handle of an axe to give a unique "lead forward" which is suited to their particular physique and chopping style and is said to give a better balance when cutting (Preston, 1980). Similar attention is given by competition crosscut sawyers to their saws.

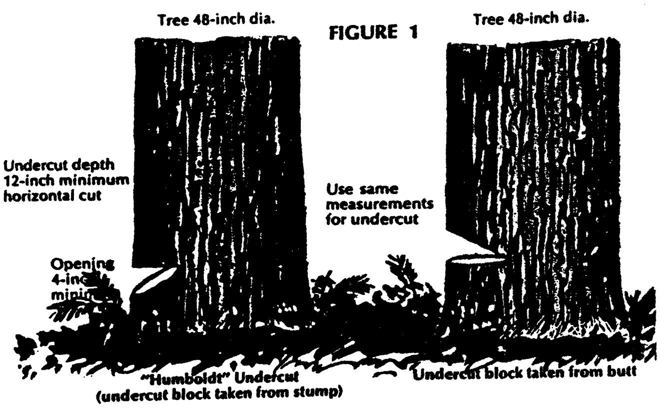
It is not possible to establish the accuracy with which men in the axe and crosscut era could fell a tree, or had to as part of directional felling in selective logging. It is easy to imagine how the strength and agility of today's competition axemen - both on the ground and the "springboard" - translates into survival of their predecessors amongst falling timber in pre-war forests. Whether the injury rate before the chainsaw era was *pro rata* less than it is today cannot be established, but apocryphal stories of feats of skill and of severe injuries are readily told by any older bush worker one might talk to (Preston, 1980, p.42-44).

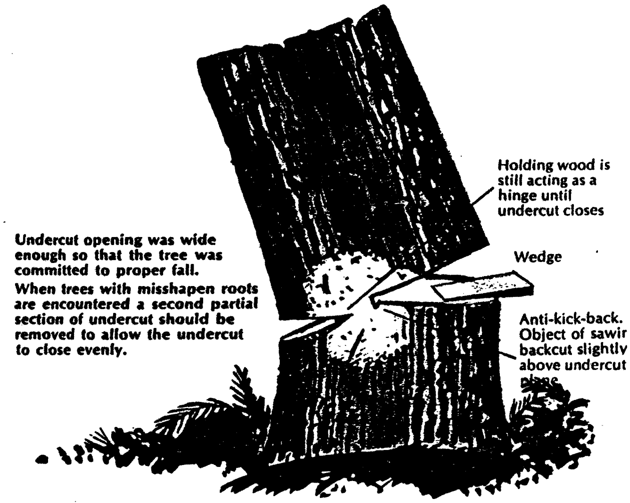
Today, just as in the past, there is little uniformity in the head or the barrel of many trees in a eucalypt forest, be it an old growth or a regrowth forest. Terrain and tree density can vary greatly while rot, defect, and fire damage bring added uncertainty to the situation. In forest conditions which may appear quite similar to the layman, the pattern of trees surrounding the work tree may be of critical importance to the feller and his task. Even if the hardwood feller carefully follows the stages of "safe working practices" in work-technique manuals as listed in Figure 3.2, it is not a fool-proof formula for a successful fall.

Felling a mature Australian hardwood in a natural forest with a chainsaw is not simply a case of following a Scandinavian felling training manual, or of using the North American style of cuts to the base of the tree. The job requires information processing skills and physical skills consistent with the demands of Australian forest conditions if it is to be carried out efficiently and without injury.

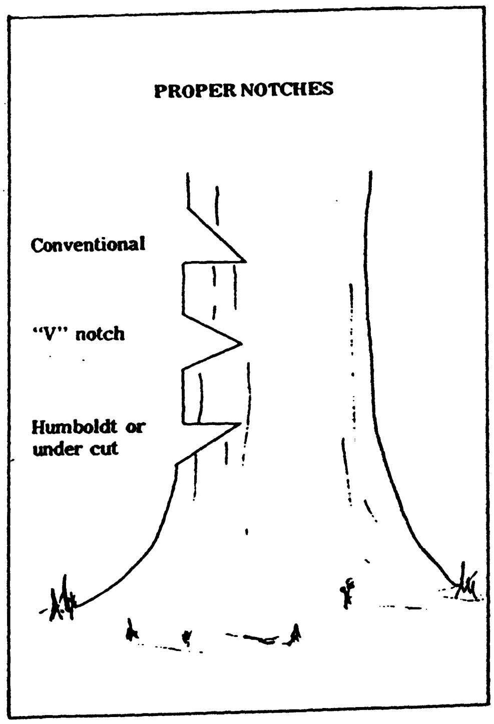
Several overseas felling work-technique manuals of varying quality and detail (e.g., Conway, 1973; Dent, 1974; FAO/ILO, 1980; Lidberg and Skaaret, 1966) describe techniques and practices considered to produce "safe" directional tree felling for their particular working conditions. Recommendations cover not only use of chainsaws and the manner in which cutting proceeds on the actual physical cuts in the stump of the tree, but appraisal of the tree and its immediate environment, estimation of where the tree will fall, preparation of escape paths, assessment and monitoring of risk during cutting, and retreat when cutting is completed and as the tree begins to fall.

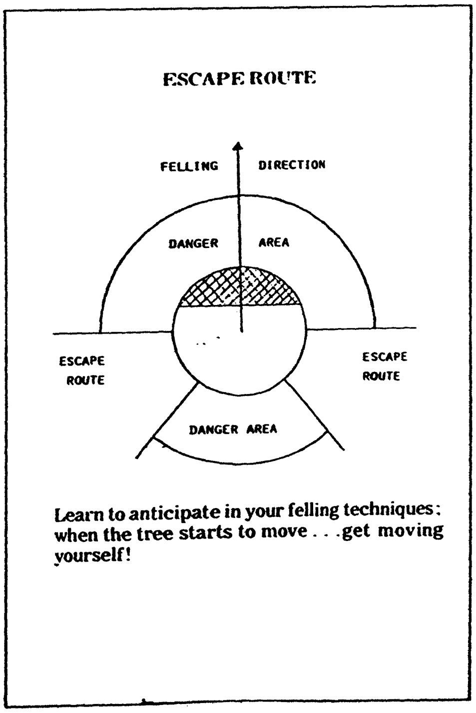
These manuals and books, as well as bush instructors themselves, emphasise how each natural felling situation is different with every tree being in some way unique. Unless a number of men have been observed trying to fell trees in a mature forest it is difficult to appreciate such an assertion. In rudimentary terms, tree felling involves "picking" the lean and then cutting of a wedge shape "scarf" out of the "front" of the tree to a depth of one quarter to one third the diameter. Cuts are then made into the "back" of the tree at a slightly higher level than the scarf cut until the tree begins to fall in the desired direction (see Figure 3.1). In the past, particularly difficult trees were "sighted", "laid-in", or "faced" using two equal length poles which were laid out from the corners of the scarf cut, with the apex of the triangle thus formed showing the precise direction of the tree's likely fall (Edlin, 1949). In modern work-technique manuals that are most relevant to the Australian hardwood situation (i.e., Dent, 1974; FAO/ILO, 1980) the essence of professional directional felling is seen as: the correct identification of the tree's natural lean; the choice of an achievable and low-risk fall; cutting a deep, wide angled, and clean scarf without over-cutting into the hinge wood; back cutting to achieve a strong, wide hinge that will "control" the fall of the tree in the chosen direction, as well as provide the correct height of step above the scarf to prevent the tree jumping back over the stump as it falls. In a forestry article on felling Australian eucalypts in particular, Crowe (1985) has discussed the practice of having scarfs deeper than one third diameter in trees such as the fast grown mountain ash to prevent the tree splitting longitudinally during back-cutting (the tombstone or barber-chair). As well as noting the problem of cutting wide-angle scarfs in large diameter trees, he presented data on the range of felling cuts adopted by a group of tree fellers in the Victorian ash country in Australia. For North American trees and forest conditions Dent (1974) shows diagrams of scarf angles close to 45^0 and recommends a depth into the tree of at least one third the diameter, while Conway (1973) shows scarfs of some 30^0 for the cutting of large trees and a similar depth. Defect can prevent cuts being put into the tree as fully as books on felling technique would suggest.





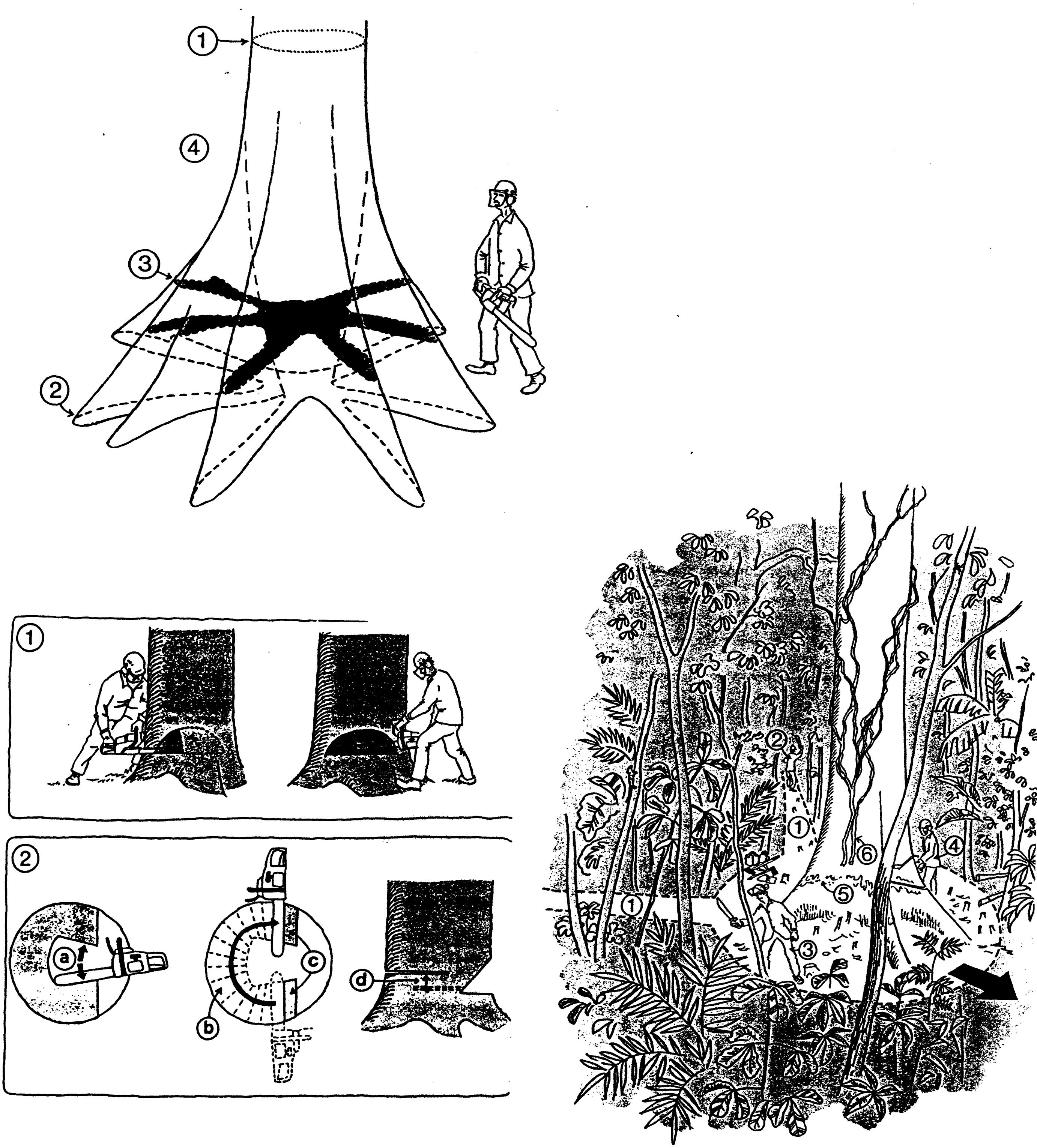
Fallers and buckers handbook (WCB/BC, 1977) p. 14, 16.





Proper felling techniques (F. P. A. P. A., 1981) p. 7, 22.

Figure 3.1 Diagrams of recommended felling cuts in large timber and hardwood.



Chainsaws in tropical forests (F A O 1980) p.27, 37, 41

Figure 3.1 (Cont.)

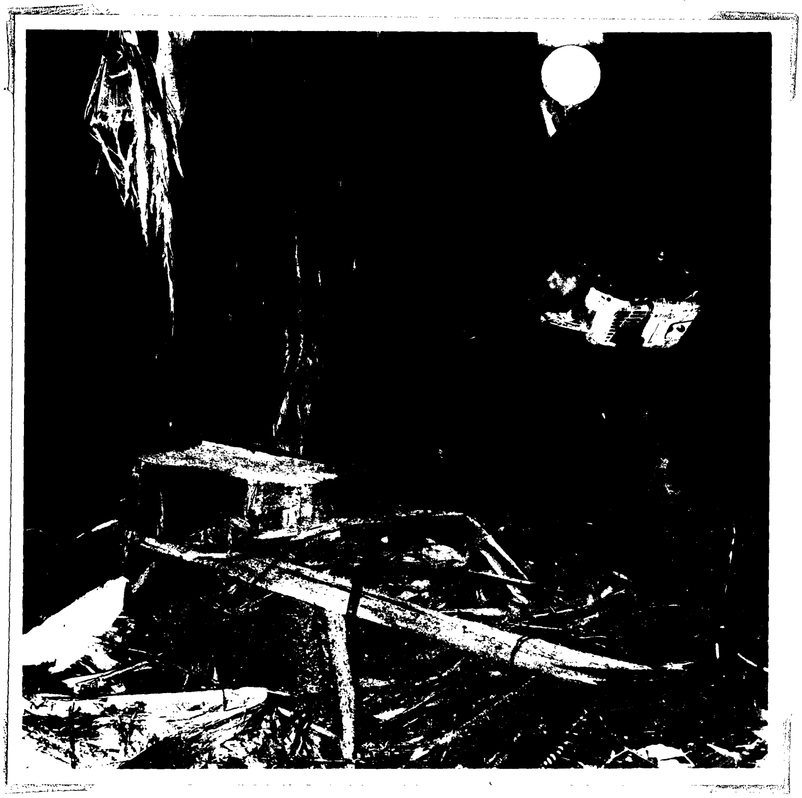


Figure 3.1 (Cont.) Two examples of differing felling cuts in smaller trees.

The usual stages or elements in the felling of a single tree, including aspects of special relevance to the eucalypt situation, are summarised in Figure 3.2. In order to investigate objectively some of the information processing and decision aspects of the job, the tasks need to be described systematically in a work-study type of approach as well as in terms of the more psychological ideas on skills analysis and error discussed earlier in the current chapter.

3.2.2 Reading the tree

Planning of a felling pattern is the first step in a low-risk felling operation when a professional bushman reaches a new area, even to the extent of walking around the block or coupe looking at tree density, predominant leans, problem trees, etc. This important aspect to felling should be mentioned even though the present chapter concentrates on the information processing within the felling of individual trees. The first stage in the actual felling cycle is that of judging the tree's natural lean during what is usually termed "reading the tree", and then deciding on a felling direction. The natural lean of the tree is said to be influenced by head and barrel lean (head and side lean in North America and Canada), and at least one work-technique manual claims that "correctly picking the [natural] lean is one half of the job" (Dent, 1976, p.48). The other half of the job might be seen as being able to readily achieve the over-riding goal of felling accuracy whenever it is required, as was emphasised in chapter 1 (p.28). In the initial stage of choosing a felling direction work-technique manuals suggest the man should take at least the shape of the tree crown and prominent branches into account, as well as the wind, the slope of the site, defect within the tree, and the shape of the barrel or trunk (e.g., Dent, 1974; FAO, 1980; WCB/BC, 1977). No guidance is given in these training documents as to the weighting and combining of such a catalogue of factors affecting the final choice of felling direction for the tree.

Many things militate against a straightforward "reading" of the tree. The tree may or may not have a straight trunk, the branches of the head may be deceptive as to where the heaviest limbs really are pulling (e.g., seemingly heavy and important limbs some 20 metres or more above the worker may contain a great deal of rot and thus carry little real weight), the slope and other trees close by may affect the perspective on the viewer and, for example, influence his judgements about the tree's "pull up the slope". Besides the overall size and shape of the tree as well as its apparent lean, the health of the tree and the amount of fire damage or defect in trees of that age and type are reported as important aspects in some felling decisions. The influence of visible or assumed defect in the tree stump can be a

Hardwood Felling: Work elements

1. "Read" the tree and assess the natural lean. Decide on certainty about the natural lean. Decide importance of prevailing wind conditions on fall.

2. Identify hazards in the head of the tree being fallen and of surrounding trees, including interlocking branches between trees, and hazards and debri on the forest floor.

3. Decide on a chosen felling direction or felling with the perceived natural lean.

4. Intuitively or overtly decide on how certain they can be of achieving their chosen option.

5. Intuitively or overtly rate the risk or danger of making the fall, and the difficulty making the front cuts.

6. Decide on and cut an escape path or paths, if considered essential.

7. Cut a scarf of a certain depth, width and shape. Make minor adjustment to the cuts, or in some cases decide on a minor change of direction.

8. Carry out the back cutting, and in rare cases decide on a change of direction during the cut. The placing of wedges or gluts during the back cutting. Sometimes cutting through part of the hinge as the tree falls.

9. Decide on remaining close to the stump or making a definite planned escape as the tree starts to fall.

10. Consciously or intuitively assess the success of their work in that fall or reasons for failure, to consolidate any new lesson on technique or hazard that may have occurred.

* Source: BC Workers Compensation Board 1977; FAO/ILO 1980; Dent 1979.
(Appendix 20 describes these work elements in more detail and is based on various versions of recommendations for "safe working practice" in larger timber felling e. g., Dent 1976, FAO 1980).

Figure 3.2 Basic work elements in production felling with mature eucalypt hardwoods.

particularly troublesome issue in the case of older trees. However, some experienced tree fellers suggest that the problem of defect is in most cases irrelevant, as long as there is enough solid holding wood on a few outer inches of the tree's circumference to support the felling hinge. Others maintain that the position of defect might have a major influence on the final choice of felling direction and the danger involved. The facts of the matter lie somewhere in between. With this sort of information-processing complexity and difficulty at the various stages in the felling cycle, it would be understandable if the men opted for one or two main cues as to their perception of the trees lean and felling direction in the real working situation.

When a tree is not fallen with the perceived natural lean it is termed a "pulled fall". Various names are given to the cuts used to pull a tree away from its perceived natural lean. The best known and most dangerous in the felling of larger tree is the "Swing Dutchman". Pulling a tree involves the manipulation of the hinge or holding wood in a stump away from the uniform pattern of cuts of the "normal" type of fall (see Dent, 1974, p.111, p.93-126). A number of tree fellers used the term "calculated risk" when discussing the felling of trees that were thought to be particularly dangerous or those needing to be pulled away from the natural lean. Such a precise term would seem inappropriate for the intuitive decisions the man is expected to make on the range of factors outlined above (section 3.2.2).

3.2.3 Risk while cutting

Once cutting has commenced at the actual stump, judgements about rot inside the tree, the weight distribution of the head of the tree, or the precise direction of the natural lean may turn out to be dangerously in error. On older trees the man will try to verify his initial assessment of defect within the tree from the way his chainsaw is cutting and the quality of the chips and "mud" or rotten wood fibre coming out of the cut. Thus, as the experienced man perceives the reactions from the tree itself, and senses the way the saw is cutting, he may suddenly realize he would have fallen the tree in an somewhat different way. As the man is half-way through cutting the back of the tree, for example, he may suddenly realise that the scarf he has cut is no longer appropriate, or that a tree he considered not relevant to the fall is suddenly dangerously close to where the tree may now fall. In this way the level of risk involved in a decayed or fire damaged tree in particular can change very rapidly once cutting in the front or back of the tree is underway. On such occasions the tree feller may feel he has simply compounded the original problem of felling a difficult tree, with the attendant increase in risk. Finally, once the tree begins to move the man cannot recover from any of his errors of commission or omission, but must escape along the 45^0 escape path which is enshrined in all work-technique manuals.

3.2.4 An exploratory model for field work

Chapter two examined some of the work physiology implications of the generic model of the factors that Lagerlof (1979) and other Scandinavian forest ergonomics researchers had considered important for low-risk tree felling performance. In the present chapter, the introductory review of the specific literature on field research into skilled blue-collar job performance (and error) firstly emphasised the naturalistic-observational nature of any strategy that might be adopted, and the importance of obtaining scales of measurement suited to actual percepts, decisions and overt activities of the men at work. Ideas and recommendations from the various work-technique manuals that were available formed a second source of information (Figure 3.2, Appendix 20). Last, but not least, preliminary field observations of the men working in different forest types and discussion with experienced instructors and workers helped clarify the more informational components of felling performance that appeared essential if the man was to stand the best chance of day-to-day survival. From these three sources it became feasible to question the assertion that (a) consistent hazard perception and assessment, (b) consistent felling accuracy, and (c) consistent escape reactions were basic skills that even highly experienced (and skilled) hardwood tree fellers would always have readily to hand. The exploratory model of felling behaviour underlying the tree-assessment part of the fieldwork can thus be summarised as follows: [1]

> Workers who can accurately pick the natural lean of the tree as the baseline for chosen felling direction; who respond with a variable and realistic perception of certainty and risk about different trees; who can (on demand) fall the tree where they have predicted with a high degree of accuracy, *[who can rapidly detect when a tree is beginning to fall abnormally - Chapter 4]*; who respond with a realistic retreat distance and position; and finally, who show evidence of learning from their errors will be the ones (all other environmental factors being equal) who will have the greatest chance of daily survival.

Because not all of the job elements in Figure 3.2 were readily measurable in the field setting, the research goal became one of moving from this exploratory model to measurements of the man's judgements and felling performance that would be

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1 FOOTNOTE: The assumption was made that each man had the ability to select a felling direction that would always minimise the chance of hitting other trees or dislodging limbs. A list of the suggested criteria for low-risk felling of eucalypts is given in full in Appendix 20.

Assessed	Job element Number (Fig 3.2)	Component
+Yes	1	(a) Perception and certainty regarding natural lean
no	2	- Indentify general hazards
+Yes	3	(b) Choice of actual felling direction
+Yes	4	(c) Certainty of success in chosen direction
+Yes	5	(d) Perceived risk & awkwardness of the felling
no	6	- Decide and make escape path
no	7	- Cut scarf (later stump measurement)
no	8	- Make back-cut (later stump measurement)
+Yes	-	(e) Outcome - A measure of felling accuracy
+Yes	9	(f) Retreat distances and direction
+Yes	10	(g) Self evaluation of performance

Figure 3.3 Final choice of field measures in S-tree assessment and felling.

feasible in the working situation. The final choice of measures that were attempted is given in Figure 3.3, with the rationale briefly described in the paragraphs that follow.

(a) Perception and certainty of natural lean:

Much is made in work-technique manuals (e.g., Dent 1974, p.58-63) and amongst tree fellers themselves of the need to determine the tree's natural lean before deciding on a final felling direction. For obvious reasons felling with or close to his perception of the tree's natural lean and pull of gravity is the man's preferred option, but this is not always possible in many native forest situations. Natural lean is a subjective judgement (even when it is assessed with a vertical axe handle or plumb bob) with no objective methods yet available to the tree-feller to determine this characteristic. A man's certainty regarding his perception of the natural lean of the tree might affect his choice of the final chosen felling direction. In this sense the men's perception of the natural lean and their confidence or certainty in the judgement is said to form the backdrop for their decisions and certainty about final felling direction.

(b) Choice of fall and certainty

In making a controlled fall the consistency of being able to specify a precise direction and achieve it is critical. The more accurate and consistent predictions are, the less likely it is that the worker will be caught unprepared during felling. The overall performance measure employed within the study was the average error between the chosen fall and the actual result across all the special test trees (hereafter: S-trees) that the tree feller dealt with. Discussion with felling instructors on the issue of certainty of achieving an accurate directional fall brought out two perspectives on the problem. Some men asserted they had to be as certain as possible about where a tree would finally fall if escape paths and options were to be properly prepared. Equally, it was suggested by several workers that the feller should never allow himself to be totally certain that a tree would fall in a particular direction. As one instructor put it, "you always have to be expecting the unexpected." The relationship between the feelings of certainty about the tree's perceived natural lean and the certainty of the men's chosen felling direction was an unknown factor. The question of equivocation and uncertainty about the felling direction was also important in planning the escape direction to a safe place, even if an escape path was not prepared in the physical sense. High ratings of certainty for achieving an accurate fall could have a positive or negative implication according to whether the tree was finally fallen accurately or not. The more certain the man was about achieving an accurate fall, when in fact the fall turn out to be inaccurate, the less prepared he might be for other eventualities.

(c) Perceived risk and awkwardness in making felling cuts

Two components involved in any risk situation are the probability of alternative dangerous outcomes to the presumed safe one, and the likely severity of the injury involved in the dangerous alternative (Vlek and Stallen 1980, p.237). The terms "danger" and "risk" of a fall were used interchangeably by the fellers. With the special S-trees in the field testing situation the expectation of the subjects was inevitably that of a controlled and accurate fall, for it would have been irrational for the man to have responded otherwise. Pilot study work had revealed that clear alternatives to a normal or safe fall would not often be volunteered by the men in these test conditions. When asked what might go wrong with the fall, the frequent response was that of being somewhat unwilling or unable to say what might happen other than the rather sensible global response that "anything could happen." Specific injury possibilities were not verbalised. Since it appeared that specific alternatives to a normal and safe fall would not be readily volunteered by the men, a rating of risk was considered to be one way to tap into any underlying anticipation of a bad outcome. Thus, in a similar manner to certainty about a fall, the less risk perceived for a subsequently inaccurate fall, the less the man's preparedness might be for unexpected events if felling error occurred. The awkwardness of making the felling cuts was considered an important issue in terms of the potential risk of the fall and this was confirmed by instructors. A rating of the perceived awkwardness of making the felling cuts could also be linked to the final outcome of felling accuracy.

(d) Actual target accuracy

From the point of view of work efficiency and safety, being able to achieve the chosen felling direction was the key end result of all the man's judgements and reactions to the tree. In the everyday working situation pin-point felling accuracy is not needed on every occasion. In many instances nominating a fall in terms of the eight points of the compass is sufficient. Only in the more demanding circumstances, which were observed throughout the study, will the need for such precise accuracy exist with the majority of the trees of the day. In the research situation the men were asked for their best performance in terms of accuracy on a special sub-set of trees, (S-trees), out of the total number of trees in the day's felling. This arrangement approximated the normal felling situation of fluctuating demands for accuracy in felling.

(e) Retreat distance

Based on the literature on injury in chapter 1 and the model previously described, retreat distance from the stump was an important behavioural outcome, while the direction of the retreat relative to the line of fall could also be a deciding factor in escaping injury. Any person remaining within three metres of the stump of a falling hardwood tree is in a very high-risk zone. For example, a study by the Western Australian Timber Inspectorate study found that some 73% of serious injuries to hardwood tree fellers occurred within 3 metres of the tree stump (WA Forest Department, 1974). While it was not possible to measure accurately these distances given the need for observations of spontaneous retreat behaviour and constraints of the field arrangements, they were subjectively recorded by an experienced forest technician in terms of three categories of distance away from the stump.

(f) Subjective evaluation of performance

The objective evaluation of one's own work performance is obviously of considerable importance in a job which is as high-risk as hardwood felling. If error was occurring then the man should have some awareness of this in the constant round of trial and error and adaptation that forms the basis of improved skill and remaining uninjured. The man's self evaluation of his performance after felling a tree (as described in the model p.103, and Element 10, Figure 3.2) could begin to indicate the level of feedback and self-correction that might exist in a group of men like those studied. In addition to the subject's rating of his own performance, and subsequent to the day's field measurement activities, the instructor-interviewer rated the research subject on what were seen as four key areas of basic job skill using a set of 7-point rating scales (Appendix 22).

3.3 Method

3.3.1 Subjects, field conditions, and S-trees

Details of the 39 subjects who provided felling performance measurements during the fieldwork are given in Chapter 2, while the location and description of forest types for each case are given in the map and descriptions of Appendix 21. The distribution of subjects within the three main forest types was as follows:

Eucalypt forest *(High quality ash type)*	13 subjects
Eucalypt forest *(Ash, Peppermint gum to scrub type)*	21 subjects
Temperate rainforest *(Brown top, Swamp gum, ash type)*	5 subjects

During the field day the subjects cut the normal run of trees as they worked their way through the forest. Within these trees there were also the smaller set of S-trees, which were more carefully selected for the feller to assess and cut down. While the work physiology preparations were taking place the instructor-interviewer and time-study technician went into the working area of the forest and selected a series of S-trees that were subsequently interwoven with the normal trees that were cut throughout the day. The goal was to have a representative range in S-trees in terms of size and felling difficulty for that particular work site. The criteria for this selection included having no more than one in 10 S-trees below 0.5 of a metre in butt diameter wherever possible. Trees were also not to contain widow makers that were likely to put the subject at excessive risk or decayed limbs that were obvious candidates to break away during a fall. At least two of these S-trees with the least risk possible under the particular conditions of the day were selected for oxylog measurements. On occasion the lack of normal diameter trees (between 1-2 metres) dictated that fewer than ten (but relatively larger diameter) trees were selected for the subject. In approximately two thirds of cases S-trees were selected taking into account instructor-interviewer's knowledge of the skill level of the particular subject. The subsets of all these S-trees were numbered and marked with a cross and number in luminescent paint.

3.3.2 Data collection and materials

3.3.2.1 Overall procedure

The four main methods and strategies involved in data collection were: a structured tree-assessment interview on each of the S-trees; compass bearings to the chosen felling direction (felling target), and the final direction of the fallen tree; video filming and time study observations; and measurement of tree characteristics and the cut tree stump. As reported in Chapter 2, preparations for other work physiology aspects of the study were undertaken at the beginning of the fieldwork day (p.35). Following these preparations the response cards and scales used in the S-tree interview were explained to the man, and questions dealt with (Appendix 22). A practice S-tree interview was also conducted with the subject at the log landing before entering the felling work site proper. There were seven main phases to the day's activities:

* Preparation of the subject and explanations of the day's procedures;

* The felling of normal non-interview trees throughout the day (work physiology), besides the set of S-trees;

* Tree-assessment interviewing at the base of the S-trees and the taking of compass bearings;

* Filming of the cutting of the S-trees prior to the actual fall;

* Film of the man's behaviour in the actual fall, including the choice of a retreat path;

* The instructor's debriefing of the subject after a fall.

The completion of paper and pencil questionnaires at the end day of fieldwork was a separate exercise from the S-tree and felling data collection (the questionnaires, their administration and results are fully described in chapter 2).

3.3.2.2 Filming the interview and fall

During the S-tree interview video film was taken from immediately in front of the tree with the subject facing the direction of his chosen felling direction and towards the interview camera. During cutting, views were taken from both sides of the worker, as undergrowth and surrounding trees permitted. In the actual fall, the camera was positioned at least 5 metres along and behind a 45^0 escape direction relative to the line of intended fall. The video filming and the direct time study observations enabled a permanent record of cutting behaviour and retreat that could be analysed in detail and cross checked at a later date. The camera was a National Panasonic NV-35 with matching portable VHS video recorder NV-3000, with the units being carried on the investigator's back and hip in aluminium frames and harnesses specially constructed for the research project. Figure 3.4 provides a schematic of the usual filming situation.

3.3.2.3 The S-tree questionnaire

A structured S-tree interview schedule provided a standard procedure for collection of these particular data, enabling a usually unverbalised pattern of decisions to be partially tapped in a consistent manner. The questionnaire was devised with a set of questions that were mainly answered using rating scales. Some open-ended questions were included in the instructor-interviewer schedule to deal with the qualitative judgements and information that interspersed rating questions. The instructor was at liberty to use these open questions, or any that he thought would facilitate the inquiry, as part of the natural flow of the conversation with a fellow tree feller. The interview prompt cards and rating scales were in transparent

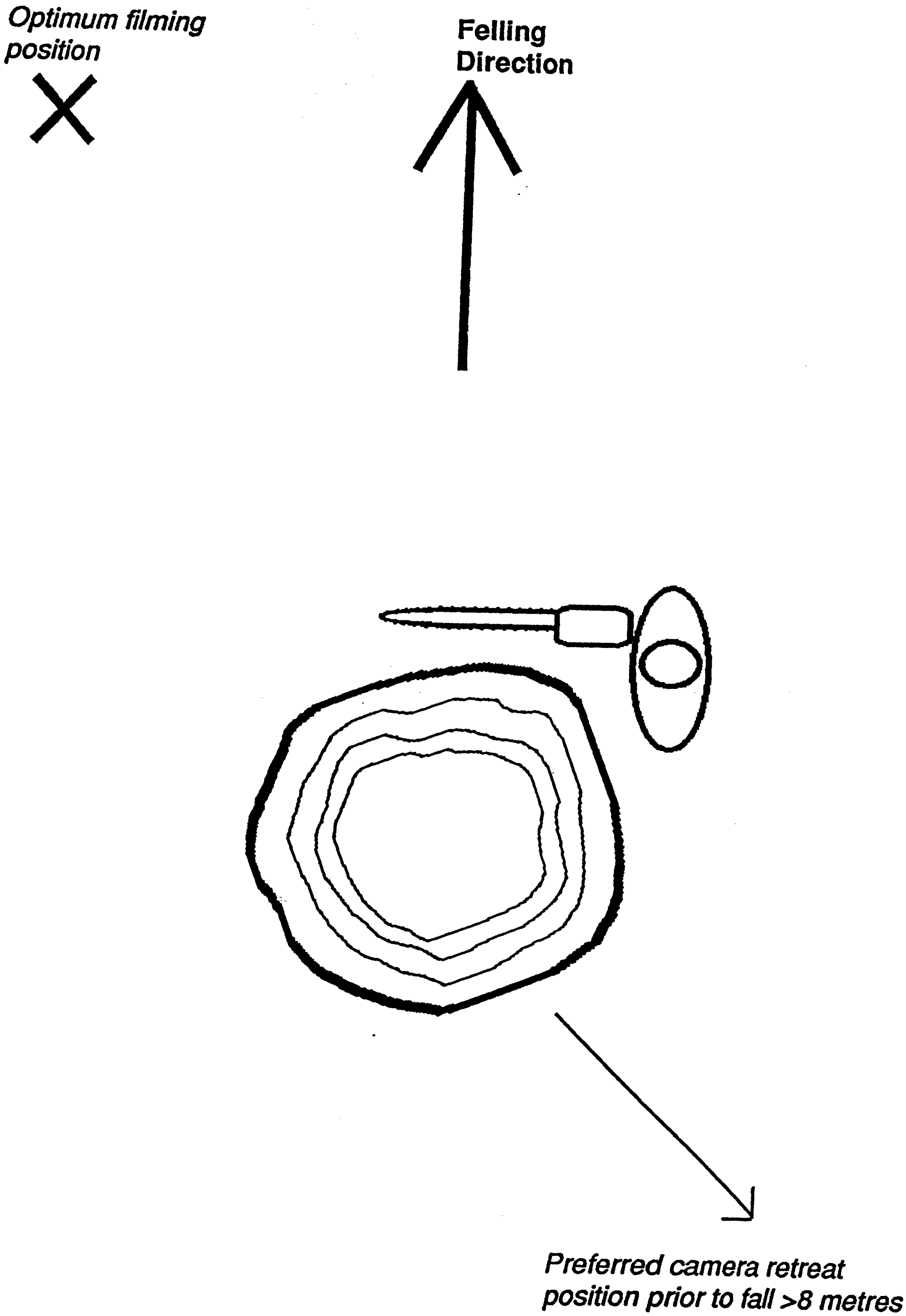

Figure 3.4 Diagram of the positions adopted in filming.

waterproof cases carried on a ring clip and lanyard by the instructor. The interview and subject's responses were filmed (S-tree questionnaire, pro-formas and checklists used in fieldwork are reproduced in Appendix 22). An expert felling instructor was used for the field interviewing for three main reasons: first, to facilitate rapport with a sometimes reticent subject who was being filmed for the first time talking about his ideas on felling; second, to have a knowledgeable person who could use the open-ended part of the interview schedule to best advantage; third, to have a knowledgeable person who could guard against attempts at felling that might be too risky, either for the feller or the research team. The instructor-interviewer was given some additional training to augment his previous interviewing experience as a felling instructor and police sergeant. Questions and their operational definitions were as follows (see Appendix 22):

Question 1 - "*Initial thoughts on the fall*". An initial open-ended question was one requesting the man's "first thoughts on the tree as he walked up to it." The main questions then followed.

Question 2 - "*Identification of the tree's perceived natural lean*". The feller was asked to nominate the exact direction in which he believed the tree would naturally fall if it was cut straight through by indicating a particular feature in the environment such as a bush, rock, tree stump, etc where the centre of the main trunk beneath the head would land. In cases of indecisiveness or in open terrain, the forest ranger moved to a precise spot indicated by the man, and the compass bearing of this spot was then recorded.

Question 3 - "*Main factors thought to be dictating the tree's natural lean, particularly the relative importance of either the head or the barrel lean*". The major factor or factors thought to be dictating the natural lean of the tree were also requested in an open ended question if they had not already been volunteered by the subject.

Question 4 - "*Certainty regarding the direction of natural lean*". Using a rating scale from 0 to 100% with 5 point increments marked on it, the feller was asked to indicate how certain he was that the tree would fall naturally in the direction he had predicted.

The use of any value between 0 and 100% for their certainty was emphasised to the men. Certainty had been defined to the men at the beginning of the field day, using the same 0 to 100 analogue scale with an example of the subject's own certainty of predicting rain the following day.

Question 5 - "*Choice of where the man would attempt to fell the tree*". The feller was asked to nominate the exact direction in which he believed he could fell the tree by indicating, as before, a particular feature in the environment where he felt the centre of the top of trunk of the tree would hit the ground.

Question 6 -"*Certainty of outcome in the chosen felling direction*". That is, how confident the feller felt about the tree falling directly as he had predicted. Using the same rating scale from 0 to 100, the feller indicated how certain he was about hitting the target point in his chosen direction.

Question 7 - "*Perceived risk*". The risk was defined for the men as follows: "By risk we mean the likelihood of you being hit by branches, rubbish on the ground, brushed by the tree as it falls, that is, an accident or near-accident of any type." A 6 point rating scale was shown to the subject with responses ranging from "No risk at all" to "Extremely high risk" and the subject was asked to nominate a specific category with every tree. Open-ended questions on ground debris and other hazards were also canvassed by the instructor-interviewer where appropriate to the situation (not reported here).

Question 8 - "*Awkwardness of making cuts*". Awkwardness was defined for the men as follows: "By awkward we mean the awkwardness of placing the cuts to make sure you will hit the target spot you have chosen." The responses to the awkwardness question were made on the same type of six point rating scale from "Not awkward at all" to it being "Extremely awkward" to place the felling cuts in the tree".

Question 9 - "*How well the man himself thought he had performed the felling operation*". After the tree had fallen, and to conclude the interview, the man was asked how he felt the fall had gone in general terms. He was then asked to specifically rate the fall (and his felling performance) on a 7-point scale from "bad"... through not-quite-right", to what he felt was ... "perfect" or "spot-on" (Appendix 22).

3.3.2.4 Felling accuracy and retreat distance

Compass bearings of the perceived natural lean and chosen felling direction during the S-tree interview were taken by the forest technician who stood immediately behind the interviewee as the different directions were nominated. The final resting position or bearing of the tree was again recorded by the forest technician who had taken the compass bearings of the natural and chosen felling direction. Felling, or target, error was derived from the actual fallen position of the tree based on the judged centre line of the trunk at the head junction and from the previous bearing for the chosen felling direction. Felling error was defined as:

> "An objective measurement of the discrepancy between the man's chosen direction and where the tree actually fell."

To compensate for measurement error, any values for felling error (the difference between the Chosen - Actual felling direction) below 5^0 were disregarded during analysis. As previously emphasised absolute target accuracy with every tree is not typical of normal working conditions. In such cases as open terrain with large distances between trees, for example, accuracy would not be required. However, in this study only five subjects were judged to be working in such open conditions. Appendix 23 provides a better idea of the range of tree density commonly encountered. As already reported in detail in Chapter 2, time studies were made on both the normal and the S-trees by a forest technician with many years experience in such work. The technician also recorded the tree feller's retreat distance, using the categories of 1-2 metres, 2-4 metres and greater than 4 metres, and estimated the man's general direction of retreat relative to the actual felling direction of each tree.

3.3.2.5 Tree and stump measurement

Once the tree had fallen and the area was declared safe, the forest ranger and marker measured overall tree length, log length to the first prominent head limb, and overall length of the head to the nearest meter. Mid-diameter and log length were then used to calculate estimated volume from the Forestry Commission tables commonly used for this purpose. The tree stump diameter was measured in two directions in line with the scarf and at 90^0 to it and the average of the two measurements used. The depth of scarf relative to diameter was also measured as well as the inclusive angle of the scarf of wood cut from the tree. Other stump measurements included the hinge width on both sides of the periphery of the tree to the nearest centimetre, and the height of the hinge wood from the scarf line to the level of the backcut, again on the left and right side (see figure 3.1 c). The scarf bearing was measured at right angles to the line best representing the intersection of the two scarf cuts in the stump. At a later stage the amount of defect in each trees stump was assessed from photographs of the stump taken after the fall, and/or from a sketch of the defect and rot in the stump made by the forest ranger on his tree measurement pro-forma. Grading was made on the basis of the overall tree shape being split into eight segments using perspex gauges made for the purpose. These measurements of tree length, girth and dimensions of the stump provided an overall specification of each tree that could be associated both with the perceptions of it by the subject and the final outcome of felling accuracy.

3.4 Results

3.4.1 The sample of S-trees

Following the brief description of the S-trees used in the field tests, the results of the interview and felling measurements are reported in the same order of information as is laid down in Figure 3.3, which lists the final field measures adopted. In all, the felling of 266 S-trees were studied across the 39 field data subjects. Four of the subjects had 9 - 10 S-trees for study, with 70% of the group having 6 - 8 S-trees. Five subjects had only three S-trees, albeit mainly of larger diameter (see Appendix 24). The main characteristics of the S-trees where tree-assessment interviews took place before felling are given in Table 3.1. Some 50% of the trees were between 50 to 100 cm in butt diameter (dbh - diameter at breast height) and 42% between 101 and 200 cm butt diameter, while of the remainder the three largest S-trees were over 320 cm in diameter. The most common tree height was 25-26 metres. The falling time was the average of three measurements taken from the video film of the felling episode.

Table 3.1 The range of S-trees in the felling tests.

All 266 S-trees	X	SD	Range
Height (metres)	29.1	11.7	6 - 69
Volume (tonnes)	9.0	10.7	1 - 87
Diameter DBH (cm)	113.8	52.7	24 - 350
Falling time (seconds)	5.8	1.7	<2 - >9

Close to half the S-trees (128 trees) were classified by two independent judges as having a noticeable degree of internal defective wood and decay, with 30% of the trees having at least two of the eight sectors of the tree classified as unsound. Only 22 of the 266 trees had over half the tree stump (four or more sectors) graded as defective. In terms of defective wood on the circumference of the tree a smaller number of trees, 75 or 30% were classified as having at least one sector of defect. The complete distribution is shown in Appendix 25. The correlation between the subjective grading of internal defect and circumference defect was high ($r = .81$, $n=260$, $p < .001$). The grading of the roundness of the tree's circumference at stump height had a much more varied distribution across trees than the assessments of defective wood in the stump, with 165 or approximately 60% of the trees being judged as having more than half the stump uneven in shape, and fewer than ten trees having the sort of cylindrical circumference typically found in Scandinavian or Australian softwood, such as *Pinus radiata* (Appendix 26 shows typical examples of the tree stump qualities of shape, defect, and irregularity once the tree was cut).

The major types of scarf shape cut by the men (see Figure 3.1) were the conventional scarf (57%), followed by those classified as v-notch (23%), with the humbolt or undercut being least used by the group (20%). The distribution of the type of scarf in the set of error trees closely followed the same pattern. The distribution of the angle of the scarf that was cut out of the trees as well as the depth of the scarf cut into the tree as a percentage of the average stump diameter is also given in Appendix 27.

3.4.2 Certainty of tree falling direction

3.4.2.1 Influences and natural lean

The first concern of the fieldwork model was the confident and (accurate) perception of the natural lean of the tree (p.103), a perception which is reported as often forming the baseline or background to the final choice of felling direction. The pattern of direction found for the perception of natural lean in the S-trees was varied with no particular part of the compass taking main priority in the men's choices in terms of an analysis of quadrants, or the eight points of the compass (Appendix 28). Three prominent groups of responses emerged from content analysis of answers to the open-ended question on the main influence on the trees lean. These confirmed the barrel and head pull dichotomy found in work-technique manuals. The choice of a main barrel pull occured for 81 or (34%) of the trees. A general pull of the head covered 38% of comments, with a small number (16) nominated as a heavy head pull. The combined influence of head and barrel acting together in a tree were seen as dictating lean in 15% of the responses. Only one tree out of the 266 had wind as a major influence on where it would fall naturally. Thus in approximately 85% of the trees the men appeared willing to report influences on a tree's natural lean in these somewhat global terms.

Ratings of certainty for the perceived natural lean of the tree were obtained for 184 trees. Close to one third of these cases reported complete uncertainty about the exact direction of the natural lean of the tree. The apparent conflict between the willingness to respond in terms of the global influences on the tree's direction and the significant amount of uncertainty with a specific rating scale is difficult to explain. Possibly the habit of intuitively picking head or barrel lean does not equate to an aided decision on precise natural direction using a rating scale. All judgements about the natural lean of the tree below a 50% level of certainty were termed equivocal or the 50/50 decision point, while high certainty was defined to be that above 95% level. Overall nearly half of the obtained certainty ratings for natural lean were at or below the equivocal decision of a 50/50 rating. Only a few trees were given certainty ratings for the natural lean which were rated above 95% certain while none of the trees received a 100% rating of certainty about their natural lean. This extent of uncertainty about the natural lean had not been expected from discussions with instructors and experienced men or from inspection of the training manuals, which tended to imply that a tree-feller could easily pick a natural lean with a high degree of accuracy (e.g., Dent, 1976 p.48-50). The results support earlier comments in the thesis of the complexity of cues in the tree "reading" situation.

3.4.2.2 Chosen felling direction

The pattern of direction for the chosen fall across the whole group of men showed a similarly even distribution to the points of the compass as that found for natural lean, with only a slight preponderance in the men of choosing to fall to the north-west sector (34% of falls) (Appendix 28).

Certainty ratings for the chosen felling direction were obtained for 230 falls (Table 3.2). An initial expectation was that there would be high certainty in natural lean and less certainty about achieving an accurate fall. However, the distribution of the ratings of certainty for natural lean was significantly different from that for chosen fall ($\chi^2 = 61.92$, $p < .001$). In comparison with the certainty ratings for natural lean a significantly higher proportion of the chosen falls were given a full 100% certainty of success i.e., zero vs 21%. As might be expected, there were no cases were the man was completely uncertain about achieving the direction of his chosen fall. Only 12% of the 230 trees were below a 50% certainty for the chosen fall, with the large majority well above this value (Appendix 29).

Table 3.2 Frequency distribution and the differences between the certainty ratings for the natural lean and the chosen felling direction.

	Proportion of group *			
Certainty Rating	Natural lean (n=184)		Chosen fall (n=230)	
	N	%	N	%
0 to 5%	53	(29%)	0	zero
6 to 49%	15	(8%)	27	(12%)
Equivocation	*Equivocation {37%*		*vs*	*12%}*
50 to 95%	108	(59%)	143	(62%)
96 to (98%)	8	(4%)	11	(5%)
(100%)	0	zero	48	(21%)
High Certainty	*High Certainty {4%*		*vs*	*26%}*

* figures rounded to whole numbers

Table 3.2 provides an overall comparison of the distributions for classes of certainty rating for the chosen felling direction and the perceived natural lean, where the equivocal assessments about certainty of natural lean were three times that of the certainty of chosen direction, i.e., 37% Natural vs 12% Chosen. Similarly, the proportion of cases of almost complete certainty (above 95%) was far greater for the chosen fall than for the Perceived natural lean, i.e., 4% Natural vs 26% Chosen.

The overall mean values for the two types of assessment were $51^{+}/_{-}4$ for certainty of the natural lean, and $75^{+}/_{-}22$ for the certainty of the chosen fall. There was no correlation between certainty for the direction of natural lean and for the certainty for the chosen felling direction in the total group of trees that were studied ($r = -.06$, $n=184$. $p > .05$). The major differences between certainty about the natural lean and about the chosen felling direction across all trees were to be found in the "high" and "low" regions of the certainty scale.

The operator's choice of a felling direction was exactly the same as his perception of the natural lean of the tree in some 60% of cases (160/266 trees). In this set of trees where the perceived and chosen direction was precisely the same, a close association between certainty of perceived lean and chosen direction might be expected. This was not the case ($r = -.09$, $n=115$, $p > .05$).

Where the subjects had very low or completely uncertain judgements about the natural lean, they might have seen the tree as particularly dangerous and capable of falling spontaneously in any direction under the minimum of disturbance. Alternatively, they may have seen the tree as straight and evenly balanced, and capable of being worked on so that the tree could be controlled and felled almost anywhere. Quite clear results emerge (Table 3.3).

Table 3.3 Certainty of accurately achieving chosen fall when the certainty of natural lean is zero (n=50).

Certainty Value	Frequency N	Percent %	
20	1	2	
40	1	2	50/50 Cut off
60	3	6	
70	2	4	
80	5	10	
90	2	4	86% >80 certainty level
99	1	2	
100	35	70	

Taking the 50 cases of a total lack of certainty about the natural lean only two of the judgements for chosen falling direction on these trees were below 60% certain and most were high, mean 91% certain. This suggests that the men generally perceived non-leaning trees as balanced and capable of being felled in a wide range of chosen direction, possibly feeling for example that they did not have to combat an awkward lean. The objectivity and reliability of these perceptions of natural lean will be discussed in the felling error section.

In summary, these tree fellers were more certain of the tree's direction when they were intervening and possibly felt in control of the tree's chosen direction. Particular levels of certainty about the trees natural lean were not mirrored in the man's certainty about the chosen fall, even when in the same direction. Although the chosen felling direction followed the perceived lean in the interview schedule, there was the possibility that some men will sub-consciously decide on chosen felling direction before their first overt interview choice of the tree's supposed natural lean. Thus the men's supposed perception of natural lean at the start of the S-tree interview may have been subconsciously following their preferred felling direction from when they first looked at the tree. When the direction of natural fall was reported to be completely uncertain the certainty about chosen felling direction was much higher than in any other circumstance, which is again contrary to the folklore within work-technique manuals.

3.4.3 Risk and awkwardness

Following the questions on perceived lean, felling direction, and certainty, ratings of the risk involved in the fall and the anticipated awkwardness of making the felling cuts were obtained before the man began to cut the tree. The risk and awkwardness rating of each fall gave skewed distributions towards the low end of each six point scale (Figure 3.5). As is shown in Table 3.4, over 60% of ratings of risk are at or below the value 1 of a ("small level of risk"), while some 80% of ratings were not beyond the value 2 of a ("moderate level of risk"). These low ratings of risk are in contrast with the more varied judgements on the certainty of achieving a good fall, but they do seem to support the self-evaluation data reported below in terms of high certainty of success being linked to low perceived risk. Only 17 trees or 7% of the total sample of S-trees were rated as "a great deal of risk" or "extreme risk". On the rating of the awkwardness of cutting and positioning the felling cuts almost half the trees were thought of as " not awkward at all" with 86% at or below the third value of "moderately awkward". A similar skewed distribution to the risk ratings was found for awkwardness of making the felling cuts. The correlation between the risk and awkwardness scales, $r = 0.53$, $n=244$, $p < .001$, was probably

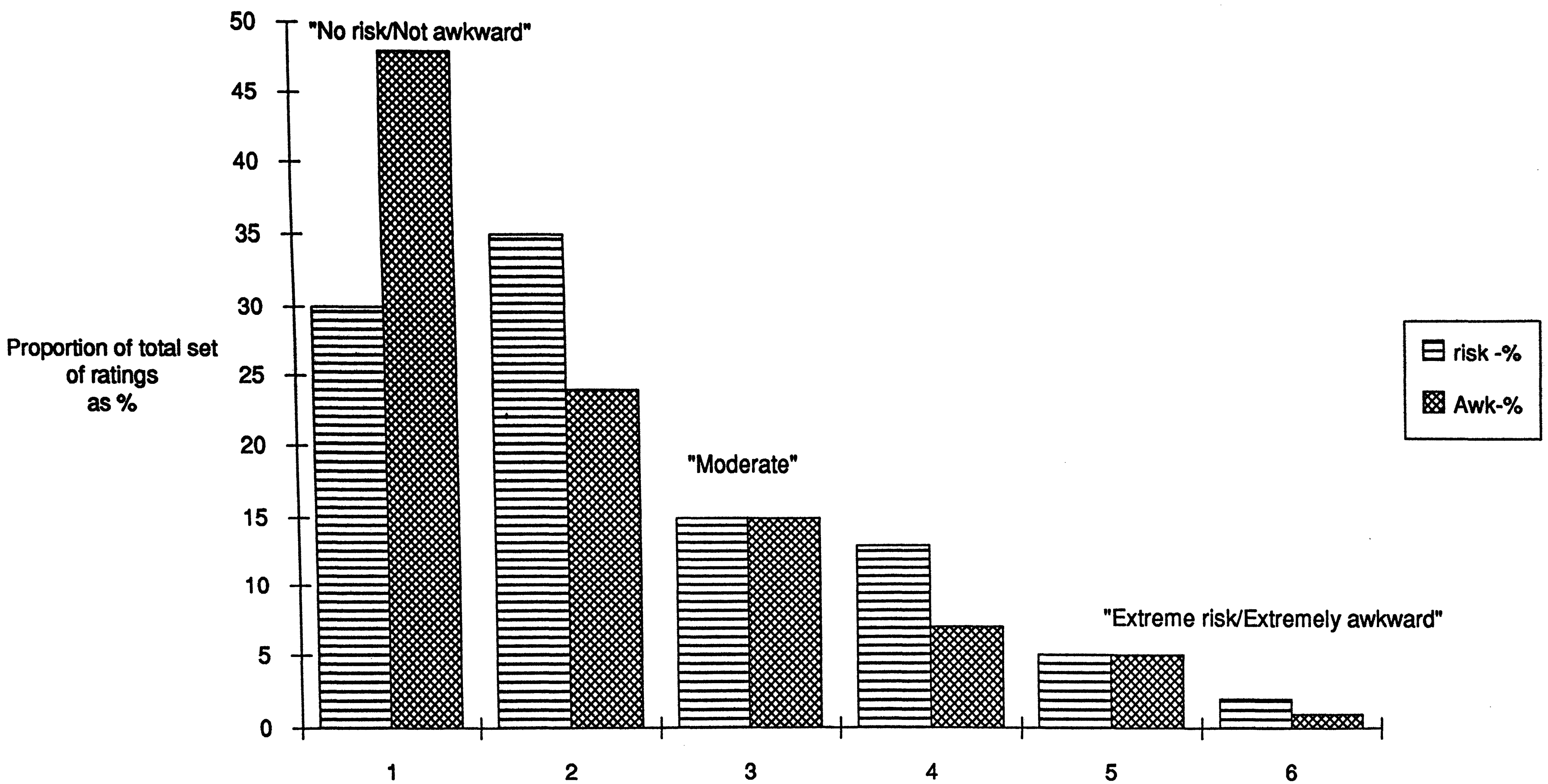

Figure 3.5 Distribution of the rating of "risk of the fall" and of "awkwardness of the felling cuts" over a 6-point scale (n=244 trees).

as a much an artifact of the restricted range of the two rating distributions as evidence of a response set.

Table 3.4 Ratings of felling risk & awkwardness of making the felling cuts (n=244 trees).

Label	Freq	Risk	Awk	Freq	Label
	N	%	%	N	
1.No risk	73	30	48	117	Not awk.1
2.Small level	85	35	24	58	Slightly.2
3.Moderate risk	37	15	15	36	Moderate.3
4.Quite a bit	32	13	7	18	Quite awk.4
5.A great deal	13	5	5	13	Very awk.5
6.Extreme risk	4	2	1	3	Extremely.6

The consistently low risk ratings across the majority of subjects and virtually 80% of trees may demonstrate the simple coping mechanism of denial about the obvious felling dangers and difficulties observed during field work. As far as the Tasmanian rural logging worker is concerned, minimising the perceived risk is one response to remaining in a regular job when few other local employment opportunities exist. However, the results are consistent with research of Ostberg (1980) who studied perceived risk in felling scenes shown to Scandinavian tree-fellers. An alternative is the man does not attempt to make a general judgement on risk, but tends to concentrate on specific issues in the fall related to the risk. The present results are interesting because they came from the actual working situation and not a questionnaire or pictorial simulated-risk test.

3.4.4 Tree felling error

3.4.4.1 Extent of the problem

A major question of the felling behaviour investigation was how frequently the tree did or did not fall precisely in line with the man's chosen felling direction. Of the 266 S-trees studied, close to half (n=135, 51%) had noticeable target error greater than 5^0, and in this large group of inaccurate and potentially dangerous trees the majority (n=90, 67%) were ones where the chosen felling direction was the same as the man's perceived natural lean. The sub-group of error trees was similar in terms of physical characteristics to those of the main group. Height was $27.5^+/_-11.2$ metres, estimated volumes ranged from 1 to 85 tonnes, and diameters were similar in range. The distribution of falling time was the same, $5.8^+/_-1.6$ seconds (Appendix 30).

The use of group data should not detract from the important point that each tree felling episode was a distinct event in its own right, with an objective level of hazard for the worker, no matter what their own subjective rating of risk might be. The distribution of tree felling error for cases up to one sector (< 45^0) of the felling circle is given in Figure 3.6. Felling error occurred across almost the whole range of felling conditions and men, despite instruction to achieve maximum accuracy in each S-tree fall. The majority of felling errors were in the sectors up to 20^0 (103 trees, 77%). The 11 cases with felling error beyond 60^0 included an number that fell backwards over the scarf line (Appendix 31). Though the plateau at 10^0, 19^0 and 20^0 in Figure 3.6 are artifacts of "rounding-off" of the compass bearing taken by the forest work study technician, the errors are well above the 5^0 measurement-error limit that was set in the study. This amount of measurable error in half of the sample of S-trees is more than enough to create major hazard under close felling conditions. As might be expected, felling error showed considerable variation both between subjects and within a particular subject's set of S-trees. The extent of felling error plotted against the certainty of obtaining the chosen felling direction is shown in Figure 3.7 for the cases up to 45^0 error. As can be seen, a wide range in certainty about a fall exists across the whole spectrum of felling error; for example, see the range of certainty among the seven readings at the 10^0 error point, and the similar range in certainty in the readings at the 40^0 error point. For the error set of trees the correlation between certainty of the chosen direction and error was not significant, $r = -.15$, $n=121$, $p > .05$. In the eight instances in which the tree fell fully backwards from the scarf line such extreme error was generally not anticipated. The mean certainty of felling direction for five of these backwards trees was above 90%, and the remainder ranged between 20-50% certain (overall mean certainty of all eight backward trees 72%). There was no evident relationship between felling accuracy and age, experience of the eight separate subjects involved, or the certainty of fall or degree of pull involved in the fall (Appendix 31). Such relatively rare events might therefore be seen as the random near-accidents discussed in chapter 1 of the thesis (p.15).

Physical measurement of the cuts in the tree stump included the dimensions of the scarf cut out of the tree and the scarf angle, the width of hinge wood, and the height of the step between the bottom face of the scarf and the backcut. The angle of the scarf was not related to felling error. Only the maximum depth of the scarf into the tree was correlated with felling error, $r = .17$, $n=105$, $p < .05$, although the more meaningful depth of scarf as a percentage of estimated diameter was not significantly associated with felling error (Appendix 32). The gradings of defect in the stump or on the tree circumference were not associated with felling error.

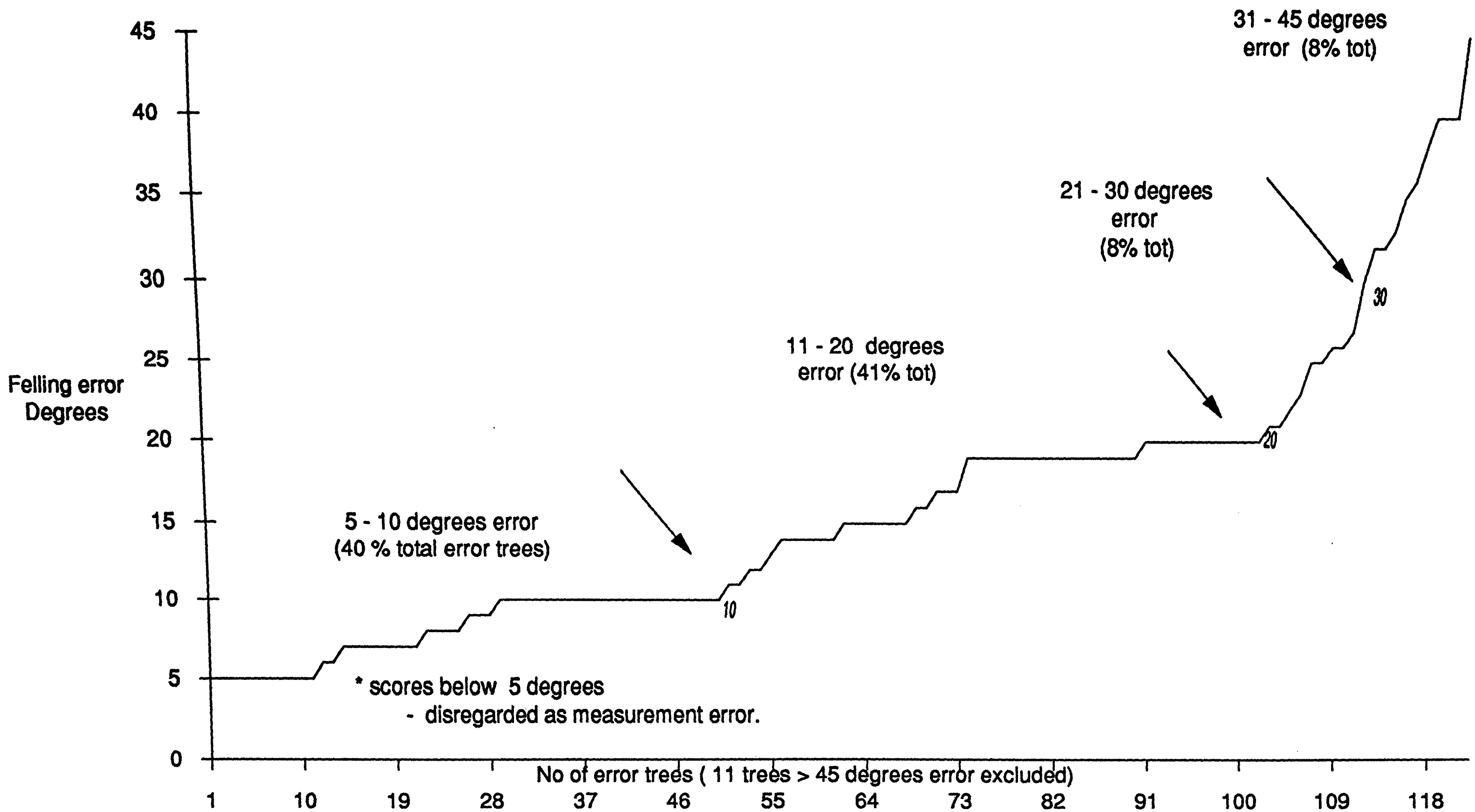

Figure 3.6 Distribution of felling error - by trees - up to 45 degree error.
(Approximately 50% of total S-tree sample)

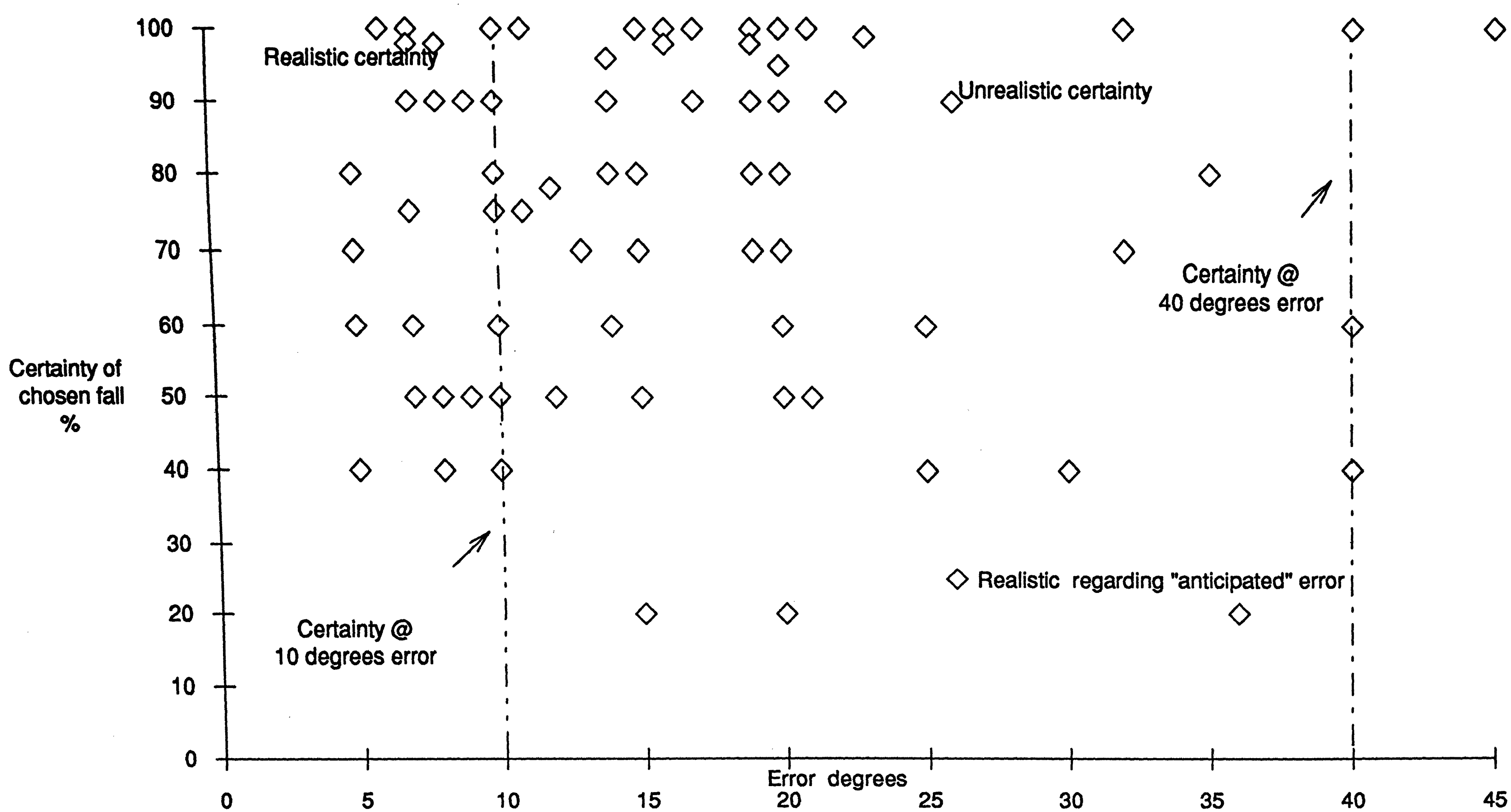

Figure 3.7 The wide range of certainty against final felling error
Hope versus reality - for the specific error group.

The line of the scarf cut could be determined after the fall in approximately 70% (n=185) of the total sample of trees. The final compass bearing of the fallen tree was within 5^0 of the direction of the physical scarf line on the tree stump in some 114 (62%) of this sample. This left a significant proportion of trees that could not be seen as closely following the direction of the line of the physical scarf. In the set of 135 error trees the bearing of the scarf line on the stump was obtained in 95 trees (70%). Within this error sub-group, the final compass bearing of the fallen tree was within 5^0 of the physical line of the scarf-cut in the stump for 61 trees (64%). Thus, in some 34 (36%) of these trees the direction of the fallen tree deviated from the physical scarf line by more than 5^0, with most over 10^0 away from the bearing of the scarf line and six trees with a discrepancy of more than 30^0. These results confirm that a significant proportion of trees in the production situation are still likely to be diverted from the physical scarf-cut line by such factors as dominant limb weight, severely conflicting head and barrel lean, sloping scarf faces, lack of a bite out of the front of the scarf, the tree possibly rotating on the way down, or the tree propping on a major limb and falling away from the bearing of the physical scarf line in this manner. [2]

3.4.4.2 Mean error

Although approximately half of the total number of S-trees involved measurable felling error, 34 out of the 39 men had measurable target error in one or more of their S-trees. Only five men were deemed to have placed all the trees in their particular set on the target area they had specified. The number of men in the different categories of average felling error is given in Table 3.5 (a). Over 80% of the subjects were within the 10-30^0 range of average felling error, with two thirds of the men having an average tree felling error of between 10 and 20^0. In practical terms even the minimal figure of 5 - 10^0 error means the difference between a clear fall and a major risk of other trees being hit or large limbs being thrown back towards the man. A classification that places the men into discrete groups of the proportion of trees in a man's S-trees set involving error is provided in Table 3.5.

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2 FOOTNOTE:The post-fall stump and scarf line measurements were made by the forest ranger as opposed to the workstudy forest technician who had previously recorded the natural, chosen and actual felling directions during the S-tree interview.

The largest group was men where 26-50% of S-trees in the set were error trees. Close to one quarter of the men had 50% or more of their set of trees with noticeable error in the fall. Though a significant number of men had both large average target errors and a large proportion of trees in their total S-trees set with target error, there was no significant relation between average target error and the proportion of trees that suffered noticeable target error ($r = .13$, $n=39$, $p > .05$).

Table 3.5 Number of men in each class of "Average Felling Error" and number of men with a particular "Proportion of Error Trees" in their S-tree set with noticeable felling error.

[a] Number men in each class of Average Target Error for all S-trees			[b] Number men in Groups with Certain Prop of Error Tree		
Average error	Fellers N	As a % group	Fellers Proportion of trees	N	As a % group
No error	= 5 men	13%	No error trees	5	13%
$5^0 - 20^0$	= 26 men	67%	up to 25%	2	5%
$21^0 - 30^0$	= 6 men	15%	26% to 50%	18	46%
$61^0 - 90^0$	= 2 men	5%	51% to 75%	10	26%
			76% to 100	4	10%

In some cases there were seven trees on target and only one in error, while in others, there were three out of four trees with felling errors between $10\text{-}20^0$. For example, there was a case of the subject who had one tree with close to 90^0 error, while his other two large trees were without error (S15). Another worker had one tree with a 60^0 error when it was being pulled from the perceived lean by 35^0, while his remaining seven trees were without error even though one of them was being pulled 65^0 from the perceived lean (S36).

3.4.4.3 "Pulled" trees

Of the full complement of 266 S-trees, 83 trees (31%) were pulled cases; that is, for nearly a third of the trees the men were attempting to fall the tree away from the natural lean as they subjectively perceived it. A comparison of the pattern of felling error between the three key groups of: (i) overall error group; (ii) error group where the perceived lean and chosen fall were the same, and; (iii) error group for pulled trees is given in Figure 3.8. There was little difference in the pattern of felling error

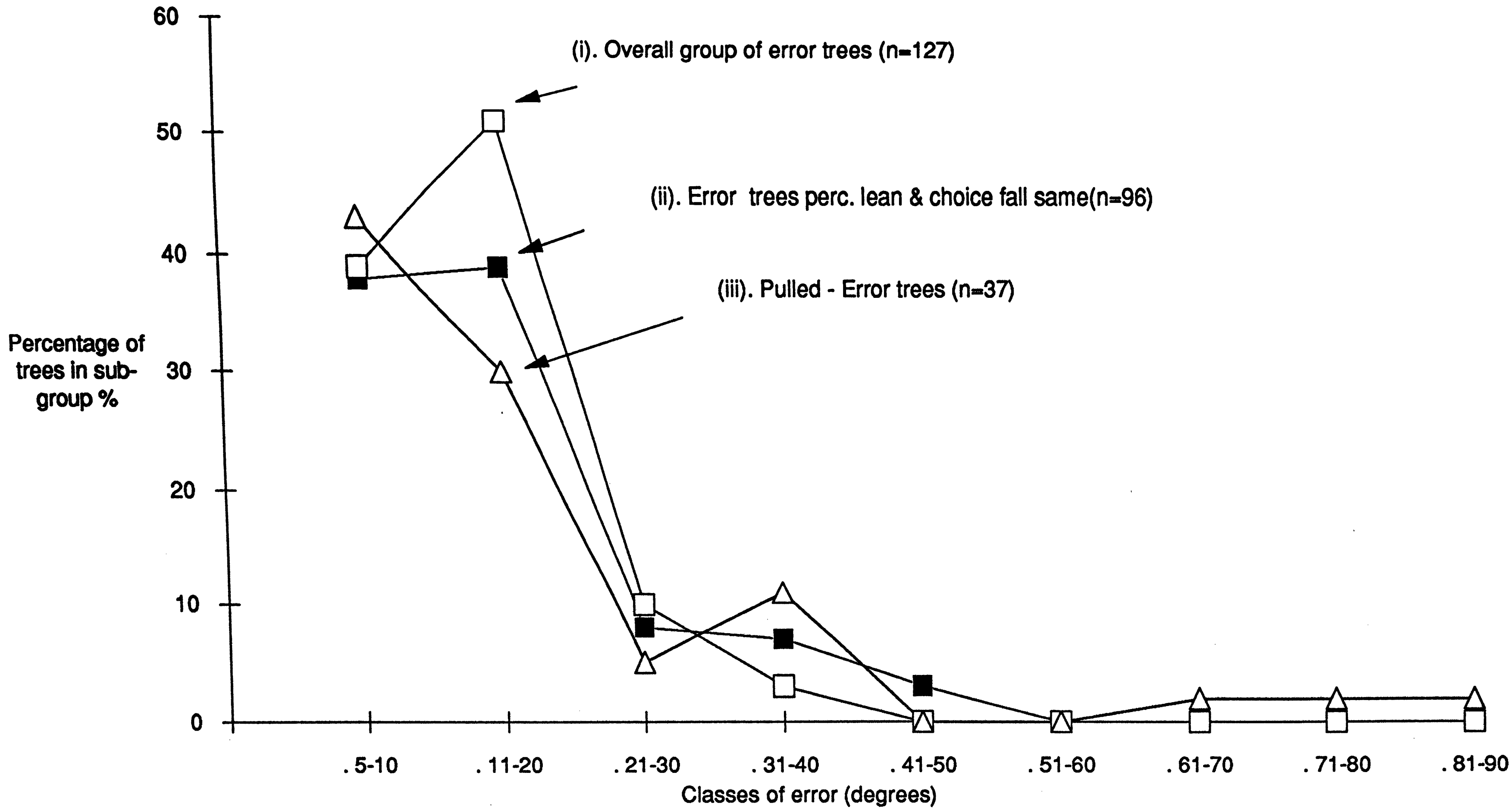


Figure 3.8 Percentage of Pulled error trees by error classes
- compared with the two other main types of fall.

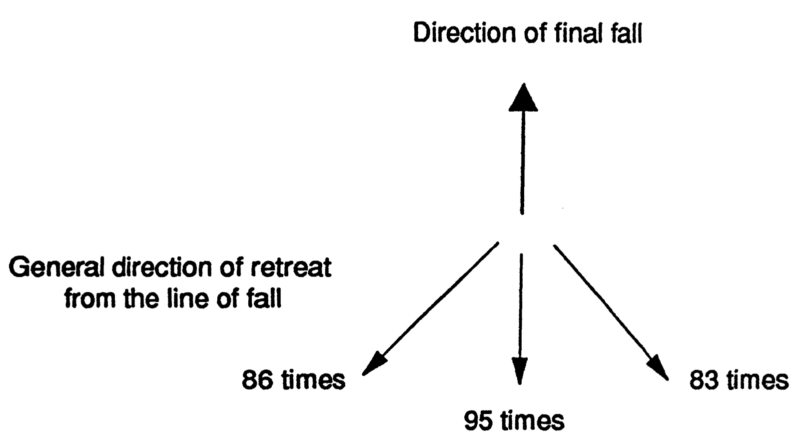
in these three classes of fall. In the smaller pulled-error set of trees all but two out of the 39 subjects attempted to pull at least one tree away from where they perceived the natural lean, with many pulling up to a maximum of seven trees away from perceived lean. Table 3.6 shows the range in "pull" attempted in the field study where the main classes were those trees being pulled off the perceived natural line from 5 - 40^{0}. Of the group of pulled trees, approximately half (n=43) were successfully fallen away from the natural lean to the degree nominated; that is, pulling the fall to the target direction nominated <u>if</u> their perception of the natural lean was indeed accurate. In those cases where the man failed to pull the tree away from the perceived natural lean (n=40), the tree followed the direction of the man's perception of the natural lean on only five occasions. This places further doubt on the reliability of the men's perception of the natural lean as a baseline for felling decisions. In the pulled trees most were errors of 10^{0} or more (n=34 trees). However, the correlation between the degree of pull being attempted and the final amount of felling error for the pulled-error group was still not statistically significant ($r = .37$, $n=40$, $p > .05$).

Table 3.6 The distribution of desired "pull" in the sub-set of 83 S-trees.

Angle of pull in degrees	No of trees	N as percentage of 83 trees	
5-10	14	17%]]	
11-20	14	17%]]]	72%
21-30	19	23%]]]	
31-40	12	15%]]	
41-50	6	7%	
51-60	5	6%	
61-70	4	5%	
71-80	3	4%	
81-90	3	4%	
> 90	5	6%	

3.4.4.4 Summary

Across all the subjects it was found that half of the total S-trees that were fallen had noticeable target error, while only five out of thirty nine workers had sets of S-trees that were without noticeable felling error. While just over one quarter of the group had at least half of their set of S-trees as distinct error cases, some two thirds of the men had an average target error of between 10-20^{0}. The present analysis offers a more objective basis for deciding what can be expected in terms of



Estimates of distance from stump
0 - 2 metres 101, 38%
2 - 4 metres 146, 55%
> 4 metres 17. 6%

Figure 3.9 Observations and estimates of retreat distance by experienced forest work study technician.

felling accuracy and tree control under real working conditions in Australia's native hardwood forests. It questions the myth of felling accuracy on which many safety practices in the industry are based. Hardwood fellers are frequently at risk through inaccurate falls. These field data from the practical working situation also demonstrate that men will try to pull a significant number (up to one third) of their trees from what they perceive as the natural lean, and that the extent of the pull, though large in many cases, is not systematically connected to final felling error. The results suggest that the direction of perceived natural lean was not a great influence on the error involved with pulled trees. Being able to precisely "read" the natural lean of a tree may not be as important in many cases as is commonly supposed.

3.4.5 Retreat distance and direction

Following judgements on the tree and the subsequent felling of it, two related aspects were considered. As a final observation the forest technician noted the approximate distance and the direction of the man's retreat as the tree fell. For the total number of trees the assessment of retreat distance was distributed as in Figure 3.9. Results were essentially those of a subjective classification by an experienced work-study technician and should be treated as such. Close to 40% of the men's retreat distances could be confidently stated to be within 2-3 metres of the stump, while only a few retreat distances could be found beyond 4 metres from the stump as the tree fell. These short retreat distances of the worker link in with both the generally low rating of risk during felling, the mainly high levels of certainty about the fall, and the over-confident assessment of their own felling accuracy. The direction of retreat as observed in relation to the tree's resting position shows an unacceptably high proportion of over one third of the men retreating directly behind the direction of the fall, which is absolutely contrary to recommendations in all the work-technique training manuals. These simple tabulations are far from encouraging, especially when one considers these reactions occurred when the man had the extra safe working reinforcement of the investigators and the felling instructor being present.

3.4.6 Relations between variables and outcomes

The relationships between tree characteristics and variables from the S-tree interview and the principal outcomes are summarised in Table 3.6. It was useful to look at the main outcomes of hr nett, felling error, and to a lesser extent retreat distance, in terms of (a) tree characteristics, and (b) subjective responses to the felling problem. The lack of variability in the men's rating of risk and awkwardness prevented use of these measures in a correlation analysis. Ratings of certainty and choice of felling direction remained as the key subjective responses to the felling problem.

Tree length was the tree characteristic most expected to relate to heart rate nett, both from the physiological point of view (with height being indicative of walking distance and crown size in terms of trimming), and from the psychological point of view with height being the most intimidating and easily discerned visual cue for the worker. However, the main tree characteristics that were correlated with physiological cost in the form of hr nett were tree diameter ($r = .24$, $n=260$, $p < .001$) and volume ($r = .20$, $n=252$, $p < .001$) where the correlation between volume and heart rate nett is essentially dependent on the diameter-volume relationship. Certainty about the natural lean and choice of felling direction had no association with the hr nett measure, while the degree of pull was also not linked to the heart rate response to the job. Heart rate thus appears to be a purely physiological reaction to the physical exertion of cutting the tree rather than having any psychological component.

Table 3.7 Correlations between selected variables - Full field data set 266 trees.

	Tree			*Inter'w*			---------Outcomes---------		
				___*Cert'y*___			*Hr*	*Fell'g*	
	Lgth	*Vol*	*Dia*	*Nat*	*Choice*	*Pull*	*nett*	*Error*	*Retr't*
Tree									
Length	—	.49***	.44***	-.05	-.03	-.10	.05	.16**	.41***
Vol		—	.78***	-.10	.06	.04	.20***	-.04	.26***
Dia			—	-.13	.11	-.03	.24***	.02	.17**
Cert'y									
of nat. lean				—	-.06	-.01	-.09	.06	.13
Choice fall					—	-.16	-.10	-.08	.05
Pull						—	-.15	.29**	.15
Hr nett							—	-.13	.13
Felling Error								—	.10
Class of Retreat Distance									—

* $p < .05$ ** $p < .01$ *** $p < .001$

Of the three measured tree characteristics only tree length was marginally associated with target error, $r = .16$, $n=256$, $p < .01$. In practical terms this result tends to support the view that gross tree characteristics *per se* are not a major part of the error nexus. There was no overall association between the men's certainty ratings on a tree and the felling error (including the majority of cases where the natural lean and chosen fall were in line, $r = -.07$, $n=90$, $p > .05$).

One question of particular interest was whether level of physical workload in terms of heart rate had any association with the global performance measure of felling error. A fatigue effect might contribute to felling error in combination with other factors. For example, an excessive workload in terms of hr nett (especially above 40 bpm), might influence the man's ability to execute the proper scarf cuts as the day progressed, or hinder his persistence in identifying hazards in the crowns of trees past which he must fall the S-tree. Because of the problem of covariation with terrain and workstyle factors, a significant correlation between heart rate nett and error would not demonstrate causality. There was a low correlation between hr nett and felling error for the error group of trees ($r = -.15$, $n=135$, $p <. 035$), but the relationship was opposite to the hypothesised direction. Average hr nett for the error and non-error trees across all subjects was not significantly different, $\underline{t}$ (263) = -1.45, , $p > .05$. This result mirrors the finding of no essential differences between the two groups of trees in terms of mean diameter, length, or tree volume. All these results argue against a link between the level of physical workload and felling error.

There was a strong correlation between retreat distance and measured tree length ($r = .41$, $n=254$, $p < .001$) (Table 3.7), but lower correlations with the other two tree characteristics. Neither of the ratings of certainty about the tree, the amount of pull, or felling error in particular, was related to retreat distance. There must also be reservations about the correlation between tree length and retreat because of the rudimentary nature of the classification of retreat distance by the forest technician. A similar association was found in the sub-set of target error trees between retreat and tree length ($r = .44$, $n=126$, $p < .001$).

3.4.7 Subjective assessments of performance

3.4.7.1 Self-assessments by fellers

The final part of the S-tree interview was self assessment of the felling performance by the men themselves. In the case of the 135 error trees, 112 self evaluations by the men were obtained. A number of subjects were reluctant to evaluate themselves when significant error occurred after high certainty ratings and no judgement was obtained. Table 3.8 shows the distribution of subjective ratings of men for their own performance on the error trees. The total sample of trees is given in parenthesis. As can be seen, the men were over-confident about their abilities, especially when the amount of target error across almost every man's set of S-trees is taken into account. Thus, in a group where noticeable target error did take place fewer than a quarter (23%) of the self assessments acknowledged this critical fact. Three quarters of the falls that had noticeable error were assessed as "good" or above, and 60% or more of the falls were assessed as "very good" or "perfect". These findings have clear implications for training. Whether these results are due to the speed of the fall, the broad limits the men place on what they term a "a very good" to "perfect" fall, or their reluctance to face the objective facts on performance produced by the study, there should be a much greater proportion than approximately 19% of trees being seen as "not quite right" to "bad" in terms of the success of the fall. The same over-confident pattern of the trees fallen with noticeable error is mirrored in overall group results. Three quarters of the error trees were seen at the "good" or a higher level of performance.

Table 3.8 Self assessments of felling performance in the case of the trees exhibiting target error (n=112)(Total trees=241).

Response	Error trees N	Error trees %	(Total trees) (N	%)
1 Bad	1	-	(1	-)
2 Poor/equivocal	8	7%	(14	6%)
3 Not q/right	18	16%	(30	13%)
4 Good	16	14%	(24	10%)
5 Very good	44	39%	(104	44%)
6 Perfect	25	23%	(61	26%)

The correlation between the self evaluations and target error was statistically significant and negative ($r = -.22$, $n=110$, $p < .01$). However, in combination with the data of the frequency table above, the result is not distinct enough to conclude that the men were sensitive to their own felling error in the practical situation. This is especially the case when other aspects of their efforts (e.g., cleanness of the scarf cut or the uniformity of the hinge wood) may have influenced self evaluations when the observed target error was well within their own everyday standards of felling accuracy. It is a cause for concern that in a large group of S-trees where noticeable target error did take place, fewer than a quarter (24%) of the self assessments acknowledged this critical fact in interview. Such denial might be even greater under normal working conditions.

3.4.7.2 Expert-instructor assessments

At the end of each field day the expert-instructor rated each man on the four basic job skills of "preparing around the base of the tree" (Sk1); "making the scarf cut" (Sk2); "avoiding danger as the tree falls" (Sk3) and "control of the saw while cutting" (SK4). Seven point scales on a prepared pro-forma were used (Appendix 22).

While significant inter-correlation between the scales might be expected, the strong correlation, for example, between "making the scarf cut" (sk2) and "control of the saw while cutting" (SK4) might be indicating observer bias as much as real connection between the two observed behaviours.

Table 3.9 Intercorrelation between the instructor's skill ratings and average values of the main outcomes of the study.

	Sk1 Base	Sk2 Scarf	Sk3 Avoid	Sk4 Saw	Hr nett	Fell Error Av	Fell Error Prop
Sk1 Base	1.00	.54**	.41**	.48**	.22	-.33	-.42**
Sk2 Scarf		1.00	.51**	.78***	.17	-.43**	-.19
Sk3 Avoid			1.00	.52***	.00	-.25	-.41**
Sk4 Saw				1.00	.00	-.20	-.34

* $p < .05$ ** $p < .01$ *** $p < .001$

The extent to which the four skill ratings correlated with average hr nett, average S-tree error and proportion of trees with error is given in Table 3.9. Of the four expert but subjective assessments, the only significant predictor of a man's average felling error across all his S-trees is his rated skill in "making the scarf cuts" (Sk2). Ratings of skill in "preparing around the base of the tree" (Sk1) and in "avoiding danger as the tree falls" (Sk3) were significantly correlated with the proportion of S-trees that exhibited error, but not with average error.

3.5 Discussion

3.5.1 The exploratory model and questions

Early sections of the chapter considered the problem of skill, risk, and error. It was suggested that, contrary to popular timber industry myth, consistent hazard perception and risk assessment, consistent felling accuracy and certainty about achieving this, and consistent and appropriate escape reactions were three skills that even highly experienced men might not always have readily to hand. Rudimentary classification of the defect and shape of tree stumps following felling confirmed that that defect and an irregular barrel in the tree are familiar issues for the hardwood tree feller. However, contrary to the implication that tree characteristics were strongly linked with error, the group of S-trees in this particular sample that involved felling error were very similar in terms of their average dimensions, to the overall group of S-trees. These data and the low correlations between three measured tree characteristics and felling error (Table 3.7) tend to suggest that tree characteristics are not a direct or consistent element within the error nexus.

The key question posed in the chapter was the extent to which the men fulfilled different parts of the exploratory model of low-risk felling behaviour proposed in section 3.2.4 (p.103). From data on actual behaviour in the forest it was shown that eucalypt hardwood felling in the Tasmanian native forest is consistently associated with noticeable felling error. Out of 39 men in the study only five (13%) had no noticeable error in the sub-set of S-trees amongst the others they had fallen as part of a day's work. The average target error was between 10^0 and 20^0 for the majority of men, even though the instruction to subjects emphasised maximum felling accuracy for S-trees.

None of the 39 men reported absolute certainty about perceived natural lean. For over half the trees the judgements about natural lean were equivocal (below 50% certain). In one sense this implied the men considered that the tree would fall where it was cut, and not where they felt it might have a slight lean. Since the target error occurred in the large majority of cases when the man was felling with his perception of the natural lean, the results cast doubt on the proposition that tree fellers are usually accurate in detecting the tree's real natural lean. The results clearly demonstrate that certainty about achieving a carefully chosen felling direction is not a reliable predictor of felling error. In those cases where the man was completely uncertain about a tree's natural lean, he was none the less usually highly certain about achieving an accurate fall with such a tree. Felling inaccuracy was at approximately the same levels for the overall error group, the error group with the natural and chosen direction the same, and the error group when the tree was pulled off its supposed natural line. As suggested earlier the man may on numerous occasions perceive a natural lean in line with the direction he has already sub-consciously chosen to fell the tree. When error did occur with trees being pulled away from the perceived natural lean few of them went in the direction of the man's judgement of natural lean. This also places some doubt on the view that the experienced hardwood feller's judgement of natural lean was as accurate as generally believed in the industry. In further work it would be worthwhile to instruct the subject to fall always with the perceived natural lean in order to obtain a clearer estimate of felling error and a better understanding of the judgement of natural lean.

In the part of the fieldwork model that specified the need for a realistic and variable perception of risk, there was remarkably little variation in these ratings across a widely differing range of trees and felling. It was suggested that low risk ratings across all subjects and virtually all trees may demonstrate the simple coping mechanism of denial of the obvious felling dangers and difficulties observed during field work. These results on perceived risk in the Australian forest work setting support data on perceived risk obtained in pictorial representations of dangerous Swedish felling situations, as discussed in chapter one (Lindstrom and Sundstrom-Frisk, 1976; Ostberg, 1980). A lack of sensitivity to risk (at least at the non-verbal level) seems untenable. The alternative possibility of the men concentrating on specific issues in the fall, rather than desiring (or being capable of making) a general judgement on risk, needs to be explored in future research. This apparent stoicism in a rural blue collar workforce is not unexpected, and the mainly positive self assessments of performance that involved felling error tends to support this conclusion. In spite of obvious difficulties in cutting that were apparent on many occasions during fieldwork, the low ratings on the awkwardness of making the felling cuts is so similar to the ratings of risk that a response set between these two scales is quite likely.

Contrary to the underlying philosophy of overseas work-technique manuals some experienced bushmen do question whether even a solid hinge and clean scarf line will control the fall of a large or over-mature eucalypt in the same manner as it does in solid softwood trees. The final position of the fallen tree relative to the centre line of the scarf cut can be influenced by defective holding wood as the tree goes over, barrel or head weight being greater than foreseen, and random effects of wind in the case of the small trees. The number of cases showing a discrepancy between the final fallen position of the tree and the direction of the physical scarf line, questions the notion of sighting and a wide scarf being the complete answer to safe hardwood felling. However, these two components should still be regarded as one of the cornerstones of low-risk felling.

On the main question of whether this diverse sample of the hardwood feller workforce could consistently fall the tree where they had chosen, the results are clear: they could not. While it is not always necessary for the man to operate with pin-point accuracy, when the man was explicitly required to do so the error rate persisted. Therefore unlike the uniform softwood trees of Scandinavian forests that have led to training techniques based on precision felling, there seem to be natural limits to accuracy in the hardwood forest that has a significant proportion of non-uniform trees. As far as this type of tree-feller is concerned these inherent limits to accuracy question the reported benefits of spar felling practice to prepare the man for the real job (Jansson, 1988).

In the matter of retreat behaviour, the empirical result was not as anticipated. Nearly 40% of the men's retreat distances were within 2 metres of the stump, with most retreats (94%) being judged to be within 4 metres of the stump. The men were judged to have retreated beyond 4 metres on only 17 occasions out of the 264 observations in spite of the audience effect of the research team. Without more detail on every fall, it is difficult to suggest why the short retreat distances occurred so frequently. It may have been the influence of heavy undergrowth in some cases, or fatigue and the heat of the day in others. The retreat behaviour was consistent with the generally unrealistic felling certainty and the low level of perceived risk. In a similar manner to retreat distance, the 95 times when a man retreated directly behind the stump is an observation needing further investigation. These results show that the retreat distance recommendations and regulations that are so familiar to logging managers and safety officers are not often observed in practice by the workers themselves.

Finally, in the case of the men's assessment of their own performance immediately after the fall we see the same over-confident rationalisation that they exhibited with certainty of chosen felling direction. In the practical working situation the men were too certain and too confident about many of the episodes where error did subsequently occur. At this stage there is no evidence of the worker having well articulated strategies for learning from day-to-day felling error. More research needs to be carried out to clarify the learning processes that must still be assumed to be occurring with these men.

How successful was the study in combining Singleton's skill-ergonomics rationale of a more naturalistic observation style with the need to measure some key antecedents and outcomes in the hazardous environment itself? Although the study broke new ground in exploring concepts that are typically examined in a laboratory setting, as with any field study it is clear that the measures employed were less than perfect. The following remarks relate to the measures that were employed. Preliminary discussions with hardwood felling instructors and work-technique manuals emphasised the need for the feller to be able to fall with pin-point accuracy when necessary. The definition of accurate felling in the research as being on target to the nearest 5^0 may have been too precise, yet field observations did confirm that at least this level of accuracy is part and parcel of the demands of the job in close felling situations. In the case of the large decayed tree some measurement error was inevitable if the tree split on impact, or propped and rolled in the fraction of a second between contacting the ground and coming to rest. However the 5^0 allowance for such measurement errors between chosen and actual fall was thought to deal adequately with the problem in all but a few cases. Future studies will need to address the training and personal factors that influence a man's own standards of felling accuracy and margins for error. Having the compass bearings taken by the forest technician during S-tree interviewing gave no reported or observed difficulties. Measuring felling confidence and certainty with a 100 point analogue scale did prove to be acceptable and it is hard to suggest improvements to this measure. The use of a similar scale on the risk and awkwardness dimensions may have produced more varied response, but this had to be balanced against the problem of response set within the scales that were used. The use of six point rating scales on issues like job risk or job difficulty is common practice, but obviously needs to be re-assessed in the case of the high risk worker. The categories for retreat assessments were based on the one Australian study of serious injuries and the man's distance from the stump (WA Forest Department, 1974). Though the distance of retreat from a stump was an estimate made by a highly experienced forest technician, with hindsight smaller categories might have been included in this assessment. One way to have made the assessment more precise would have been for the preparation team to mark areas around the base of the tree during the tree selection phase. Such markings could, however, have acted as a cue and stimulus to alter the feller's spontaneous retreat distance. It could also be suggested that some averaging bias may have been operating in the field observer, but it was not possible to check this.

3.5.2 Towards a model of human reliability in felling

Overall, do these empirical results support the view of the voluntary acceptance of carefully calculated risk with consistently accurate felling outcomes or a pattern of inevitable and "normal" errors of which the worker is not fully aware, possibly because of the intrinsic complexity of the information processing in the task? It seems the latter is more likely. Given the field study results described above, what theory of a feller's reliability, or unreliability, and risk behaviour in the forest can begin to be developed? The notion of accurate "reading" of the natural lean of the tree is put in some doubt through the amount of error that still occurred with chosen falls that were aligned with the perceived natural lean, as well the many pulled falls that exhibited error and yet did not follow the direction of perceived natural lean. It could thus be suggested, contrary to the folklore surrounding the job, that the man's perception of natural lean does not always appear to be a reliable baseline for choosing the optimum felling direction. If there is consistent hazard perception occurring it was not evident using the simple scales of risk and cutting awkwardness employed in the study. While the reported perceived risk remains distinctly low across most situations, certainty about the job being carried out successfully was generally high. However, this all important judgement of certainty about the fall was not a predictor of differences in felling error from tree to tree. The extent of error associated with half of the felling choices questions the validity of the chosen felling directions in many of the felling episodes. There was evidence that an important feedback mechanism for learning was not available for many of the men because there was no clear association between the degree of error in a fall and the man's self assessment of his own performance. There may be a need for renewed emphasis on rigourous directional felling in Australian conditions, and accurate judgements of when a tree does need sighting from the points of the scarf cuts, or an explicit acknowledgement that pin-point sighting cannot (and will not) be adhered to in the production situation.

Based on the proposed model of low-risk hardwood felling these empirical facts about flaws in performance could begin to explain the injury and death rate, over and above the truly random accident events discussed previously in chapter 1 (p.15-16). The field results may go some way to establishing the realities of hardwood felling accuracy and felling reliability. The conclusions naturally lead to the question of prevention of injury events once these quite "normal" errors in detecting natural lean and choosing felling direction, as well as the actual felling, have occurred. The observed failure in terms of adequate retreat distances also adds to the problem. This question is taken up in chapter 4 with the emphasis on tests of escape signal detection as the tree is actually falling. With further work this initial study should prompt a re-evaluation of the whole idea of standards of felling accuracy and the way they relate to current regulations and recommendations regarding escape paths and retreat distances.

Chapter 4

Signal detection in a simulation

Chapter 4

Signal detection performance in a simulation

4.1 Introduction

4.1.1 The escape phase in felling

The focus in chapter 3 was on evaluation of decision making and performance by tree-fellers in the natural work setting of the hardwood forest. In contrast to the widely held belief that an experienced tree-feller can generally fall trees with precise accuracy, it was demonstrated that a majority of a representative sample of fellers make significant felling errors even when under instruction to achieve the maximum accuracy possible. In a set of test trees during field work half resulted in a felling error, and nearly 30% of all test trees were off-line by more than 10^0. For various reasons such as the high levels of certainty of success, the prevalence of a low perception of risk, over-confident assessments of performance, and consistently short retreat distances, it appeared that many tree-fellers must essentially accept felling inaccuracy as "normal" performance. There was, however, significant variability amongst fellers in their capacity to predict felling direction accurately.

The field study provided a powerful context for exploring information that workers use in the natural environment, but a limitation of the approach is that the investigator cannot manipulate the kind of information available to the worker. An alternative strategy for identifying information processing pertinent to tree felling is to determine the ability of people with different levels of experience or training to predict outcome during simulation of trees being felled. Signal detection analysis is used in the present study in determining how sensitively experienced tree fellers can distinguish abnormally falling trees through observation of video recordings. A further interest is in establishing the stage during felling that sufficient information is available for the abnormal/normal outcome to be predicted accurately.

As discussed in chapters 1 and 3 recommendations in training manuals (e.g., Dent, 1974; FAO/ILO, 1980) cover not only use of chainsaws, appraisal of the tree and the manner in which cutting proceeds, but preparation of escape paths and retreat as the tree begins to fall. Though the official recommendation in every felling work technique manual (e.g., Dent, 1974; Workers Compensation Board-BC, 1977; FAO/ILO, 1980) is the cutting of two 45^0 escape paths relative to the felling direction, some Tasmanian bush instructors had suggested with typical pithiness that "when the tree falls you should try to be where the danger isn't."

While retreat distance is a critical survival factor according to manuals and practical experts, it was shown through unobtrusive assessments in the field that a high proportion of the fallers remained consistently within two to four metres of the stump. The correlation of the measured tree length to retreat distance (Table 3.7, p. 130) though significant was compromised by the simplicity of the retreat distance assessment. None of the performance variables employed in the field work correlated with the retreat distance. The retreat direction away from the intended line of fall also revealed many inconsistencies. Guimier (1980) provides falling times and acceleration velocities of a series of theoretical trees of different sizes and shapes. Approximately 70% of total falling time is taken by the first 45^0 of the fall. Combined with data from the tree assessment field work, this suggested that final decisions on which way to escape would need to take place early in the fall before the tree was halfway to the ground (average total falling time $5.8^{+}/_{-}1.6$ seconds, Table 3.1).

In the field the feller initially predicted the type of fall or outcome he hoped to achieve. Many factors could change between that initial prediction, the completion of front cuts, and the moment that the tree started to lift from the stump. Even at this late stage defective wood, or wind in the case of smaller trees, can play a decisive role in where the tree finally lands. Judgements can rapidly change irrespective of the man's original predictions or his initial certainty of achieving a normal and accurate fall. On occasion the man may not feel confident about what the tree will really do until one or two seconds into the fall itself. The static setting out of two regulation style escape paths is a sensible first step but the escape task of the faller who might be in heavy undergrowth on piece-work is patently more than this. In actual practice one escape may be to retreat a few paces and stand watching for projectiles like thrown limbs, another may be to run 5 metres behind a tree, another may be to take the prepared escape path, if this is indeed appropriate. One instructor regarded the way the back cut opened and the way the tree began to leave the stump as the most crucial cues for escape direction, but opinions varied considerably among the fallers as to the most important cues to making a good escape.

Experienced tree fellers report being able to "read" a tree while working on it, and hence be sensitive to possible hazards. They claim that by anticipating when a tree will fall abnormally rather than normally they can take preventive actions in sufficient time to avoid accident or injury. The concern in the study now to be reported is with the capacity of the tree fellers to discriminate between trees that will fall normally and those that will fall abnormally, and particularly the bush lore that the men can decipher such information before cutting the tree has commenced. The main proposition under test is that general felling experience is associated with accurate signal detection during the actual fall of the tree. It was expected that a group of experienced timber fellers would be more able to detect abormality than a group of control subjects who were familiar with the forest environment but had no experience in tree felling. An additional hypothesis was that on-the-job instruction would have a positive influence on a feller's signal detection performance in all three of the information stages used in the simulation.

4.1.2 Theory of signal detection

4.1.2.1 Introduction

Signal detection theory was initially concerned with the detection of radar signals (Peterson and Birdsall, 1954). More recently Welford (1968) sought to apply the theory across a wide spectrum of problems from simple reaction time through skill acquisition to more speculative propositions on social behaviour. More than 30 years after the seminal publication by Swets, Tanner and Birdsall (1955) signal detection theory is referenced in basic human factors texts (McCormick and Saunders, 1982) and afforded a central role in some treatments of human performance (e.g., Wickens, 1984).

The basic concept in signal detection theory is that the organism is always operating in terms of detecting environmental information against the background of random neural noise and other masking, conflicting or interfering information within the processes of the central nervous system. The theory is said to be applicable in any situation in which there are two discrete though not necessarily easily discriminated states of the external world. These states are represented in theory by two normally distributed sets of energy or information values (see Appendix 34). The first, the so called "noise alone" distribution, is general environmental stimulation and neural noise. The second, the "signal+noise" distribution is the values of the noise distribution plus those of the relevant signal. The task of the observer is to detect whether the signal is present. The four possible states in the theory are:

Hit - the signal is present and is correctly identified;
False alarm - the signal is said to be there, but it is not;
Correct rejection - the signal is said not to be there, and this is true;
Miss - the signal is said not to be there, but it is.

The hit rate and the false alarm rate obtained from binary yes-no judgements under a given condition specify a point on an isosensitivity curve, and the plot of hit rate against false alarm rate as response criterion varies at a fixed discriminability level and defines the receiver operating characteristic (ROC) curve for the observer. Parametric signal detection measures, such as d' and B, calculated from binary yes-no data can be validly interpreted only when the underlying signal and noise distributions are normal and have equal variance (see McNicol, 1972). However, the alternative approach of requiring an observer to make judgements using a confidence rating scale that covers a range of criterion values allows the complete ROC curve to be generated. Nonparametric measures of sensitivity, P(A), or the proportion of the area under the ROC curve, and response bias, B, the decision points or criterion being employed by the operator, can then be derived (McNicol, 1972). The ROC analysis is said to "give a measure of discrimination that is independent of the location of the decision criterion and is presumably uncontaminated by the processes such as expectation [probability] and motivation [utility] that affect the response" (Swets, 1973, p.995).

4.1.2.2 Diagnostic medicine

The field of medical diagnosis has been seen as a fruitful environment for the application of signal detection theory. A main theme in ROC analysis has been evaluation of medical imaging techniques in radiological examination. Lusted (1971) and Swets (1979) have shown how diagnostic performance in radiology can be quanitified using an ROC curve. Abnormalities in the form of disease symptoms or tumors are either present in the display or they are not, The task is to make a simple yes/no decision as to whether there is abnormality present. The strength of the signal, and therefore the sensitivity of the human operator P(A), is related to factors such as the number of converging symptoms for the potential abnormality and the training of the physician to focus upon the relevant cues. Response bias, on the other hand, can be influenced by both signal probability and benefits of identification. Influences on signal probability include the disease prevalence rate, and whether the patient is being examined in initial screening (probability of disease low, beta high) or referral (probability higher, beta lower). Lusted (1976) has argued that physicians' detections tend to be less responsive to variation in disease prevalence rate than optimal. Factors that influence payoffs include the difficulty in quantifying consequences of hits (e.g., a detected malignancy that will lead to its surgical removal with associated hospital costs and possible consequences), false alarms (an unnecessary operation), and misses. Placing values upon these events based upon financial costs of surgery, malpractice suits, and intangible costs of human life and suffering is obviously one of the difficulties in such research, yet there is little doubt that they do have an important influence on a physician's detection rate. Swets and Pickett (1982) provide extensive detail describing the appropriate methodology that should be employed when using signal detection theory to examine performance in medical diagnosis.

Though detection of particular abnormalities is only part of a physician's role the continual introduction of more sophisticated scanning equipment has changed rather than removed the problem of accuracy in diagnosis (Eddy, 1982). Rhea, Potsdaid, and DeLuca (1979) estimated the miss rate for detection of abnormalities to run between 20 and 40%. Swennsen, Hessel, and Herman (1977) have examined the effect on detection of directing a radiologist's attention to a particular area of an x-ray plate in which an abnormality is likely to occur. They found that such focusing of attention will indeed increase the likelihood of the tumor's detection, but will do so by reducing beta rather than increasing sensitivity. Swennsen et al. (1979) have also compared search for x-ray abnormalities between conditions in which the plates contain only the abnormality (in some proportion) and conditions in which the critical target abnormality is mixed with plates containing other pathologies. While the former condition produced a higher hit rate, it was accomplished by a reduction in beta. This shift in beta was such that the sensitivity was actually reduced compared to the mixed plate conditions. Parasuraman (1985), in comparing detection performance of staff radiologists and residents, found major differences between the two populations in terms of sensitivity (favoring the staff radiologists) and bias (radiologists showing a more conservative criterion in general). A third dimension of contrast between these groups, and one with important implications for training, related to the adjustment of beta. The staff radiologists were much more responsive than residents in adjusting beta according to the disease prevalence rate.

4.1.2.3 Blue collar vigilance tasks

In the area of signal detection and hazardous blue collar jobs the main emphasis has been on inspection or military type studies, usually of relatively simple vigilance tasks (e.g., Craig, Wilkensen and Colquhoun 1981; Drury and Fox, 1975: Warm, Loeb, and Allusi, 1970; Weiner, 1987). In an industrial application with some similarities to the present study, Blignaut (1979) used signal detection analysis to test mine workers' ability to discriminate visually between the dangerous and safe rock conditions that are found in South African gold mines. In this study Blignaut examined the effects of experience and special practice on signal detection by novice mine workers and those with some nine months underground experience. The task was to discriminate between safe rock and three levels of danger in loose rock, as depicted by stereoscopic slides. The responses were given on a 6 point scale ranging from "absolutely certain safe" to "absolutely certain dangerous".

Using four comparison groups Blignaut found that novice workers who had skills training with the test slides performed marginally better than experienced but non-skills trained men in terms of signal detection of the simulated dangerous rock surface images. He also found a general improvement in sensitivity as the level of danger depicted in the slides increased. In making a plea for special job hazard training in addition to job method training, Blignaut still emphasised the problem of evaluating the transfer of training from simulated signal detection to actual behaviour at the rock face.

Differences between use of ROC analysis in medical diagnosis, detection of loose rock hazards, or tree felling abormality are pronounced. The physician can view the stimulus material a second time or change his decision many hours later. A miner or tree feller has dynamic information with direct effect on his own chances of survival rather than that of a patient. A short search and evaluation time is available before reacting and moving physically to escape from a tree that does not behave as anticipated or a rock fall or rockburst that occurs without warning. The concern in the present study is with detection of information that distinguishes abnormally falling trees ("signal" events) from normally falling trees ("noise" events). In a between-group comparison sensitivity and response bias measures are compared for experienced tree fellers and forestry students who were familiar with forestry conditions but lacked experience in tree felling. In the within-group comparison tree fellers who had received field instruction from a company instructor within the preceding four months were compared with tree fellers who had not received such training.

4.2 Method

4.2.1 Subjects

The experimental group comprised 18 tree-fellers who were recruited from among the 39 men participating in the previously reported field study. Ages ranged from 22 to 47 years (mean $34.4^{+}/_{-}7.9$), and the men had between one and 26 years (mean $9.7^{+}/_{-}8.6$) of full-time experience in tree felling. Nine of the 18 men had received between 10 to 24 hours on-the-job training from a company instructor over the preceding four months, while the other nine tree-fellers had not received such instruction. The comparison group consisted of 18 second-year and third-year forestry students at the Australian National University. They ranged from 17 to 45 years of age (mean $21.56^{+}/_{-}6.37$). Eight of the 18 students had some experience in the use of chainsaws, but none had worked full-time in tree felling or had cut trees of the size and type used in the simulation film.

Within the tree-feller group, the instruction sub-group ages ranged from 23 to 47 years (mean $32.2^{+}/_{-}13.2$), while their experience in full time felling ranged from less than one year to 28 years ($12.44^{+}/_{-}9.8$). The non-instruction group ages ranged from 22 to 45 years (mean $31.8^{+}/_{-}8.9$), with full time felling experience of less than a year to 24 years (mean $6.6^{+}/_{-}6.6$).

4.2.2 Materials and procedure

Video records of tree felling that had been obtained during the field study were inspected to find five examples of abnormal falls that covered problems in the four quadrants of the falling circle. The five abnormal falls, each of which constituted a "signal" event in the signal detection analysis, were:

(a) the tree fell to the front, but jumped back and bridged on the stumps,

(b) the tree sat on the back cut, and then went over backwards,

(c) the tree twisted to the right as it left the stump, with the potential of hitting other trees,

(d) the tree twisted to the left as it left the stump, with the potential of hitting other trees,

(e) the tree fell fully sideways at 90^0 to the intended direction.

The set of five normal falls, each constituting a "noise" event, were falls that had not only proceeded as the worker had predicted, but were judged as good falls by the instructor and forest work study technician at the time the film was taken at the worksite.

The 10 episodes were edited so that the starting sequence and the important stages in cutting before the fall began were available for viewing by the observers. Scarf cutting had been filmed from directly in front of the scarf at a distance between six and 12 metres, depending on tree size. The cutting of the back of the tree was filmed from the left (facing) side of the worker. The signal and noise events were presented in a random sequence in a single testing session lasting about one and a quarter hours. Immediately prior to each felling episode a static segment was shown, and details of the estimated height and volume of the tree were given, as well as the comments the original worker had made about the tree before felling began. This information was given in the same voice and intonation on the video tape for each tree.

The tree fellers were tested in their own homes alone in a quiet room. The portable video unit (Philips A-910 30.5 screen size) was located at eye height 1.2 metres from the subject, and illumination of the screen was maintained at between 100 and 150 lux (Yew Luxmeter, Type 3281). The control subjects were tested in a university laboratory under similar viewing conditions at a later time. The instructions to subjects emphasised that the task assessed the person's skill in "reading a fall" and predicting what each tree might do. Each time a judgement was required the subject had to report whether the fall being viewed was "abnormal" or "normal" and how certain he was in this response ("possibly", "probably", "certain"). Judgements were thus made on a six-point scale ranging from "certain abnormal" to "certain normal". For each tree the video was stopped at three stages during felling: when the scarf cutting was complete, when the tree had visibly listed, and when the tree had fallen 30-45^0 from vertical. Subjects made judgements of outcome at each stage. No information was given about the accuracy of these judgements. Two practice trials, one depicting an abnormal fall episode and the other a normal fall episode, were given prior to the 10 test trials. Although subjects were invited to ask questions and to make comments during the practice trials, neither comments nor questions were allowed once the test began.

4.3 Results

The principal purpose in using signal detection analysis was to establish whether the tree fellers were more accurate than a control group of forestry students in predicting outcome on the basis of the information available at three stages in the video recordings. For descriptive purposes ROC curves were generated for tree fellers and forestry students by pooling data across subjects in each group. Figure 4.1 shows ROC curves for the two groups when scarf cutting was complete and when the tree had fallen 30-45^0 from vertical.

Judgements made by the groups at stage two when the tree had begun to visibly lift off the stump are not given in the figure, but these judgements are included in the statistical analysis that are reported below. Discriminability is defined by the percentage of the unit area under the ROC curve; the closer the curve lies to the upper left hand corner, the more accurately the observer has been able to differentiate signal from noise events. Performance at chance level would yield a

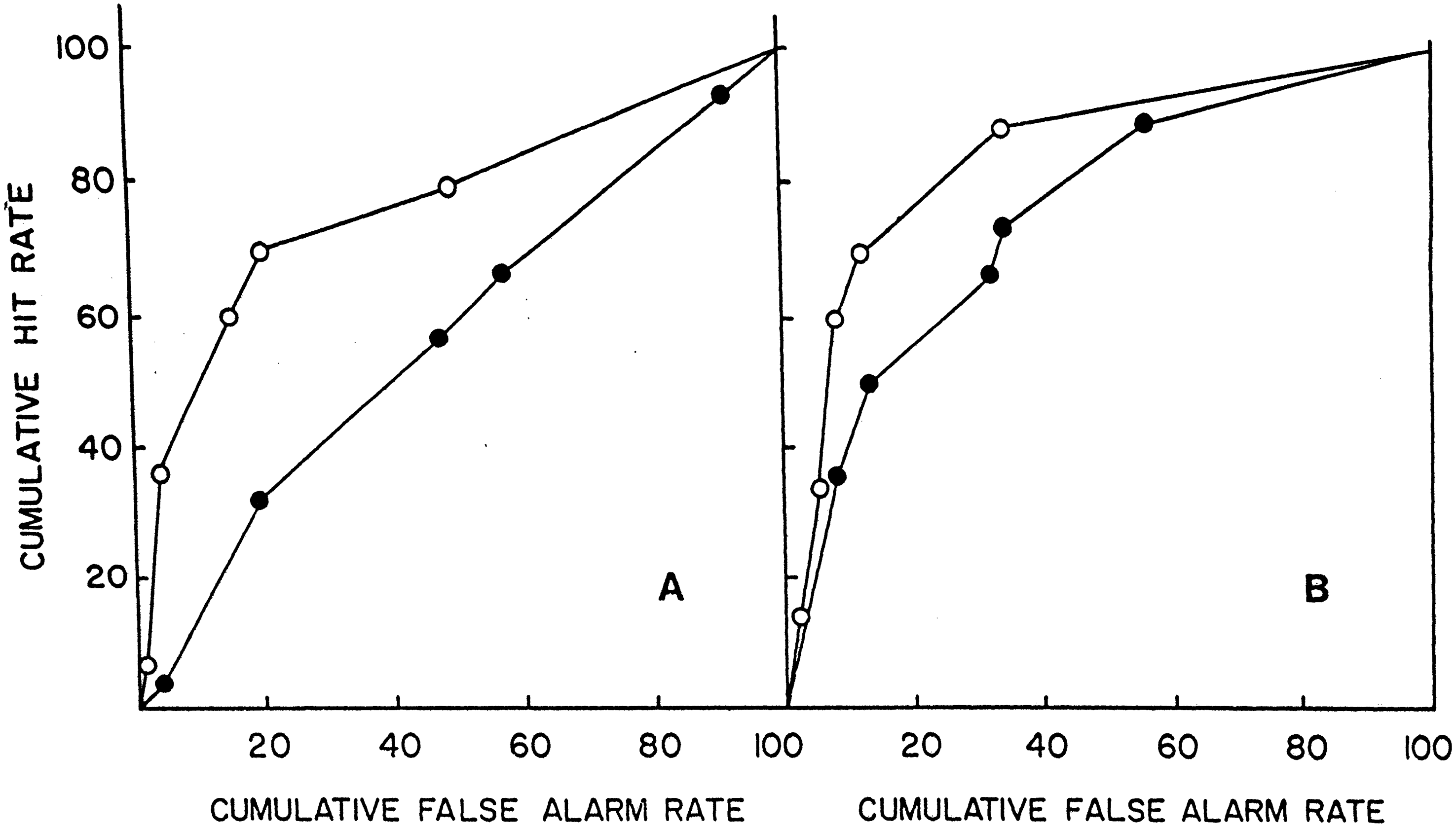


Figure 4.1 ROC curves of discriminability P(A) transformed scores for -
(A) stage 1 : Scarf cuts complete , (B) stage 3 : Tree had fallen 30-45 degrees
○ Tree feller group ● Forestry student control group.

diagonal ROC line. It is clear from inspection of Figure 4.1 that tree fellers were more accurate than forestry students in predicting whether falls would be abnormal or normal, and that even when the tree had fallen 30-45^0 the forestry students were not as accurate in their assessments of outcome at that late stage, as the tree fellers had been in the initial judgements they made when only the scarf cutting was complete.

The trends evident from inspection of Figure 4.1 were confirmed through statistical analysis based on the nonparametric indices of discriminability and response bias calculated from the ROC curves generated from the ratings provided by each subject. The discriminability values were transformed to 2 arcsin/P(A). Table 4.1 reports the mean discriminability and response bias values at the three stages of felling, together with standard deviations, for tree fellers and forestry students.

Multivariate analysis of variance showed a significant difference in measures between groups, mult. $\underline{F}$ (2, 33) = 16.37, p < .01. Univariate tests showed that tree fellers had significantly higher discriminability scores than forestry students, $\underline{F}$ (1, 34) = 19.90, p < .01. Measures varied across the three stages of felling, mult. $\underline{F}$ (4, 136) = 4.12, p < .01, and univariate tests showed that there were significant differences in discriminability across stages, $\underline{F}$ (2, 68) = 5.67, p < .01. Multiple comparisons between the discriminability means showed that abnormal and normal falls were overall differentiated more accurately when the tree had fallen 30-45^0 than when scarf cutting was complete or the tree has visibly lifted.

There was a significant interaction between group and stages, mult. $\underline{F}$ (4, 136) = 2.78, p < .05, and at the univariate level the differences were again restricted to discriminability, $\underline{F}$ (2, 68) = 3.36, p < .05. Multiple comparisons showed that tree-fellers were significantly more accurate in predicting outcome than forestry students when scarf cutting was complete and when the tree had lifted visibly, but not when the tree had fallen 30-45^0 from vertical.

There was a significant difference between tree-fellers and forestry students in response bias, $\underline{F}$ (1, 34) = 12.93, p < .01, but for response bias the interaction between group and stage in felling was not significant, $\underline{F}$ (2, 32) = 2.97, p > .05. Since the forestry students had lower mean B values than the tree-fellers, they were the more likely group when making judgements to report that a display was an instance of an abnormal fall. The forestry students were thus not only less skilled than the tree fellers in distinguishing between normally and abnormally falling trees, but they were biased towards false alarms when making judgements.

Table 4.1 Mean sensitivity and response bias values for tree-fellers and forestry students at 3 stages in felling.

	Sensitivity P(A)				Response bias (B)			
	Tree-fellers		Forestry students		Tree-fellers		Forestry students	
Stage	Mean	sd	Mean	sd	Mean	sd	Mean	sd
Scarf cuts complete	2.20	.48	1.64	.33	3.50	1.01	2.72	1.02
Tree vis lifted	2.08	.29	1.76	.23	4.22	.73	2.72	1.13
Tree fallen 30-45^0	2.23	.32	2.01	.37	3.83	1.10	2.83	1.29

A further multivariate analysis of variance was undertaken in order to compare the performance of the nine tree-fellers who had received recent on-the-job training from a company instructor and the nine tree-fellers who had not been given such training. Discriminability and response bias values were the dependent variables in this analysis, while group membership and stages in felling were the independent variables. Judgements of outcome did not differ significantly between the two groups, mult. F (2, 15) = 1.06, $p > .05$, or across the three stages in the simulation film, mult. F (4, 60) = 1.86, $p > .05$. The two independent variables did not have significant interactive influence, mult. F (4, 60) = 1.86, $p > .05$. Recent on-the-job training thus had no significant effects on simulation judgements made by the tree-fellers.

4.4 Discussion

4.4.1 The two groups

The tree-fellers differed from the forestry students in the extent to which they could extract from video-recordings information as to whether a tree was falling normally or abnormally. The tree-fellers as a group demonstrated the ability to "read" a tree, while the forestry students could essentially do no better than chance in the first two stages. Performance on the part of tree-fellers was a peak level when scarf cutting was complete (typically several minutes before the tree hit the ground), and viewing the tree later on when it was visibly lifting or had fallen 30-45^0 from vertical did not improve discriminability. In contrast, the forestry students were most accurate in identifying outcome when the tree had fallen 30-45^0 from vertical (and was within a second or so of hitting the ground), and their assessment of outcome at earlier stages in cutting was not much greater than chance discrimination.

The results show that tree-fellers are skilled in processing information relevant to whether a tree will fall normally or abnormally. The skill is related to the specific experience of tree-fellers, since other individuals who had knowledge of the forest environment but lacked experience in felling trees could not assess outcome accurately until very late in the fall. The aspects of experiences that are important, and the types of information employed in making judgements, merit investigation in further research. The decision processes through which outcome is assessed accurately can be identified by asking subjects to report after each judgement the rationale for their response. The limited period for which tree-fellers were available for testing in the present study precluded use of this approach. As a further strategy for investigation of information processing, parts of the display can be masked or subject to distortion to establish whether loss of specific information lowers accuracy in decision making.

The tree-fellers differed in terms of the period over which they had worked in this occupation, and in terms of whether they had recently received field instruction. However, years of experience was not correlated with accuracy in discriminating abnormally and normally falling trees ($r = -.11$, $n=17$, $p > .05$). In terms of discriminability indices, there was substantial variability among the 18 tree-fellers. The transformed P(A) values ranged from 1.50 to 2.41 for the judgements obtained when scarf cutting was complete, and from 1.79 to 2.54 for assessments of outcome when the tree had fallen 30-45^0. Neither the basis for individual variability nor the importance of individual differences on the signal detection task for performance under normal working conditions in the forest could be established on the basis of the data collected in the study.

The objective of assessing performance on the signal detection task was to study under more controlled conditions judgements based on the type of information that tree-fellers have access to when making decisions in their work environment. Whether the videorecordings did in fact provide the information that tree-fellers use in appraising a tree they are about to fell was not directly under study. However, it would need to be demonstrated that discriminability and response bias as assessed through signal detection analysis correlate highly with skilled performance in tree-felling before measures obtained on the signal detection task can be used for purposes such as selection of personnel, training tree-fellers in information processing and decision making, and evaluating levels of competence. In settings such as medical diagnosis, improved levels of skill in practical decision making have been achieved by providing originally inexpert workers with extensive training on a signal detection task (see Lusted, 1972; Swets and Pickett, 1982). These gains have been demonstrated when the analogue setting (signal detection task) has closely resembled the work context (diagnosis). It has been shown in the present study that tree-fellers can discriminate trees that will fall abnormally from trees that fall normally by the time scarf cutting is complete (several minutes before the tree falls). A question of interest is whether training in the use of information of the type provided in the videorecordings will benefit decision making and other aspects of performance during felling in the forest.

4.4.2 Reliability and validity

A question can be raised regarding the use of a two dimensional television image as opposed to slides, or the stereoscopic stimuli used by Blignaut (1979). The need for dynamic information on the execution of the scarf and back cuts was considered essential by the experienced instructors who were consulted regarding the simulation material. Three dimensional perspective was lacking but some writers have argued for the use of video images in performance measurement studies (e.g., Kennedy et al., 1982; Nunneley, Reader and Moldonado, 1982). In the simulation visual and auditory cues were available to the subject but the tactile one of feedback through the saw, as well as the visual one of being able to look up at the head of the tree from the base position as it starts to lift, were not. The size of the screen image could also be seen as reducing the validity of the simulation because the full panorama of the the fall was not available, and the retinal image was not as it would have been in the forest situation. A further question exists as to whether using three stages of information was valid in view of the brief average duration of a fall. Blignaut (1979) in using three levels of danger in each his simulations of loose rock could see no better solution, and indeed did not include dynamic movement. In the job the escape signal detection phase of a tree's fall occurs in an average 2.4 seconds (if the data and calculations of Guimier (1980) are accepted). The increasing performance of the control group over the three stages suggests it is feasible to examine stages in information processing prior to impact.

The strongest evidence of stimulus fidelity is the clear discrimination of the normal falls from abnormal ones. The subjects were picking up relevant information even if its basis could not be clearly articulated. The substantial differences in the proportion of hits and misses between the 18 subjects in the abnormal episodes also lends weight to this opinion. It is most unlikely that these patterns of response occurred by chance.

The differences in discriminability between the experienced worker and control groups were not large. On the other hand, however, failure to identify one abnormal fall in five would be a serious cause for concern in the field situation. Loss of statistical power relates not only to the restricted number of signal detection trials that were possible, but to the essentially skewed clustering of the normal falls at one end of the distribution of certainty ratings. Cautions to be considered particularly when false alarm rates are quite low are discussed by Long and Wang (1981) who suggest that even if signal detection theory is appropriate, "meaningful and independent estimates of sensitivity and criterion as represented by the d and B scores are not automatically forthcoming from a signal detection analysis ... caution would appear particularly appropriate in applied contexts in which additional processes like attention or learning may be involved or where, for practical reasons, rather limited trials are employed" (p.230).

From the outset, the recognised limitation of the sensitivity and bias analysis was the small number of signal+noise and noise alone trials that were feasible with these subjects in the time available and the home setting. The content of the simulation in placing skilled subjects in a controlled test situation was thought to justify the attempt and counterbalance this weakness. The length of each assessment episode was edited to the minimum possible, while still allowing a realistic set of felling episodes on the screen. In the final event a greater number of trials would have improved the statistical reliability of the study. The calculated P(A) values must be seen, quite rightly, as only approximations based on the proportional coding of a limited data set of 10 trials.

There are many interlocking components in the skills necessary to survive in felling work. Even small improvements in a bushman's ability to pick potentially dangerous falls will increase the chances of survival. In terms of the external validity of the simulation, the results suggest tree-fellers do become aware of the cues associated with an abnormal fall and with the passage of time they develop a degree of skill in using these cues and information. However, do the statistically significant differences between worker and control groups represent large enough differences in the practical situation? In the actual job the worker only has time to make his initial assessment of the fall in a conscious and relatively leisured manner. Other stages in the simulation may be partially redundant from the escape calculation point of view, except in the sense of split second and automatic responses. The performance of the control group did improve with the additional information at each stage to nearly the same level as the tree-fellers. It is also possible the tree feller group responded to the simulation in a realistic fashion in that once the tree moves there is little time to make further conscious decisions.

4.4.3 Further research

Further research should focus on the basis of pre-crash predictions before any tree movement takes place. The link between anticipation of outcome and the failure to use prescribed technique needs to be more thoroughly explored in unskilled and expert workers. In view of the proven need for feedback in maintaining signal detection performance, it would be useful to know whether the feedback available to these men when their cuts and judgements for a normal fall are wrong is adequately understood and classified by them. It is also necessary to have a clearer understanding of how the relevant near-accidents are recalled to the best effect in other dangerous situations. In spite of prior claims to the contrary, the instruction/no-instruction analysis demonstrated that field instruction does not appear to give such men a greater advantage over their untrained peers in identifying an abnormal fall. The results suggest that current instruction in the field gives no significant improvement in these specific perceptual-escape skills gained through day to day experience. An obvious question is whether a different type of instruction employing more sophisticated simulations would produce a larger difference between experienced and novice workers as well as instructed/non-instructed ones. The study suggests that the idea of anticipatory escape is in part a convenient myth for management in terms of the set escape path regulation and for the feller in the form of a misguided defence mechanism. The fact remains that these fine discriminations in variation of the abnormal fall in the bush should be one of the things that separates the skilled from the unskilled. It is as yet unproven. Because of the relatively small difference between experienced felling workers and the control subjects at the final stage of information in the fall, there can be little doubt that the problem of signal detection differences during the actual fall requires more detailed research work.

Chapter 5

Conclusions and further work

Chapter 5

Conclusions and directions for further work

5.1 Summary of chapters and results

The aim of the thesis was to test four key components underlying a model of the work performance of a group of high-risk rural workers, namely: (a) physical work effort in the form of oxygen consumption and heart rate, (b) the judgement and prediction of dangerous work outcomes, (c) felling accuracy on the job, and (d) signal detection in a critical final phase of the work cycle. These issues were examined through measures taken in the forest work setting as well as in a controlled simulation. The set of separate but inter-related studies can be considered a starting point in testing a model of ergonomic demands in hardwood felling. Without such basic research more advanced theoretical work with this occupation, and others like it, is premature. Overall, it was hoped to advance a more scientific explanation of performance failures and error for this particular type of high-risk outdoor worker.

The first chapter reviewed the models and studies of factors thought to be involved in tree feller accidents and introduced the behavioural-ergonomics orientation of the thesis, while the literature review in chapter 2 examined the issue of the measurement of tree feller effort and explored the assumed role of physical workload in felling errors. The literature review of chapter 3 emphasised the need to investigate judgement and physical skills in the forest with an observational-interview style approach. An exploratory model was proposed of judgement and decision factors connected with the felling accuracy and day-to-day survival amongst falling trees. The third chapter also highlighted both the necessity and difficulty of applying the skill ergonomics approach (Singleton, 1979) to the fieldwork part of the thesis. In chapter 4 the rationale for using signal detection in testing a simulation of the men's discrimination in the escape phase of the tree felling cycle was given. In attempting to integrate these themes in a final chapter, the results reported in each of the three data chapters are briefly reviewed before overall conclusions are drawn.

In **chapter two**, where the match between the worker's physical working capacity and the demands of the job across a range of forest conditions was assessed, it was found that over 60% of the men in this representative sample could be placed in at least a high physical working capacity (VO_2 max) classification. Although absolute values of predicted physical working capacity (VO_2 max) were moderate or above for all but three subjects, actual predicted physical working capacity (corrected for age) was consistently higher in the worker groups above 30 years of age. This suggested both a training and a possible selective attrition effect in terms of the physical aspects of the job.

Physical effort as indexed by oxygen consumption gave average levels of energy expenditure which were lower than had been anticipated from the literature. Compared with a study of Australian softwood tree fellers (Fibiger and Henderson, 1982) and their data for felling and trimming, the hardwood subjects were under a lower level of average load (i.e., 30.4 vs 27.4 kJ/min) but the men experienced distinctly more delays imposed by the research than those in the softwood study. Such delays (which might sometimes also occur under production conditions) could act as recovery time in hardwood felling, especially for workers with lower working capacity. Only three workers exceeded the 50% limit for utilisation of capacity recommended for manual workers of a high physical working capacity classification. Although approximately half the group had utilisation of below 35% of VO_2 max, the utilisation of capacity was found to increase consistently with the age of the worker. The men in the above 40 age group had the highest average level of utilization at 41% of VO_2 max, but this could not be seen as excessive in view of their relatively higher physical working capacity and probably higher skill level. Large differences in energy expenditure and utilization of VO_2 max were found not only between subjects with the same class of physical working capacity, but in the same subject dealing with different size trees during the tests. Extrapolations from the higher levels of energy expenditure of 30-36 kJ/min found in the research suggested that between 40-46% of the sample would be operating at above 40% of their maximal physical capacity (VO_2 max) at such higher demand levels, and some 30% of the group at over 50% (VO_2 max), the maximum permissible limit for workers of very high PWC. However, the frequency of productive and non-productive delays in the working situation are important factors to take into consideration in such extrapolations.

Physical work effort indexed by the full day's heart rate measures indicated that the physical cost of the job was more strenuous than suggested by the more limited spot sampling of oxygen consumption on specially selected trees. Levels as high as 180 beats/min were found, with all subjects having average heart rate nett values above the 40 beats/min nett medical recommendation for an 8 hour work day (Hollmann et al., 1976; Hunting et al., 1974). It was argued that because of the heavier chainsaws and the amount of arm work involved (especially with the less experienced men), an over estimation of the VO_2 max base-line measure using the bicycle ergometer might have occurred. This in turn may have resulted in the percentage utilisation of VO_2 max being underestimated in the forest. No systematic upward trends in heart rate were evident across subjects, and the addition of the risk interviewing periods during the day prevented any firm conclusion on fatigue effects in relation to the heart rate measure.

In **chapter three** a model was developed of essential behaviours for tree felling accuracy and tree-to-tree survival. It was shown that noticeable felling error occurred for approximately half the sample of S-trees that were cut down in spite of the men being given specific instructions and ample time for maximum felling accuracy. A significant majority of these off-target trees occurred when the subject was placing the tree where he had perceived the tree's natural lean to be. Approximately two thirds of the error group (approximately one third of all test trees overall) had their average felling error in the 10^0-20^0 range. Close to one quarter of the men felled 50% or more of their set of S-trees with measurable error. There was no relationship between the two major performance indices of average felling error and the proportion of error trees in the man's overall set of S-trees. Approximately half of the 83 falls that were pulled from the perceived natural lean (31% overall) were not successful, and doubt as to the reliability of the perception of natural lean as a basis for chosen direction was prompted by these and the general error findings.

Of the overall ratings of certainty about the tree's perceived natural lean nearly half were at or below the equivocation level of a 50/50 rating of certainty. The men were significantly more certain about the direction in which they had chosen to fell the tree. The possibility was raised that men may have already decided on chosen felling direction before their first overt response during interview regarding the tree's natural lean. Thus in some cases the man's perception of natural lean may have subconsciously followed the preferred felling direction from the start of the tree assessment task. The men's certainty about the chosen felling direction did not correlate with certainty about the perceived natural direction of the tree. Even when the men were distinctly uncertain about the direction of natural lean of a tree the certainty about chosen felling direction remained very high in all but a handful of cases. The consistently low ratings on the tree's risk and awkwardness were not anticipated and added little to the understanding of judgement in the felling process and felling error. Individual ratings of certainty about the success of the chosen falling direction, although more variable across the sample than the risk judgements, were not correlated with felling error. Both the self assessments of performance by the men and the inadequate retreat distances confirmed the consistent pattern of over-confidence and unrealistic perceptions of control of felling in many of the tree fellers.

The **fourth chapter** tested the proposition that the tree feller has specialist ability in detecting abnormally falling trees as compared with a control group of people familiar with the forest environment but lacking tree felling experience. Multiple comparisons revealed that tree-fellers were significantly more accurate than forestry students in predicting the outcome in the early stage of making a fall, but that substantial differences between tree fellers in signal detection performance were evident. The discrimination performance of the group of tree fellers remained essentially the same at all three stages of information in the simulation rather than showing the sequential improvement of the control group, albeit to a slightly lower level of performance than the tree feller's in the last seconds of a fall. That is, experienced tree fellers can generally discriminate situations leading to danger several minutes ahead of a control group, but fundamentally they may not possess much greater accuracy than controls in the last moments during escape from a real falling tree.

5.2 Relationships between data chapters

5.2.1 The research strategy

The research combined forest observations with controlled testing of risk perception. The first task was close to normal felling in the forest and the physical workload involved, while allowing opportunity to interview the men on tree assessments and risk, as well as monitor cutting and retreat behaviour under realistic conditions. The second task was an analogue that focussed on a critical escape aspect of the job under more controlled conditions. Seen from another perspective the research assessed three important aspects of behaviours within the felling cycle, and sought to identify where failures or blocks occurred with a representative sample of workers. A further issue is whether the laboratory measure can be validated against the fieldwork results, although both are analogues of the real work-risk situation.

Though the results of each data chapter can be judged on their own merits, relationships between the different facets of the investigation can be identified by combining data across studies. Correlations between all of the main variables of the three data chapters are given in full in Appendix 33. In this appendix the correlation matrix is presented in the four main blocks of:

(i) the physical-biographical variables;
(ii) those variables concerned with medical characteristics and work physiology;
(iii) the psychological characteristics that were measured by questionnaire, and;
(iv) the judgement and performance measures both in the field, and in the first stage of the signal detection simulation.

The interpretation of simple bivariate correlations drawn from a large matrix has its pitfalls and some caution is required in interpreting results. Firstly, one can expect to find significant results by chance to the level and proportion of the significance level one sets for a Type 1 error, in this case, $\alpha = .05$, in the overall correlation matrix. Secondly, statistics such as the average, in the case of certainty ratings for example, may be distorted by effects such as regression to the mean or the inherent unreliability of the measures used (Kerlinger, 1986). The question of attenuation of range must also be considered, since it can lead to an artificial reduction of the correlation (Skinner, 1984). Measures for risk and awkwardness were omitted from the overall analysis for this reason. In addition, it must be remembered that product moment correlations in particular assess linear relationships. Tables 5.1 - 5.4 in the following sections take up specific questions of interest on relationships between variables and the studies within the thesis.

Within the set of biological-biographical characteristics of the men, both age and experience, and weight and height were strongly correlated as expected (Table 5.1). However, weight was the only direct attribute of the men that was correlated with the predicted VO_2 max values calculated from the bicycle ergometer test ($r = .57$, $n=39$. $p < .001$). The question of the relationships between the basic characteristics of the men, the work physiology, and the felling outcome is addressed below.

In the set of four physiological field outcomes (VO_2; %-util VO_2; Hr Abs; Hr nett) (Table 5.1), the age of the tree feller was positively correlated to the average %-utilisation of VO_2, $r = .42$, $n=34$. $p < .01$, but not to any other field measure. One interpretation of this age - %-utilisation correlation is that utilization of physical working capacity depends more on motivational factors associated with age than on simple physical antecedents. Both weight and height were significantly associated with the average energy expenditure (Weight: $r = .55$, $n=34$, $p < .001$), (Height: $r = .47$, $n=34$. $p < .01$), but not with the %-utilisation of predicted VO_2 max. There was no association between weight or height and the heart rate measures. Experience in the job was not related to any of the field outcomes including average felling error. Heart rate nett was negatively correlated with resting heart rate ($r = -.48$, $n=39$, $p < .001$). This would be expected because of the strenuous nature of a blue collar job such as felling and the action of the law of initial value. Predicted VO_2

Table 5.1 Biological - biographic variables and the main physiological outcomes and average felling error.

	Biological - Biographic Variables							Field Outcomes (Averages)			
	Age	Wt	Ht	Exp	Hr Rest	VO_2 max	Av VO_2	% ut VO_2	Hr Absol	Av Hr nett	Av Error
Age	1.00	-.17	.30	.70***	.00	-.24	.24	.42**	.12	.12	-.10
Wt		--	.51***	.00	.00	.57***	.55***	.00	-.11	.00	.06
Ht			--	.13	-.12	.37	.47**	.10	-.13	.00	-.06
Experience				--	.00	.00	.11	.14	.00	.00	-.08
Hr Rest					--	.00	.00	.00	.00	-.48***	-.13
VO_2 max (B/line)						--	.32	-.59***	-.45***	-.21	.26
Av VO_2							--	.53***	.03	.00	.00
% util VO_2								--	.54***	.32	-.27
HR absol									----	.78***	-.13
Av Hr nett										---	.13
Av Error											1.00

* $p < .05$ ** $p < .01$ *** $p < .001$

max of the men was correlated with the %-utilisation of VO_2 max, but in the opposite direction to that expected (r = -.59, n=34, p < .001); and in contrast to the positive age - %-utilisation relationship detailed above. Finally, the predicted VO_2 max was significantly correlated with the average absolute heart rate for each man (r = -.49, n=38, p < .001), which is consistent with the fact that as %-utilisation of VO_2 max increases the heart rate would also be expected to increase (Astrand and Rodahl, 1977 p.347-352).

As shown in Table 5.1, the key measure of average felling error was not related to any of the biological-biographic variables, particularly months of experience in felling, nor to the physical workload in terms of either oxygen consumption or heart rate. In concert with the data for individual trees in chapter 3, these results (based on average values across subjects) strongly indicate that physiological workload is not directly related to the man's felling error, either individually or on average over a working day.

As discussed in chapter 1, the general models of logging accidents in the literature have placed some emphasis on the role of stable personality characteristics in the problem of logger "risk-taking" and accidents. An attempt was made to test this issue using a fatalism/locus of control measure and the three sub-scales of the Jenkins Activity Survey.

Table 5.2 Correlations between four psychological questionnaire measures and main outcomes in the two analogues of felling.

	Field (n=35)				Simulation (n=17)
	Av Hr nett	Av % util	Av Cert	Av Error	P(A) Stage 1
Fatalism -	.16	.20	-.07	.08	.03
Type A -	.37*	-.03	.00	.00	-.25
Speed/Impatience -	.38*	.27	.00	.00	.00
Hard/driving -	.04	.09	.00	.25	.25

* $p < .05$ ** $p < .01$ *** $p < .001$

As shown in Table 5.2 there are significant correlations between two of the psychological measures and the average physiological response of hr nett, but neither average certainty about chosen felling direction, felling error itself, nor performance at stage one in the simulation is related to these selected psychological attributes of the men. The fatalism measure that featured so prominently in discussions with instructors and experienced tree fellers does not correlate with any of the outcome measures of the study. The significant correlation between heart rate nett and the first two of the Jenkins Activity scales (Type-A, $r = .37$, $n=34$, $p < .016$; speed and impatience, $r = .38$, $n=33$, $p < .014$), are in the expected direction and serve to suggest that hr nett is the more consistent of the two work physiology parameters that were used in the research. Although the range of psychological scales employed in the study was strictly limited, these results argue firmly against these and similar personality characteristics being involved in performance failures in felling work.

When men had made significant felling errors during the day they were mainly found to be unaware or unwilling to recognise this fact. At the end of the field research day the expert interviewer-observer made general ratings of each man's skill in four areas of the job. None of these four skill ratings on each man was associated with the basic subject variables of age or experience (see Appendix 33). Out of the potentially important rating cues of weight and height, weight was significantly associated with "avoiding danger as the tree falls" (Sk3) ($r = .44$, $n=39$, $p < .005$). This might indicate that the rating of at least one aspect of a man's skill is dependent on something as fundamental as the man's size and physique.

Table 5.3 Intercorrelation between instructors skill ratings and main outcomes of the study.

	Physiology			Felling Error	
	Field VO_2	%-util VO_2 max	Hr nett	Av'ge	Prop.
Sk1 (Base) [a]	.25	.27	.22	-.33	-.42**
Sk2 (Scarf)	.37	.35	.17	-.43**	-.19
Sk3 (Avoid)	.41**	.25	.00	-.25	-.41**
Sk4 (Saw)	.00	.00	.00	-.20	-.34

* $p < .05$ ** $p < .01$ *** $p < .001$

[a] See over page.

The four different instructor ratings of each mans skill in:
(Sk1) preparing around the base of the tree prior to actual cutting
(Sk2) making the scarf in the front of the tree
(Sk3) control of the saw in terms of cutting accuracy
(Sk4) avoiding danger as the tree falls

The correlations between the four skill ratings of the expert interviewer-observer on the one hand, and the physiological outcomes, average S-tree error and proportion of trees with error on the other, are given in Table 5.3. The only statistically significant connection of rated skill to work physiology was between "avoiding danger as the tree falls" (Sk3) and the average energy expenditure in the field, $r = .41$, $n=38$. $p < .01$. None of the ratings of skill was related to the %-utilisation of VO_2 max or heart rate nett.

The only significant predictor of a man's average felling error is the rating of his skill in "making the scarf cuts" (Sk2), $r = -.43$, $n=29$, $p < .01$. Ratings of skill in "preparing around the base of the tree" (Sk1) and in "avoiding danger as the tree falls" (Sk3) were significantly correlated with the index of the proportion of trees in the man's S-tree test set that exhibited error, but not with average error. Several of these results confirm the expectation that (a) the proportion of error trees would be linked to the "clearness around the tree"(Sk1), which would facilitate working position while cutting the scarf etc; and (b) felling error would link with the "quality of scarf cutting"(Sk2). Why the proportion of S-trees with error would be linked to "avoiding danger as the tree falls"(Sk3) other than as a covariate or artifact is not clear, although the inter-correlation of Sk1 and Sk3 might be the common factor. There was no relationship between the P(A) performance in the simulation and the rated skill in "avoiding danger as the tree falls"(Sk3), which was the most likely candidate in terms of bush skills to be linked to the simulation performance (see Appendix 33).

5.2.2 Validation of the simulation

Earlier in the thesis it was suggested that accurate felling and signal detection in the escape phase might be related in terms of common underlying cognitive skills. Alternatively it could be suggested that there was no commonality between these two facets of tree feller performance. The relationship between the two analogues of the felling task thus needs to be considered. In the event, the largest correlation was that between average felling error and average P(A) value at stage 1 in the simulation, $r = .44$, $n=17$, $p < .05$ (Table 5.4). This result can be interpreted as a partially successful validation of the simulation test. However, there were only low correlations of average felling error with P(A) values at stages two and three of the simulation. At the same time it should be recognised that data on the signal detection simulation were only available for 17 tree fellers.

Table 5.4 The relationship between the average felling error measure in the field and the P(A) values of the three stages of the signal detection simulation (n=17).

	Average Felling error	P (A) Stage 1	Stage 2	Stage3
Av Fell Error	1.00	0.44*	0.17	0.10
Stage 1		1.00	0.19	0.28
Stage 2			1.00	0.83***
Stage 3				1.00

* $p < .05$ ** $p < .01$ *** $p < .001$

5.2.3 The final view

The research demonstrated that the combination of the skill ergonomics approach and an experimental methodology is feasible in research on tree feller skill and job performance. Thus, reliable measures of percepts, judgements, and outcomes can be obtained with such a high-risk blue collar sample in their own working environment, and in a simulation of part of the overall task. It has also been established that it is probably a mistake to assume a continuation of the reputed skills of tree judgement and control of the selective logging axe and crosscut days into the relatively new era of the modern high-production chainsaw feller. The results call into question some of the central skill and safety myths of the occupation of the hardwood and large timber tree feller. In addition two elements of the generic model of logging accidents described in chapter 1 (Lagerlof, 1979) were not supported in that, first, physical workload was not found to be linked directly to felling error; and second, the two personality measures selected on the basis of the literature and instructor recommendations were not associated with the main field outcomes in the study.

This was a study of real skills in a dangerous outdoor rural occupation (Rasmussen, 1985; Singleton, 1979). The man-chainsaw-tree system is a dynamic but relatively simple one in comparison with the the task of the high-technology process operator. Yet the conclusion has to be drawn from this diverse sample of felling workers that it is not a case of "the voluntary acceptance of carefully calculated risk with consistently accurate outcomes", but more a "pattern of inevitable and very normal errors of which the worker is not fully aware," (p.137). There was ample evidence of the difficulty many of the research subjects had with the cognitive aspects of the work in particular, and in their discerning that such flaws in their own performance existed. Such results with a sample of the high-risk "blue-collar" workers present a challenge to the current literature on the cognitive skills of the "white-collar" process controller (e.g., Rasmussen, 1986).

Anticipation, or lead, as one of the three cornerstones of skilled performance was discussed in chapter three (p.90). The man's subjective responses to the tree and the "reading" of it are said to enable him to anticipate how the tree would behave during the fall (e.g., Dent, 1974; FAO, 1980). In the current research the certainty of achieving an accurate fall was *the* critical subjective judgement. Fieldwork, with all its pitfalls, demonstrated that no consistent link existed between this judgement and final felling accuracy. These results and the extent of error across nearly all subjects demonstrated that many of the men in the sample were not able to "read" and control the tree in the way it is generally assumed. Results from different parts of the research converged to show that there would be regular occurrences in the work where the man is unable to predict how the tree will behave, and precisely where it will fall. This occurred even on some of the occasions where the commonly recommended scarf cuts had been made by the worker. It might therefore be suggested that the hardwood tree feller cannot be seen as genuinely skilled in the technical-ergonomic sense in this critical part of the job, simply because there is little evidence of consistent anticipation and lead in an important cognitive and decision-making area of the job. Such an assertion about cognitive skill does not detract from the fact that considerable physical and chainsaw handling skills may still be present, but without the appropriate level of judgement and anticipation skills, high levels of physical skill may mean very little to the survival of the tree feller.

A contrary view to that proposed in the thesis is that it was gratifying that approximately half of the test trees were fallen accurately, rather than the fact that half were not. As discussed in chapter 3 (p.137) it may be possible that accurate prediction of felling direction as defined in the study (and work-technique manuals i.e., within 5^0) is impossible, and only a more general margin for error of, for example 20^0, or even greater with particular types of trees, will be possible (no matter what the skill and experience of the feller). Are such wider margins of error adequate in the native hardwood and tropical forest, and is this the fundamental reason for the great preponderance of injuries and deaths (reported in chapter 1) being associated post hoc with the "tree not falling as planned"? The question thus becomes one of determining these wider margins of error with different classes of tree feller, and different types of trees, especially in relation to the mythology of the precise picking of the fall which is prevalent in the current work-technique manuals, as well as among the workers themselves.

In discussing the acquisition of high level practical skills Neisser (1980) asks the perennial question of what determines the limits of skilled human performance in different settings. His answer is that certain skills have limitations because we have not sufficiently practised them, for "mind has probabilities but no capacity". In discussing Neisser (1980), Kinsbourne (1981) proposes that "what occurs at the asymptote of practice is presumably an information-processing sequence which is maximally efficient because it unrolls in predetermined fashion *without response uncertainty*" [his emphasis] (p.77). Response uncertainty however, as Kinsbourne points out, can be inbuilt in a task in terms of the residual ambiguity of subtle choices between responses that might all be labelled correct, and the finer and finer discrimination of incoming task information with experience. Given the range of variables tested in the thesis and the more difficult and dangerous trees that were observed, it seems highly unlikely that any hardwood tree feller, in theory or practice, could reach the stage of having negligible response uncertainty with such trees. We also have the subtle opportunities for serious error at several stages in the felling cycle, as Singleton (1973) clearly describes (chapter 3 p.93).

In Sweden, where the greatest effort world-wide has been put into tree feller training over a more than a decade and where the trees are smaller and virtually without defect (as one might find in future Australian eucalypt plantations), a significant level of injuries and fatalities is still occurring in the felling workforce (Broberg, 1986). The current research demonstrates that high levels of reliability in the prediction of felling error on a single tree by the worker themselves, and/or the accurate prediction of average felling error in a set of trees nominated by the researcher, remain unattainable at the present time. There is thus a weight of empirical evidence to throw serious doubt on the viewpoint expressed by Paulozzi (1987) (see p.14) that significant reduction of tree feller injuries will be achieved by wider use of the current training methods, more regulation, or greater inspectorial efforts. In terms of the goal of reducing response uncertainty through greater ergonomic research effort, and greater development of tree reading skills in the era of the chainsaw, no "safe" limits can be set for the job of hardwood felling. There has possibly been too much reliance on making the regulation scarf cuts and preparing the regulation style escape routes, and not enough emphasis on work technique flexibility and the proper understanding of the underlying skills and limitations involved in the work. Possibly the issue of minimising risk in differing felling situations should be considered rather than following rigid regulations and procedures that give all parties the illusion of safe working. If anything, it is the nature of the trees rather than the characteristics of men that prevents one set of safe regulations and limits being applicable across all felling circumstances. The skill is in matching behaviour to circumstances on a tree by tree basis.

5.3 Further work

5.3.1 Further research

Before considering what might be done to make the performance of the hardwood fellers in the 1990s more safe and predictable, it is appropriate to ask whether further ergonomic research on this occupational group is warranted. Native forest timber fellers will be required in the forests of North America, in tropical hardwood forests and in Australia for the foreseeable future (e.g., FAO, 1980; Risby, 1987). Other recent studies have recommended increased ergonomic research in this area (Paulozzi, 1987; Holman et al., 1987). The present research has explored selected parts of the model of tree feller performance in some depth. In discussing further work in this area the research aspects are interwoven with the possible application of results. Unless more than the improvement of scientific theories is offered to such a group as hardwood fellers, further research cooperation from these men who risk serious injury on a day-to-day basis cannot be expected.

In spite of the inconclusive result in relation to physical workload and felling error rates, basic work physiology remains an important issue in this Australian example of the hardwood tree feller occupation. Walking, climbing, clambering and carrying a chainsaw, axe, and tools all require physical strength and fitness. The younger, newer, and sometimes more sedentary workers in the study generally revealed lower capacity and lower utilisation of capacity in comparison with the older and often larger and fitter, experienced men. Consequently, the concept of a single physical work capacity test (PWC) being sufficient for selection to such an occupation as hardwood felling needs to be re-considered. This may be part of the wider changes in the applied work physiology literature that were previously discussed in chapter 2 (e.g., Petrofsky and Lind, 1978a). A more compartmentalized PWC test, which is indicated by the research, should include arm and upper body work, and could be incorporated in any pre-employment medical scheme in the industry in the 1990s. A subsidiary field test that involves carrying the chainsaw in different terrain and cutting in different positions and at different levels might also be possible, and data from such tests should form a work physiology and physical skills profile of future cohorts of hardwood timber fellers in each state (elements of such an approach were being used by some instructors during the study). The question of employing sub-maximal or maximal PWC tests is yet to be determined. Pre-employment medicals and physical work hardening can be recommended for new entrants to the industry, as is common practice in other high-risk industries (Carson 1985, Mueller, Mohr, Rice, and Clemmer, 1987).

The role of work physiology in other types of operator error, as well as felling error, has still not been fully resolved, mainly because the men in the fieldwork were not operating at the limits of their physiological capacity except in three extreme cases. There is a firm need for the work physiology results of the research to be replicated under Australian or possibly other Pacific Basin forest conditions. The most important requirement is for a further study on a smaller sample of new entrants to the industry. What might be feasible is a combination of working beyond 40% or 50% of VO_2 max levels on a chainsaw carrying and cutting task, in combination with an improved version of the signal detection simulation that could be used at the same time in the laboratory or the field situation.

The results with the personality characteristics measured in the thesis give little encouragement to put limited resources into measures of this particular type in future field research. This conclusion does not, however, remove the need to consider stable psychological attributes of worker in future questionnaire or survey style research. Further work would need to build on the pioneering study of Lindstrum and Sunstrom-Frisk (1976). The significant problem of unrealistic and over-confident views of their own performance, and possibly denial in the psycho-dynamic sense, needs to be addressed in future work (McKenna and Hall, 1982). One possibility may be to look more at the personal constructs of the tree feller about the work group and logging management which may encourage him to adopt some of the behaviours found in this study (Brett, 1984).

The whole folklore of the accurate perception of the natural lean of the usually non-uniform eucalypt is brought into question by the results of the study. Further studies on this subject may have to await developments in the experimental literature on global versus specific cues in visual perception (see for example Navon, 1977, 1981a, 1981b). At least the question of how frequently the chosen felling direction actually comes before the supposed perception of natural lean needs to be clarified so that work-technique manuals can be amended where necessary.

Having carried out research on a representative sample of workers in this high risk environment, it is now appropriate to examine the performance of an elite group with improvements in the methods and measurement used in the present study. At the practical level it may be beneficial to study a small group of carefully selected subjects assessing a wide range of trees (without cutting them down), and seeing the commonality or diversity of information processing across subjects with a panel of expert bushmen as a benchmark. There is a need to study carefully matched subjects working in similar felling conditions, and if possible to explore performance of the reputedly top fellers on very carefully matched forest conditions. The reluctance of some of these "top men" to discuss or share what they see as their own hard won skills is a problem that may need to be overcome.

Any additional work on risk perception must look at the question of enhancing cues for specific risk factors rather than general risk. This work may link with that on the perception of natural lean and global versus specific cues in terms of methods and measures that may be adopted. There appears to be a need for greater understanding and acceptance of the necessity to discriminate between different types of risk on the part of the tree fellers. The use of the certainty rating scales in the current studies was considered to be a success and is recommended for use in further research.

The purely mechanical approach to felling performance might be described as "if the right cuts are made according to the work-technique manuals or regulations there will always be a safe and accurate fall". However, it would have been naive to believe that low-risk hardwood felling was simply a matter of making the regulation style cuts in the base of the tree (especially in the wide variety of trees and defect that were observed). The question under investigation was that of judgement-skill and anticipation, and not chainsaw handling skills *per se*. Field work confirmed that some trees do not always follow the line of the scarf that had been cut into the tree. In addition, results concurred with the injury statistics literature in that a significant proportion of workers are not making the or standard cuts i.e., at least 60% of the trees had scarf angles of less than the regulation 30^0, and that falling direction remained far from predictable in a significant proportion of falls. Some work has already been carried out on the mechanics of cutting in Australian hardwood felling (Crowe, 1985), and this could be developed further. Nonetheless, it should be emphasised that the feller is not simply a chainsaw manipulating robot, but a processor of information prior to and following the physical cuts to a tree. Further work should seek to establish the tree and psychological factors determining failure between the intention of the man in making the "adequate" or possibly his "best" cuts and the final quality of those cuts. Studies should include the examination of the action of a scarf that has been deliberately cut to provide face angles that deviate from the recommended pattern e.g., bottom faces on the scarf that slope away from the horizontal plane. The effect of over-cutting of hinge wood could also be objectively studied. Film material from these engineering studies could be then utilised (a) in signal detection studies that lead on from the simulation used in the current thesis, and (b) as training and testing material in the familiarisation of new fellers with the theory of the scarf and hinge in mature eucalypts, and the mechanical reasons that will cause felling error on the job. It may well be that accurate scarf cutting is a growing problem because in spite of the beliefs of some of the older workers, the younger elements in the workforce may not believe that felling accuracy is so important in terms of minimizing risk. While precision felling is only required in certain felling conditions, the connections between judgement, choice, the precision of the final cuts and directions, and final error in the fall requires further clarification.

Since the rating of the scarf quality (Sk2) of the feller by the expert-bushman of this study turned out to be best "predictor" of average felling error ($r = -.43$, $n=39$, $p < .01$), the rating of feller performance using such scales and tree stump measurements needs further investigation and refinement. The North American and Scandinavian chainsaw manuals recommend, some would say somewhat unrealistically, the "sighting" or "gunning" of nearly all trees. This neither feasible nor typical of the normal hardwood production situation. There are thus important implications for the evaluation of basic chainsaw cutting skills at the beginning of a tree fellers career, as the Scandinavian researchers in particular emphasise (Pettersson et al., 1983), and for on-the-job instruction with objective tests of cutting skills and exercises on a regular basis. These must form the basis for the licensing tests for professional hardwood tree fellers that should be operating by the early 1990s. Subjective ratings of practical skill, even if unstated, must form a large part of the bush instructor's assessments of the man on the job, and obviously needs greater research emphasis because of the results on the feller's highly over-confident self assessment that were found in the study. This might link into an applied research project of how the post-fall interview (used by the instructor-observer during the research) could be used in on-the-job testing, or by the men themselves in the case of major near accidents. These recommendations however would suffer the same problems as all incident/near-accident reporting programs (Carter and Menckel, 1985).

Accident statistics world-wide confirm that the majority of serious injuries occur during the actual fall of the tree (e.g., Broberg, 1986: Hoffle and Butora, 1980; Holman et al., 1987; McFarland, 1980; Strut, 1972). The present research revealed some of the mechanisms behind this fact. The partially successful validation of the signal detection paradigm warrants further research work. The early anticipation of the abnormal fall before the tree starts to move is important because detection of the abnormal fall signal 1-2 seconds before impact is simply too late for effective escape. The research question is thus one of how to enhance this discrimination in the new entrant to the industry. The creation of more sophisticated video graphics simulations using recent and relatively cheap advances in CAD-CAM, and where particular dimensions of the display can be manipulated, is a distinct possibility for this and other signal detection scenarios, such as in the case of widow makers for example. However, the validation of such simulations with field performance criteria would still be of paramount importance.

In keeping with conventional practice, this thesis and the studies that are proposed may serve to form a platform for a prospective study of the medical and ergonomic factors in the survival of the hardwood tree feller. Though not a direct part of the thesis the need for a reliable injury and incident recording system in the Australian hardwood logging industry is essential if long term evaluations are to take place (Purswell and Rumar, 1984).

5.3.2 The future professional

When working with an occupational group such as timber fellers one must naturally be wary of being too influenced by the stereotype and work mythology of the lumberjack that was described in chapter 1. This was not always easy during the different stages of the research. Few of the men completely matched the lumberjack stereotype in appearance or domestic circumstances. Many were family men. Many did not appear to completely understand some of the ergonomic realities of the job, and why indeed should they without research results such as those presented in the thesis. The question then becomes one of how is the hardwood feller to respond once he realises, both through such research as well as personal experience, what the ergonomic demands of the job really are?

In the hardwood feller workforce there will be those who will find it difficult to accept the results of the present study. This group will carry on with the job much as they did before. That is, either getting through the workday in as phlegmatic and low-risk way as possible, or continuing to take high-risk actions, but showing some of the forms of denial as demonstrated in the ratings of risk, awkwardness and certainty, and the self ratings of performance. A further group will be those men who have been willing to pursue strongly the different skills in the job that they realised might stand between them and serious injury. Geraghty (1981 p.260) puts the point well when speaking of the particular high-risk occupation of interest to him:

> The initial stimulus may be nothing more noble than adrenalin addiction. But for all dedicated risk sportsmen there is a learning curve: to overcome fear is to gain self respect, self possession and freedom unique in a secure, but increasingly claustrophobic, society bound by no doubt necessary rules. To win acceptance among a group who have found the same road to self respect is to join a community and achieve an identity not attainable in the fragmented isolation of urban life, the world of the electric light people.

While a number of hardwood timber fellers may see the opportunities, or indeed the necessity, of perceiving the job in this way, many appear locked in to the work for economic and demographic reasons. For those men who do understand the danger and continually challenging nature of the job, and who may appreciate both the aims and the results of this research, the camaraderie that Geraghty (1981) and Beckett (1983) sense is clearly evident in the forest, as well the wood chopping arena. High level skills require constant practice. Like any other high-risk professional some men appear to have learned to accept the inevitable problem of "response uncertainty", to use Kinsbourne's term, or "expecting the unexpected" to use theirs. They appear to appreciate that <u>every</u> tree is a new opportunity to practise life-saving skills, and that there is a need to maintain their very best level of fitness and agility, as well as to use the best equipment available. For others, and especially the young and inexperienced, the enigmatic working of chance may appear of equal importance to that of the many aspects of skill. The research study suggests, however, that there may not be as large a gap between the two types of hardwood feller, at least in terms of the probability of survival, as has generally been assumed.

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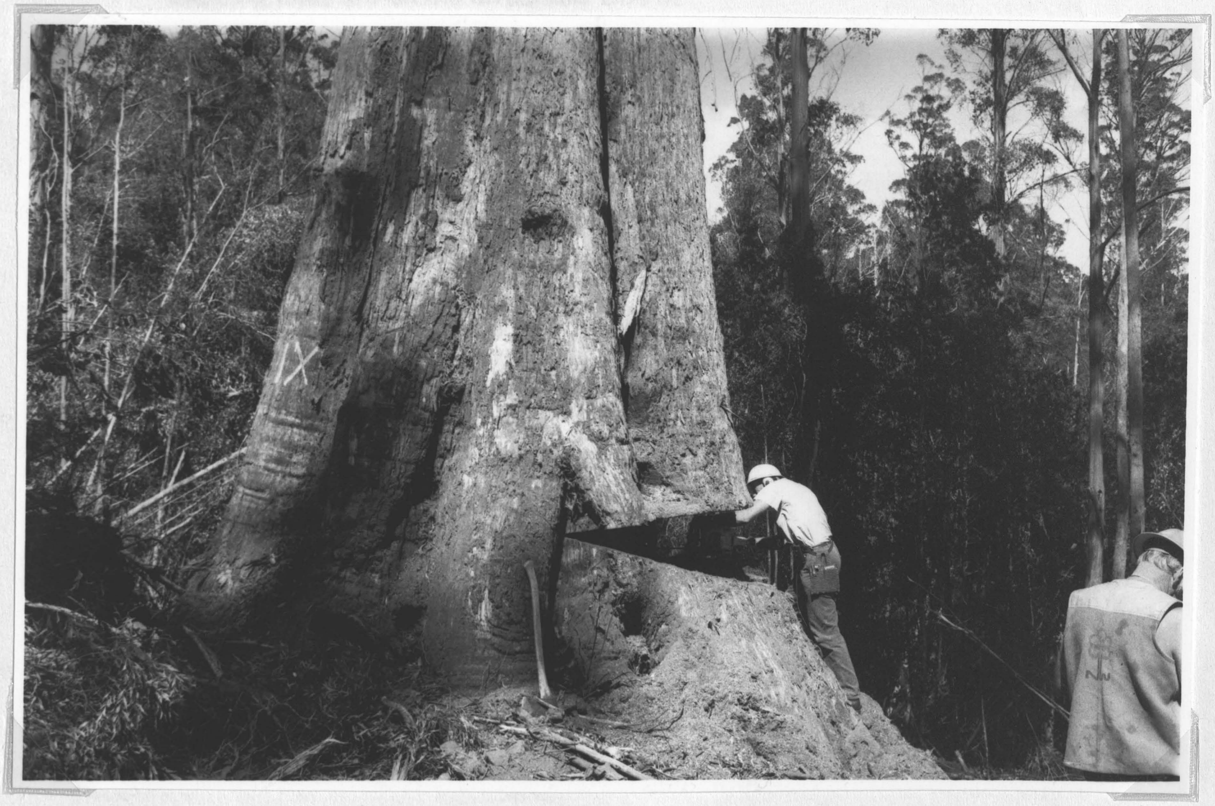
Appendices

Tradition and the Australian bushman.

Plate 1 Preparation of a blue gum pile with an adze and broad axe in the 1920s.

Plate 2 Felling a swamp gum with an axe and cross-cut.

Plate 3 A modern Tasmainian timber feller with chainsaws used for different size trees.



Appendix 2

Descriptive framework for consideration of forestry and logging working conditions

Ager (1978) provides one scheme to broadly describe the level of development of working conditions for forest workers. He suggested three case descriptions that could be used in assessing forestry and logging in any country:

Case I — Manual techniques under unfavourable socioeconomic and climatic conditions

Malnutrition, heat, poor living conditions, unstable employment, low pay, poor vocational training, high work load and accidents rates are some keywords in this case.

Case II — Moderately mechanized techniques under comparatively favourable socioeconomic and climatic conditions.

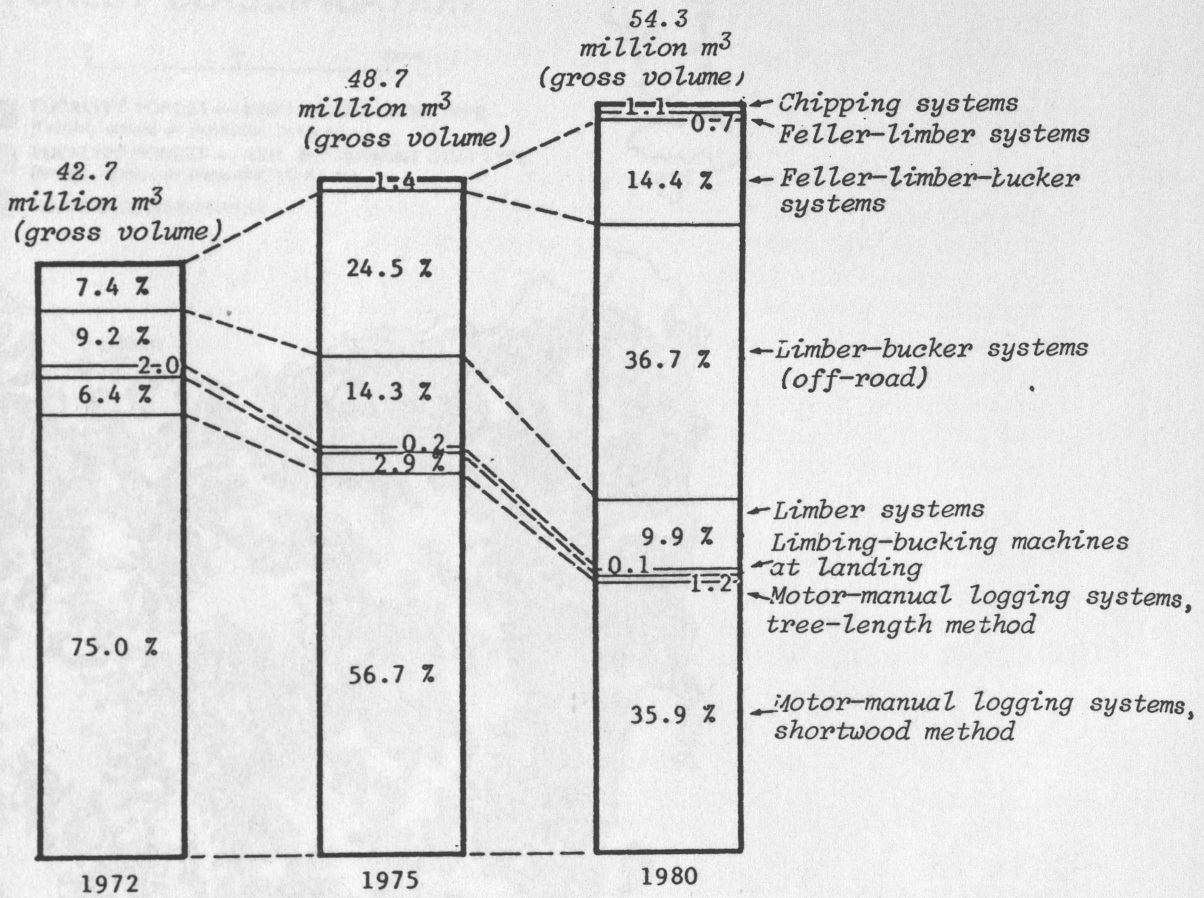
Low status of forest work, chainsaw-tractor operations, high work-load, noise and vibration and high accident rates are keywords picturing this case.

Case III — Highly mechanized techniques under favourable socioeconomic and climatic conditions.

Reasonably good operator comfort and reduced accident rates are on the favourable side in this case. But noise, lack of physical activity, monotony, mental strain and social isolation are some of the problems to remedy in this case.

Appendix 3

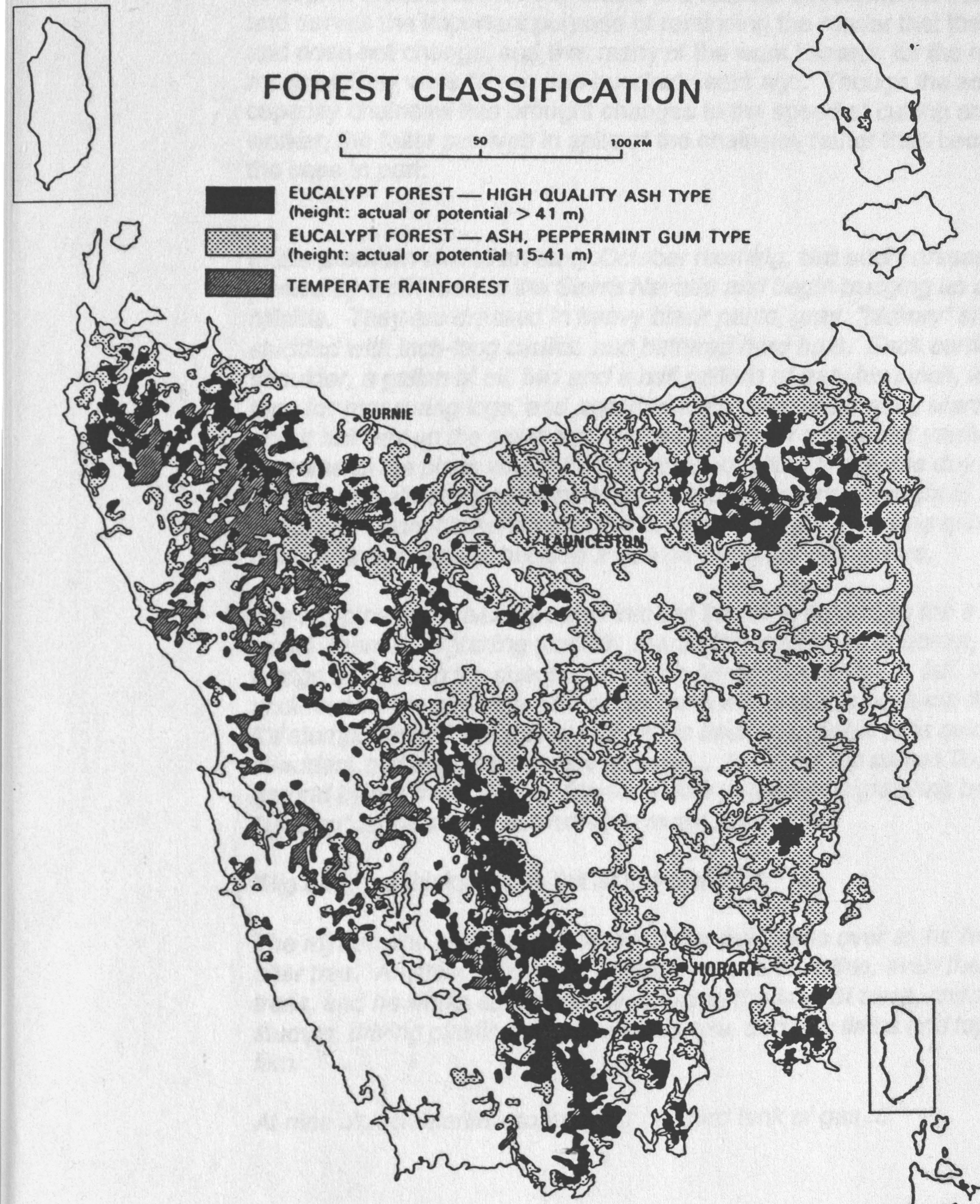
Mechanisation changes to Swedish logging systems 1972-1980 (Pettersson et al., 1983)

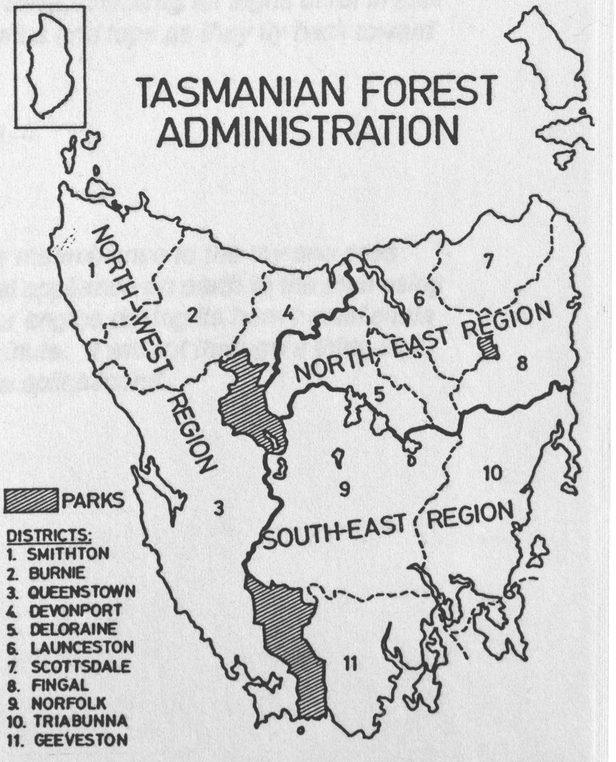


Appendix 4

Tasmania - Major forest types and areas

(map Australian Forestry, 1982, 45, 221-2)





Appendix 5

Excerpt from Hager (1980) "Proud fatalism or preventable death" - A job description.

The story behind injury statistics in native forest felling throughout the world has been eloquently described by Stan Hager (1980) who was himself an American lumberjack. Though a subjective view his article is a realistic description of the job at its most dangerous and serves the important purpose of reminding the reader that the forest has <u>not</u> changed and does not change, and that many of the work hazards for the natural forest faller remain much as they were fifty or one hundred years ago. Though the advent of the modern high capacity chainsaw has brought changes to the speed of cutting and productivity of the single worker, the faller survives in spite of the chainsaw rather than because of it. As Hager puts the case in part:

In the predawn chill of an early October morning, two oddly dressed men leave their pickup parked by a dirt road in the Sierra Nevada and begin trudging up a steep, brush-covered hillside. They are dressed in heavy black pants, gray "hickory" shirts, massive boots studded with inch-long caulks, and battered hard hats. Each carries a chain saw over his shoulder, a gallon of oil, two and a half gallons of gas, his lunch, water bag, axe, fifty-foot tape for measuring logs, and assorted tools. The older man, Martin, separates from his son about halfway up the slope and walks side-hill for a hundred yards or so in the blue-gray dimness to the place where he had stopped felling timber the day before. He is breathing heavily and already perspiring beneath the accustomed weight of his gear ...Working his way uphill , he hears his sons saw start ... and settle into a varying rythmic whine that tells him the boy is limbing and bucking a tree he felled the day before.

The big pine leans heavily uphill into the standing timber, its top a twenty foot spike of dead wood where the lightning stuck it. Martin first makes an undercut, chopping out a pie-shaped wedge of wood in the direction in which he wants the tree to fall. He then matches the undercut on the opposite side of the trunk with a single back-cut that will sever the tree from it's stump. Finishing the final inch of his back cut, Martin runs quickly side-hill as the tree shudders and begins its plunge to earth ... the snag top comes floating down to stick into the ground by the fresh stump. Martin, safely behind a neighboring bole, hears and feels a "whump" as his son, a quarter-mile away, fells a tree.

"Big one," he thinks, "to be felt at this distance."

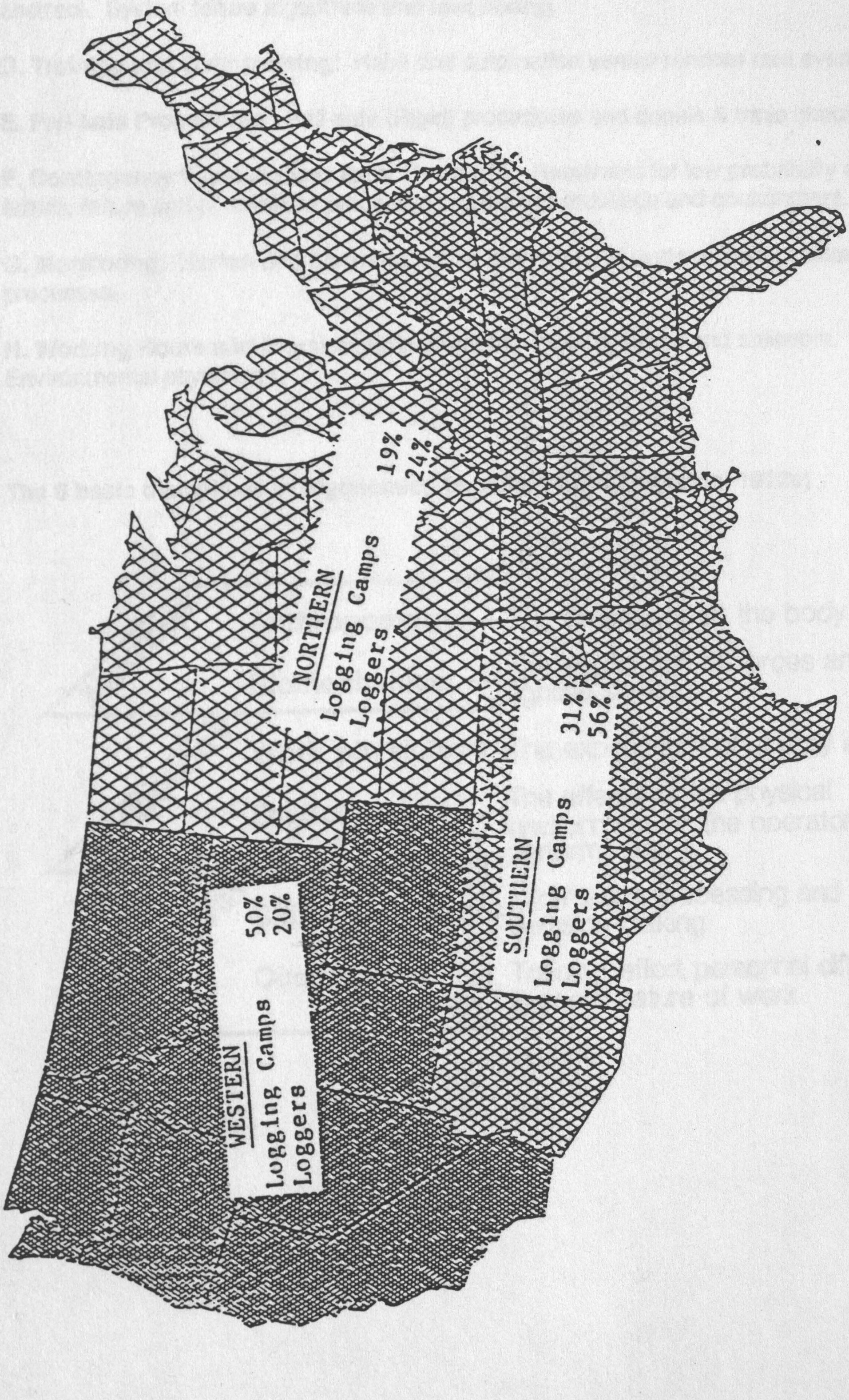
The rhythm, the working monotony of the day, takes over as he fells, limbs, and bucks tree after tree. Anything done long enough becomes routine, even the destruction of 200-foot-tall trees, and he works automatically, gauging the lean of trees, checking for signs of rot in their stumps, driving plastic wedges with his axe, dodging limbs and tops as they fly back toward him.

At nine o'clock Martin, stopping for his third tank of gas ...

... The timber faller's chief tool, a chain saw, bears little resemblance to the toy one sees advertised on television, and is arguably the most lethal appliance on earth to the man using it. My felling saw (a Stihl 090) has a fifteen-horsepower engine driving its heavy steel chain around a four-foot bar at the speed of 6,000 feet per minute. It will cut through a thirty-inch log in less then a minute and through an arm or leg in a split second.

Appendix 6

The three main American lumber regions



The total error reduction strategy and the six basic disciplines of ergonomics (Singleton, 1972a).

A. Work Organisation: Allocation of function man - machine - computer.

B. Tool, Sensors and Workplace Design: Specialist displays and equipment to augment human function, simulators of the system.

C. Selection, Personnel Skill Development: Internal models psychmotor, procedural, abstract. System failure algorithms and fault finding.

D. Training and Over-training: Habit and automation versus random rare events.

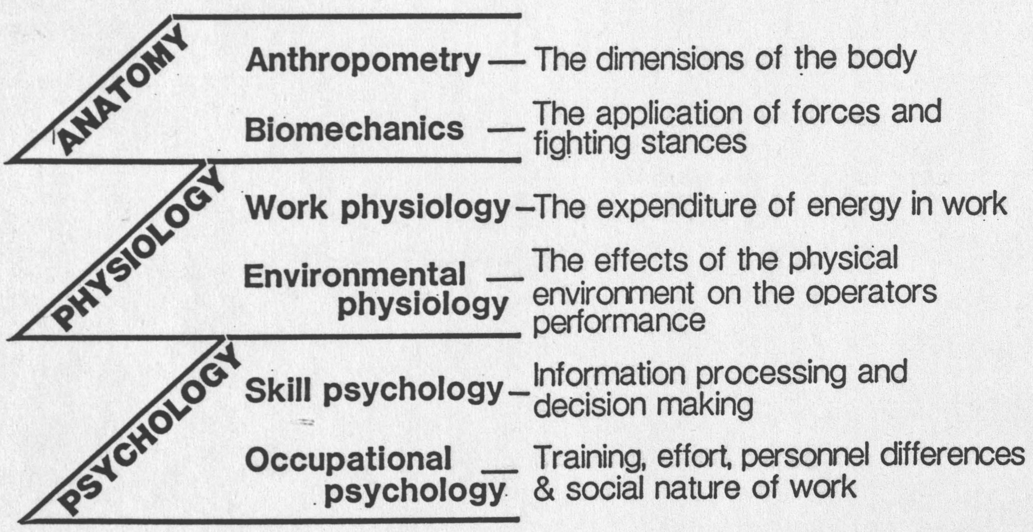
E. Fail-safe Procedures: Fail-safe (Rigid) procedures and double & triple checks.

F. Contingency Planning and Error Recovery: Readiness for low probability events. Pre-failure, failure and post-failure procedures. Damage reduction and containment.

G. Monitoring: Human and hardware based monitoring of system/product states and processes.

H. Working Hours and Physical Environment: Working hours and shiftwork. Vigilance. Environmental physiology.

The 6 basic disciplines in ergonomics (modified from Singleton, 1972a).



Appendix 8

Common law doctrine and voluntary risk.

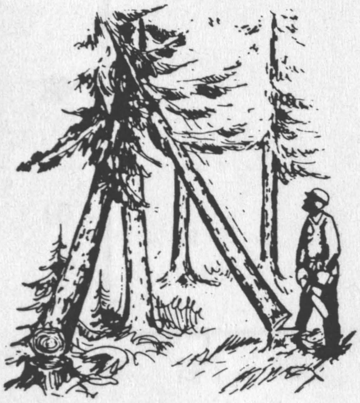
"A servant entering upon his employ saw and contemplated all the risks he would or might run and agreed to include them in all his wages and also that he had identified himself with all the others servants acting in the common employment; so that where an injury has happened through his own negligence he can have no remedy against his employer". Original source unknown, quotation dated (1886).

Appendix 9

Illustration material used in Ostberg's (1980) study of perceived risk in Swedish tree felling.

* The size of the trees should be noted.

C Freeing a lodged tree by felling the supportir tree.



D Freeing a lodged tree by felling across it.

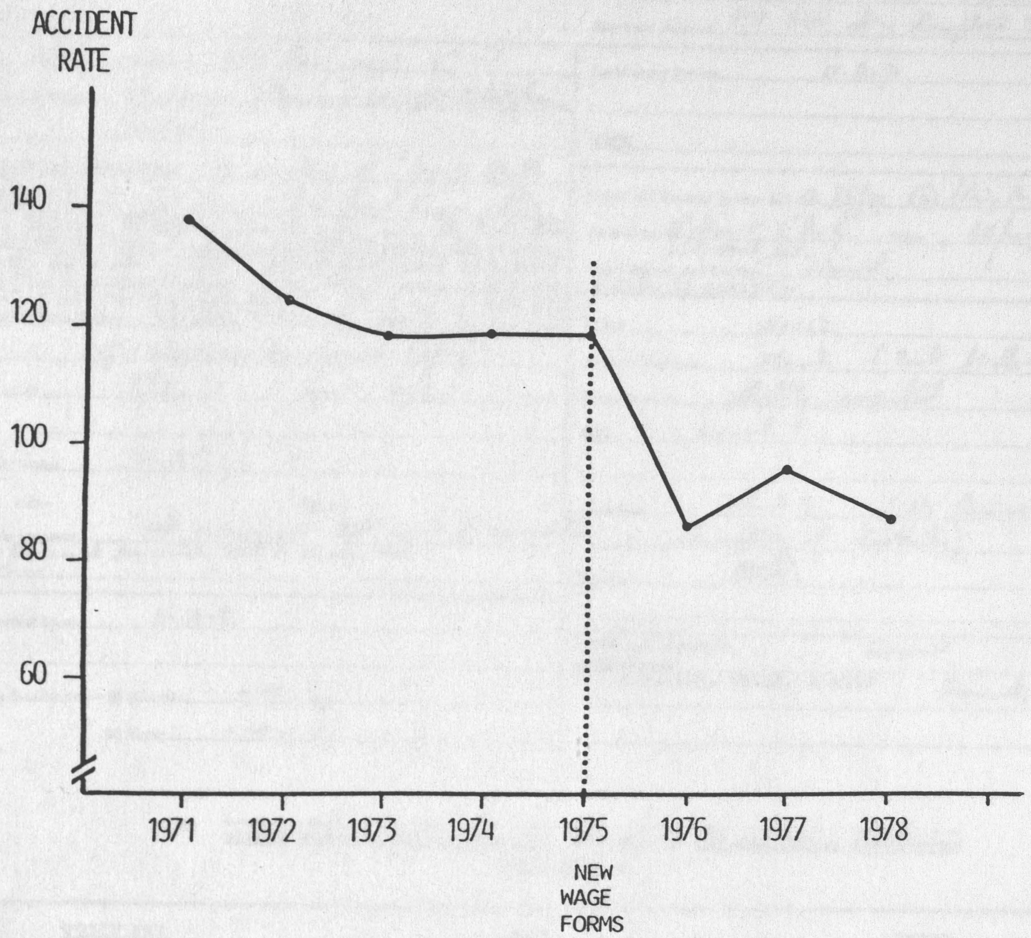
I Making proper main cut and notch but accidently cutting through the "hinge".

J Walking home along a dark forest highway without wearing any reflection strips.

(This situation served as a reference)

Appendix 10

Number of accidents per million working hours during cutting operations of Swedish Forestry Service, 1971-1978 (Sundstrom-Frisk, 1978 & 1983)



Appendix 11

Medical pro-forma used in the study

(32)

EMPLOYEES MEDICAL CARD

DATE 27/1/82

Name H.R.

Private Address

Occupation "Tree Feller"

Examining Doctor Stephen [illegible] Pugh.

Doctors Address 147 High St., Campbell Town. [illegible] 7210

Age 29. Weight 226 lb. Height 6'5".

Personal History No serious illnesses except ~~[illegible]~~ Porphyria.

Vibration Problems No sensation of "Pins & Needles" affecting hands, but fingers of both hands become white on exposure to cold, especially after using the power saw.

Accident History (1) Car accident 1970 [illegible] lung damage, + rt. dislocation of clavo-sternal joint which necessitated [illegible] at a later date [illegible] removal of [illegible] end of clavicle. # of left clavicle. # of end of little finger of left hand. No [illegible] of [illegible].

Family Medical History [illegible] of above, under Personal History.

Eyes—Left 6/6. Right 6/6.

Colour Vision N.A.D.

Ears: Left— Right—

Audiometer Not carried out but normal to conversation at 5 ft: normal for watch test + tuning fork.

Drums

Urogenital System N.A.D.

Urine Examination—(i) Albumin –ve.

(ii) Sugar –ve.

Respiratory System N.A.D.

X-Ray

Heart and Vascular System B.P. (L) 156/88 (L) (lying down) 134/82

Apex Beat 6th space 5" from mid-sternal line Pulse 60/min regular & well [illegible]

Heart Sounds and Rhythm Normal.

E.C.G. if possible

C.N.S. N.A.D.

Dental Condition Normal. (Front teeth [illegible])

Naso-Pharynx Slightly congested.

Skin Normal.

Abdomen N.A.D. (No hernia: No abnormality of Testicles).

Psycho— Stable.

L-Motor System Normal.

(Flexibility, Trunk, Limbs) Normal.

PLEASE CATEGORIZE PATIENT INTO ONE (1) OF THE FOLLOWING CATEGORIES

REMARKS

FULLY FIT	FIT	UNFIT
Considered fully fit but labile B.P. S. [illegible] Pugh MB ChB [illegible]	Capable of work in this occupation (i.e. normal for age).	Obviously has a medical problem - create doubt as to suitability for this occupation.

Appendix 12

Age correction tables for the prediction of VO_2 max (Astrand, 1960: Astrand and Rodahl, 1977).

Age	Factor	max heart rate	Factor
15	1.10	210	1.12
25	1.00	200	1.00
35	0.87	190	0.93
40	0.83	180	0.83
45	0.78	170	0.75
50	0.75	160	0.69
55	0.71	150	0.64

Comment:
Age correction for the results of sub-maximal work capacity tests begins at age 15 with a correction factor of 1.10 up to age 25, 26 to 35 is equivilant while above 35 years the correction factor is 0.87 and decreases thereafter to 0.75 for 50 to 55 years of age (Astrand and Rodhal 1977, p.352-353). Values for predicted maximal oxygen uptake were calculated, and VO_2 (age) max, subsequently adopted because of the wide range in the subjects ages.

Descriptive classes for predicted VO_2 max according to age class (Astrand, 1960).

Age	V Low	Low	Moderate (Litres O_2/min)	High	V High
20-29	2.79	2.8 - 3.09	3.1 - 3.69	3.7 - 3.99	4.0
30-39	2.49	2.5 - 2.79	2.8 - 3.39	3.4 - 3.69	3.7
40-49	2.19	2.2 - 2.49	2.5 - 3.09	3.1 - 3.39	3.4
50-59	1.89	1.9 - 2.19	2.2 - 2.79	2.8 - 3.09	3.1

Proviso:

Large interpersonal differences always exist in any occupational group.
Some subjects can have a relatively small aerobic capacity with a relatively large anaerobic capacity.

Appendix 13

The Douglas formula for the calculation of energy expenditure from oxygen consumption measurement

VO_2/min * 4.85 = Kilocalories/min

Kilocalories/min * 4.187 = Kilojoules/min

VO_2/min * 20.307 = Kilojoules.min

Appendix 14

Medical standards for heart rate and oxygen consumption-energy output at work .

Lehman (1953).

Level of effort	Energy output (kJ/min nett)	(kJ/Hour)
light	up.to - 4.35	
moderate	>4.35 - 6.24	
mod heavy	>6.24 - 13.06	
heavy	>13.06 - 17.42	786 - 1045
v. heavy	>17.42 - 21.77	1046 - 1306
extremely heavy	>21.77	> 1306

British Medical Society (Fibiger, 1976).

Level of effort	Energy output (kJ/min nett)	(kJ/hour)
light	up.to - 4.9	
moderate	>4.9 - 6.9	
mod heavy	>6.9 - 13.9	
heavy	>13.9 - 20.9	834 - 1254
very heavy	>20.9 - 28.6	1256 - 1716

Astrand & Rodahl (1977).

Level of effort	Energy output (kJ/min <u>Absolute</u>)
light	up to 10.5
moderate	10.5 - 20.3
heavy	20.3 - 30.4
v. heavy	30.4 - 40.6
ex. heavy	> 40.6

Christensen (1953) and Astrand and Rodhal (1977).

Level of effort	Heart rate absolute (beats/min)
light work	up to 90
Moderate work	90 - 110
Heavy work	110 - 130
Very heavy work	130 - 150
Extremely heavy work	150 - 170

Time Study Data (N=39)*

* *All element times in centi-minutes. Cubic metre (M³) equals approximately one tonne for estimation purposes. Some figures rounded.*

Subject Ident.	No trees	Total Volume M^3	Average volume tree M^3	Walk to trees	Prep to Fell (centi-minutes)	Felling	Trim	Cross/cut	Total time	(centi-mins) Total work delays	Prod delays	Non prod interview & /hour	Trees hour	"Approx $" for effort M^3/	Current quota
1.	19	94.3	4.96	16.70	7.70	48.75	20.88	9.68	310.6	139.6	11.0	171.1	8.2	40.5	250
2.	4	38.8	9.69	2.63	12.15	22.94	1.71	1.39	174.2	88.3	20.4	86.00	2.7	26.3	500
3.	10	30.3	3.03	9.91	12.54	15.64	14.14	3.37	273.9	177.0	5.8	196.6	7.8	23.6	300
4.	16	59.5	3.72	11.82	7.17	33.02	26.25	10.83	253.6	111.7	11.7	141.9	8.6	32.0	260
5.	3	157.6	52.53	1.82	23.93	32.91	--	--	186.4	79.0	2.8	107.5	2.3	104.5	open
6.	29	75.21	2.59	20.04	11.76	52.52	25.81	19.21	341.3	168.4	24.3	172.9	10.3	26.8	400
7.	32	49.91	1.56	13.70	15.88	48.67	20.90	16.42	362.6	161.00	32.7	201.6	11.9	18.6	280
8.	12	104.27	8.69	9.08	9.97	69.50	44.95	15.8	384.9	184.3	18.9	201.6	3.9	34.0	280
9.	30	55.18	1.84	14.45	9.79	31.10	31.28	9.38	292.8	128.8	12.59	164.0	14.0	25.7	320
10.	15	42.58	2.84	14.93	13.21	45.86	16.58	5.56	298.4	143.7	25.5	154.7	6.2	17.6	300
(subject 11)No field data.															
12.	6	92.90	15.48	8.12	13.35	27.26	12.66	32.8	324.5	147.1	30.00	177.36	2.4	37.9	750
13.	8	179.69	22.46	7.06	11.60	63.47	3.81	24.85	363.9	171.7	28.00	192.2	2.8	62.8	600
14.	9	108.99	12.11	14.29	20.63	32.77	--	12.08	377.8	154.6	29.64	223.2	3.5	42.3	600
15.	3	43.61	14.54	2.71	3.24	10.33	0.54	14.54	109.4	53.00	11.3	56.4	3.4	49.4	600
16.	30	70.84	2.36	25.66	12.70	38.44	25.26	8.61	321.5	136.8	17.8	184.7	13.2	31.1	300

Time Study Data (N=39) * (Continued)

* *All element times in centi-minutes. Cubic metre (M^3) equals approximately one tonne for estimation purposes. Some figures rounded.*

Subject Ident.	No trees	Total Volume M^3	Average volume tree M^3	Walk to trees	Prep to Fell (centi-minutes)	Felling	Trim	Cross/cut	Total time	(centi-mins) Total work delays	Prod delay	Non prod interview & /hour	Trees hour	"Approx $" for effort M^3/	Current quota
17.	19	105.10	5.53	8.50	14.11	45.60	30.28	8.22	350.5	152.6	27.25	197.9	7.5	41.3	450
18.	6	94.03	15.67	9.39	14.36	68.78	14.21	21.46	398.1	166.3	22.5	231.9	2.2	33.9	315
19.	18	52.93	2.94	11.20	9.42	41.75	23.26	7.23	347.2	120.8	8.3	22.5	8.9	26.3	250
20.	16	68.01	4.25	20.53	9.43	28.15	21.64	10.21	349.16	114.9	13.5	234.3	8.4	35.5	315
21.	14	39.90	2.85	9.60	7.00	33.55	7.59	8.54	253.5	89.5	16.5	164.1	9.4	26.8	250
22.	28	76.66	2.74	18.96	14.58	45.86	- -	- -	318.0	107.0	8.0	211.0	15.7	43.0	230
23.	12	46.25	3.85	2.27	6.82	41.21	11.64	8.15	229.8	102.1	11.7	127.8	7.1	27.2	200
24.	10	106.11	10.6	19.16	19.17	39.15	8.70	25.10	351.9	144.3	6.7	207.5	4.2	44.12	500
25.	14	203.52	14.54	6.72	4.90	21.0	3.9	14.18	221.3	106.9	18.3	114.4	7.8	114.2	990
26.	10	14.79	1.48	3.15	6.55	16.19	- -	- -	115.7	30.5	- -	85.16	19.7	29.1	open
27.	6	98.87	16.48	8.85	5.69	34.16	6.86	6.47	198.3	84.8	16.2	113.5	4.2	69.9	700
28.	20	48.59	2.43	9.57	6.43	34.77	20.43	8.90	356.0	128.0	21.5	227.9	9.4	22.75	265
29.	25	51.49	2.06	10.29	6.98	34.85	30.15	3.36	272.9	108.7	10.6	164.2	13.8	28.43	600
30.	12	115.31	9.61	7.91	8.64	34.74	4.09	3.75	238.0	74.4	4.2	163.7	9.7	93.0	265

Time Study Data (N=39) * (Continued)

* *All element times in centi-minutes. Cubic metre (M^3) equals approximately one tonne for estimation purposes. Some figures rounded.*

Subject Ident.	No trees	Total Volume M^3	Average volume tree M^3	Walk to trees	Prep to Fell	Felling	Trim	Cross/cut	Total time	(centi-mins) Total work delays	Prod delay	Non prod interview & /hour	Trees hour	"Approx $" for effort M^3/	Current quota
				(centi-minutes)											
31.	13	27.15	2.09	8.27	13.84	38.98	0.38	- -	227.1	91.0	25.3	136.0	8.6	17.90	open
32.	6	16.62	2.77	6.24	9.63	13.25	- -	- -	145.5	35.0	1.4	110.5	10.3	28.5	open
33.	17	138.97	8.17	13.46	8.93	45.64	18.39	9.56	300.0	136.2	23.7	163.8	7.5	61.2	500
(Subject 34)No field data.															
35.	6	122.03	20.34	8.62	18.21	34.91	15.43	5.94	338.8	132.8	16.95	106.0	2.7	55.2	500
36.	21	98.21	4.68	10.65	9.19	33.86	16.5	9.0	306.7	108.2	16.3	198.5	11.6	54.5	600
37.	19	94.46	4.97	11.64	14.35	32.90	28.94	4.52	344.94	137.5	25.2	107.4	8.3	41.22	500
38.	38	75.97	2.00	12.45	8.57	63.53	22.3	11.57	306.0	141.0	17.8	164.9	16.1	32.3	350
39.	42	75.26	1.79	9.26	9.3	46.2	27.98	7.71	305.7	145.2	22.0	160.5	14.3	31.1	600
40.	19	129.25	6.80	7.95	3.62	37.61	10.94	5.23	369.8	75.9	2.7	294.0	15.0	102.2	800
41.	22	84.53	3.84	14.18	7.79	54.39	26.11	21.09	346.2	166.7	30.6	180.0	7.9	30.42	600

Appendix 16

Average Heart Rates In Sample (Overall 126.9 +/_ 15.26).

Subject/no		Mean hr		Hr nett	Std Dev	No of Trees cut during study
1		154.9	Highest	90.9	11.4	19
2		126.3		57.3	10.0	3
3		111.2		45.2	5.7	10
4		129.4		53.4	6.9	16
5	Highest	155.0		89.0	1.7	3
6		134.2		63.2	7.0	29
7		127.3		48.3	4.9	32
8		119.2		59.2	7.2	12
9		124.6		68.6	6.5	30
10		129.0		68.0	8.0	15
11		No field measurement data collected				
12		136.5		68.5	9.8	7
13		116.2		60.2	6.6	8
14		122.0		58.0	8.7	9
15		127.0		57.0	6.9	4
16		111.2		43.2	5.3	30
17		132.2		66.2	7.8	19
18		126.0		62.0	8.6	6
19		122.5		53.5	9.6	18
20		130.6		54.6	5.8	16
21		128.1		71.1	8.0	13
22		121.0	Lowest	43.0	8.2	28
23		112.2		52.2	7.9	12
24		116.4		46.4	6.0	10
25		126.7		70.7	5.4	14
26		129.3		61.3	4.8	10
27		132.8		64.8	6.1	6
28		133.4		84.4	8.8	19
29	Lowest	105.8		51.8	4.8	25
30		124.1		74.1	9.2	12
31		122.3		56.3	6.7	13
32		112.8		58.8	5.4	6
33		143.4		86.4	8.4	17
34		No field measurement data collected				
35		127.8		64.8	4.4	6
36		120.0		62.0	7.7	21
37		116.3		54.3	3.7	19
38		136.0		79.0	6.0	38
39		136.2		63.2	7.2	40
40		128.3		56.3	5.0	19
41		133.3		75.3	11.0	22

(cont.) Appendix 16

Examples of Average Hr in 5 subjects set of trees

Example 1. 7 S-trees
Average Diam. 106 +/_ 24 cm

Sno	tree	Hr	S-tree	Oxy
1	1	169		-
1	2	169		-
1	3	179		-
1	4	172		-
1	5	160		-
1	6	168		-
1	7	155	1	-
1	8	156		-
1	9	149	2	-
1	10	144		-
1	11	163		-
1	12	148		-
1	13	141	4	-
1	14	149		1
1	15	137	3	-
1	16	144		2
1	17	148	5	-
1	18	149	6	-
1	19	150	7	-

Example 2. 9 S-trees
Average Diam. 88 +/_ 15

Sno	tree	Hr	S	Oxy
10	1	139	1	-
10	2	135	2	-
10	3	133	3	-
10	4	137	4	-
10	5	142	5	-
10	6	126		-
10	7	130		1
10	8	132		1
10	9	132		1
10	10	132		1
10	11	119	6	-
10	12	120	7	-
10	13	116	8	-
10	14	124		2
10	15	119	9	-

Example 3. 9 S-trees
Average diam. 101 +/_ 22 cm

Sno	tree	Hr	S	Oxy
19	1	120		-
19	2	141		-
19	3	139		-
19	4	136		-
19	5	126		-
19	6	127	1	-
19	7	128	2	-
19	8	130	3	1
19	9	120		-
19	10	124		-
19	11	118	4	-
19	12	116	7	-
19	13	117		-
19	14	120	6	2
19	15	113	8	-
19	16	112	9	-
19	17	108		-
19	18	110	5	-

Example 4. 10 S-trees
Average Diam. 129 +/_ 42 cm

Sno	tree	Hr	S	Oxy
33	1	139		-
33	2	154		-
33	3	153		-
33	4	144	1	-
33	5	152	3	-
33	6	155	2	-
33	7	133		-
33	8	150	5	-
33	9	141		-
33	10	141	4	1
33	11	128	7	-
33	12	142	8	-
33	13	142	9	2
33	14	144		-
33	15	144		-
33	16	137	10	-
33	17	129	6	3

Example 5. 4 S-trees
Average Diam. 73 +/_ 5 cm

Sno	tree	Hr	S-tree	Oxy
39	1	126		-
39	2	133		-
39	3	141		-
39	4	138		-
39	5	131		-
39	6	137		-
39	7	133		-
39	8	130		-
39	9	146		-
39	10	140		-
39	11	134		-
39	12	130	1	-
39	13	141		-
39	14	140		-
39	15	138		-
39	16	138		-
39	17	130		1
39	18	132		1
39	19	126	2	-
39	20	134	3	-
39	21	130	4	-
39	22	138		-
39	23	150		-
39	24	152		-
39	25	138		-
39	26	144		-
39	27	134		-
39	28	140		-
39	29	132		-
39	30	144		-
39	31	130		-
39	32	150		-
39	33	132		-
39	34	126		-
39	35	138		-
39	36	150		-
39	37	150		-
39	38	134		-
39	39	134		-
39	40	135		-
39	41	128		-
39	42	126		2

Appendix 17

Work and life questionnaire (Fatalism/Locus of control and work involvement)

CSIRO DIVISION OF FOREST RESEARCH
Tasmanian Hardwood Faller Project
c/o Mel Henderson (062) 818327

CONFIDENTIAL

Name .... No...... Date . Time..........

These statements are concerned with your opinions on some aspects of life in general and your work as a faller.

There are no right or wrong answers and similar to before you have a choice of 5 answers to each statement ranging from 'Strongly disagree' to 'Strongly agree'. Having made sure you understand the statement clearly, your job is to put a circle around the answer that really expresses your opinion. It is not necessary to dwell on each statement, your first gut reaction is the best.

Being out in bush I really like it

	Strongly disagree	Disagree	N	Agree	Strongly agree
The non-financial benefits of falling more than make up for the dangers and difficultues	SD	D	N	A	SA
Falling does become routine and boring after a while	SD	D	N	A	SA
I have often found in life that what is going to happen will happen	SD	D	N	A	SA
Chance or luck has played an important role in my life	SD	D	N	A	SA
Falling work is only a small part of who I am	SD	D	N	A	SA
Trusting to fate does not usually turn out as well as making a definite decision on a course of action	SD	D	N	A	SA
In my case getting what I want has little or nothing to do with luck	SD	D	N	A	SA
Work as a faller has played the greatest part (compared with marriage, hobbies, sport, etc.) when it comes to understanding myself	SD	D	N	A	SA
Many times in life I have felt that I have had little influence over the things that happen to me	SD	D	N	A	SA
I have other activities in life that mean more to me than falling	SD	D	N	A	SA
Sometimes I do feel that I don't have enough control over the direction my life is taking	SD	D	N	A	SA
People are right to say there is no such thing as luck	SD	D	N	A	SA
Money is my main reason for being a faller	SD	D	N	A	SA
Most people don't realise the extent to which their lives are controlled by accidental happenings	SD	D	N	A	SA
Falling should be the most important things in a fallers life	SD	D	N	A	SA

	Strongly disagree	Disagree	N	Agree	Strongly agree
Many times we might just as well decide what to do by tossing a coin	SD	D	N	A	SA
Some people have heavily involved in their job, for others the job is just one of many interests. I am in the first group.	SD	D	N	A	SA
What happens to me is my own doing.	SD	D	N	A	SA
It is not always wise to plan too far ahead because many things turn out to be a matter of good or bad fortune.	SD	D	N	A	SA
Taking summer and winter (heat and rain) into account, even if I wasn't a faller I would want to work in the bush.	SD	D	N	A	SA
I spend a great deal of time thinking about falling when I am not at work.	SD	D	N	A	SA
When I make plans I am almost certain I can make them work.	SD	D	N	A	SA

Appendix 18

Factor Analysis of the Work and Life Questionnaire

Fatalism/Locus of Control Items
Principal-Components Analysis Number of Cases = 36

Factor Matrix:

Variable	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
FAJI3	.65337	.23679	.22336	-.03446
FAJI4	.72532	.13532	-.07404	-.11704
FAT6	.21427	.58206	.34639	.29154
FAT7	.67996	.31877	.09008	-.21725
FAJI9	.56270	-.34074	.18892	-.46278
FAJI11	.22745	-.44844	.00519	.43511
FAT12	.08346	.73950	-.27761	-.25380
FAJI14	.48840	-.20066	-.49414	.13402
FAJI16	.46433	-.47757	-.20085	.24885
FAT18	.39075	.37489	.25163	.61986
FAJI19	.44398	.32724	-.54839	.18436
FAT22	.49142	-.17280	.64338	-.00985

Final Statistics:

Variable	Communality		Factor	Eigen	Pct of Var	Cum Pct
FAJI3	.53404	*	1	2.88201	24.0	24.0
FAJI4	.56358	*	2	1.92469	16.0	40.1
FAT6	.58969	*	3	1.35877	11.3	51.4
FAT7	.61928	*	4	1.11317	9.3	60.7
FAJI9	.68259	*				
FAJI11	.44217	*				
FAT12	.69531	*				
FAJI14	.54094	*				
FAJI16	.54595	*				
FAT18	.74077	*				
FAJI19	.63893	*				
FAT22	.68539	*				

Rotated Factor Matrix: (Varimax - Kaiser Normalization).

Variable	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
FAJI3	.68531	-.00261	.16028	.19670
FAJI4	.63435	.02742	.39964	-.02678
FAT6	-.05532	-.31656	-.18680	.67196
FAT7	.71762	-.17190	.26593	.06351
FAJI9	.65629	.16890	-.07812	-.46610
FAJI11	.00753	.65712	.07975	.06284
FAT12	.12021	-.70936	.39529	.14634
FAJI14	.14031	.33279	.61265	-.18750
FAJI16	.17487	.62510	.31411	-.16112
FAT18	.29112	.19304	.18389	.76482
FAJI19	.12771	-.06046	.77479	.13660
FAT22	.66828	.31044	-.35674	.12310

Factor Score Coefficient Matrix:

Variable	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
FAJI3	.28501	-.03702	-.01086	.10859
FAJI4	.23057	-.04730	.15515	-.05323
FAT6	.00019	-.08578	-.12027	.45688
FAT7	.30702	-.16782	.05190	-.02162
FAJI9	.32975	-.03664	-.15443	-.35735
FAJI11	-.07932	.42455	.05623	.15367
FAT12	.05449	-.43171	.22934	-.01580
FAJI14	-.05887	.17069	.37952	-.09852
FAJI16	-.02406	.35303	.18224	-.03053
FAT18	.04516	.21923	.06734	.58826
FAJI19	-.06971	-.02143	.48090	.07981
FAT22	.33514	.14521	-.34065	.10941

Principal-Components Analysis - Solution constrained to 1 factor

Factor Matrix:

Variable	FACTOR 1
FAJI3	.65337
FAJI4	.72532
FAT6	-.21427
FAT7	.67996
FAJI9	.56270
FAJI11	.22745
FAT12	.08346
FAJI14	.48840
FAJI16	.46433
FAT18	.39075
FAJI19	.44398
FAT22	.49142

Factor Score Coefficient Matrix:

Variable	FACTOR 1
FAJI3	.22671
FAJI4	.25167
FAT6	-.07435
FAT7	.23593
FAJI9	.19525
FAJI11	.07892
FAT12	.02896
FAJI14	.16947
FAJI16	.16111
FAT18	.13558
FAJI19	.15405
FAT22	.17051

Work Involvement Items

Principal-Components Analysis Number of cases = 36

Factor Matrix:

Variable	FACTOR 1	FACTOR 2	FACTOR 3
WI1	.52290	.18891	-.34323
WIR2	.17323	.05201	.85064
WIR5	.56285	.38417	-.21462
WI8	.65023	-.08839	.01635
WIR10	.82156	-.23342	-.11338
WIR13	.10011	.84733	-.18105
WI15	.86962	-.23944	-.14320
WI17	.73699	-.11013	.26562
WI20	.36979	.62349	.37598
WI21	.73775	-.13661	.05869

Final Statistics:

Variable	Communality		Factor	Eigen	Pct of Var	Cum Pct
WI1	.42692	*	1	3.70845	37.1	37.1
WIR2	.75630	*	2	1.44311	14.4	51.5
WIR5	.51045	*	3	1.16922	11.7	63.2
WI8	.43088	*				
WIR10	.74231	*				
WIR13	.76077	*				
WI15	.83408	*				
WI17	.62583	*				
WI20	.66685	*				
WI21	.56638	*				

Rotated Factor Matrix: (Varimax - Kaiser Normalization).

Variable	FACTOR 1	FACTOR 2	FACTOR 3
WI1	.47060	.38602	-.23759
WIR2	.07602	-.05683	.86446
WIR5	.43945	.55800	-.07725
WI8	.64317	.09478	.09074
WIR10	.86038	.02922	-.03471
WIR13	-.14116	.85988	-.03817
WI15	.91043	.04233	-.05834
WI17	.71066	.05327	.34344
WI20	.13386	.62294	.51076
WI21	.73708	.06600	.13690

Factor Score Coefficient Matrix:

Variable	FACTOR 1	FACTOR 2	FACTOR 3
WI1	.12043	.21593	-.24912
WIR2	-.02894	-.08482	.72439
WIR5	.08097	.32661	-.11984
WI8	.18373	-.01147	.02830
WIR10	.26710	-.07328	-.08906
WIR13	-.13559	.58937	-.06097
WI15	.28286	-.06898	-.11292
WI17	.19210	-.05779	.23808
WI20	-.06134	.37701	.39258
WI21	.21299	-.04297	.06201

Principal-Components Analysis - Solution constrained to 1 factor

Factor Matrix:

Variable	FACTOR 1
WI1	.52290
WIR2	.17323
WIR5	.56285
WI8	.65023
WIR10	.82156
WIR13	.10011
WI15	.86962
WI17	.73699
WI20	.36979
WI21	.73775

Factor Score Coefficient Matrix:

Variable	FACTOR 1
WI1	.14100
WIR2	.04671
WIR5	.15178
WI8	.17534
WIR10	.22154
WIR13	.02700
WI15	.23450
WI17	.19873
WI20	.09971
WI21	.19894

Appendix 19

A procedure for skill appraisal

General procedure for skill appraisal:

1. Discuss the skilled activity almost ad nauseam with the individuals who practice it and with those to whom and for whom they are responsible.

2. Try to make this verbal communication more precise by using protocol techniques , critical incident techniques, good/poor contrast techniques and so on.

3. Observe the development of the skill in the trainees and by analysis of what goes on in the formal and informal training procedures and in professional assessmant. Make due allowance for history, tradition, technological change and so on.

4. Structure the activity. Identify the dimensions of the percepts, the decision making, the strategies of action and the overt activities, and try to provide scales of measurement along each dimension.

5. Check as many conclusions as possible by direct observation, performance measurement and by experiment.

6. Implement the conclusions and provide techniques for assessing the limitations and successes of the the innovations.

Source:

Singleton (1979) The study of real skills - Vol 1: The analysis of practical skills. (p. 322) Appraising a skilled operator.

(See also Vol 2: Compliance and excellence. (p. 4) with the skill appraisal list points 1-6).

Appendix 20

Proposed criteria for low-risk professional felling:

From the work-technique manuals previously quoted, and discussions with experienced workers and instructors, some of the critical issues in low-risk hardwood felling were reported to be:

1. Good overall planning of the order and general direction of felling within a block.

2. Chainsaw operating at maximim cutting efficiency.

3. Felling to a face where possible.

4. Getting to the heart of the tree in terms of the scarf, up to half the diameter on many occasions, rather than the shallow scarves, that were currently recommended by some Scandinavian specialists in softwood felling.

5. Ensuring solid hinge and thus holding wood, and a high step between hinge and back-cut, especially when felling uphill.

6. Felling with the natural lean where possible.

7. The judicious and frequent use of wedges in all situations and not jarring the tree unnecessarily when inserting or hitting the wedge.

8. The taking of "calculated risks" when necessary, as long as the man had thoroughly considered the external "pressures" on him to attempt the fall, and genuine escape paths had been identified and prepared.

9. Being as certain as possible of a fall before making the final decision on escape paths.

10. Recognising when necessary that the success of a fall is uncertain.

11. The identification of hazards and hodden stumps to the front and hidden ground debris that might fly back.

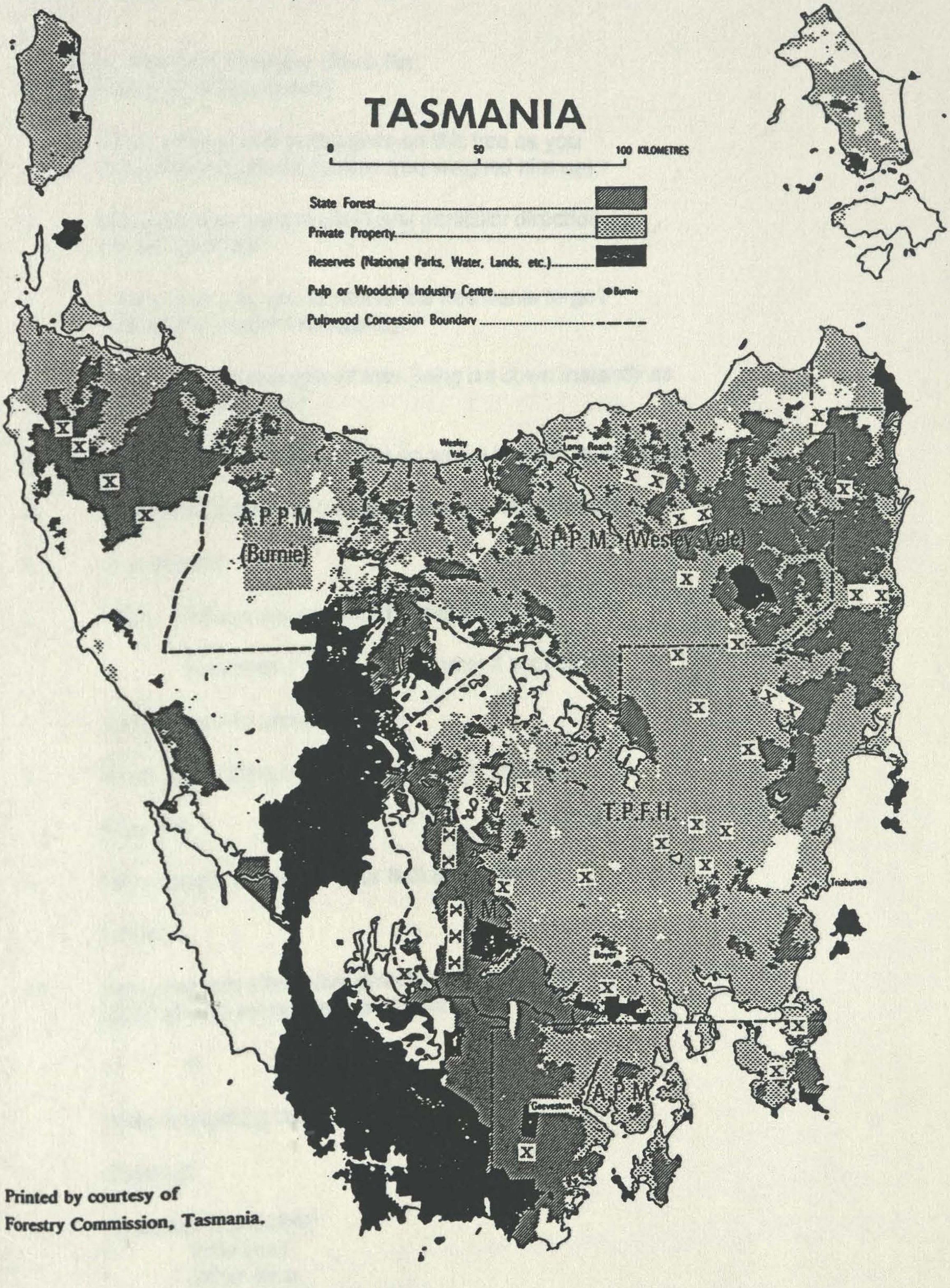
12. Careful identification of "widow makers" in the tree being cut, and in surrounding trees, both back and front.

13. The identification of trees and rotten spars both behind and in front that have any chance of being set off by the current fall, or being hit glancing blows by it.

14. Identifying safe trees to move behind, or cutting escape paths where necessary to enable you to move at least 4 metres away from the stump, and diagonally from the intended direction of fall.

Appendix 21

Research locations.



Printed by courtesy of
Forestry Commission, Tasmania.

Pro-formas and questionnaires or checklists used in fieldwork.

1. *S-Tree interview checklist (as below)*
2. *Tree and stump measurement pro-forma*
3. *Interviewer - instructor's skill rating form*

1. Tree/assessment interview check list:
(Used by Instructor-interviewer)

1. What were your first thoughts on this tree as you were walking up to it (before you weighed him up).

2. Does the tree want to go in any particular direction
*Nominate Point**

3. How certain are you of where the tree wants to go?
Start with sector if necessary.

(Use example of tree being cut down instantly as necessary)

4. What is the biggest influence on where the tree wants to go.

5. Second biggest. *NB (Clear on Barrel / Head / Both)*

6. Any others?

7. FALL Where are you going to fall the tree?

Nominate Point? (Start sector if necessary).

* *(Check Rex for chosen target)*

9. What, if anything, could go wrong with this fall.

(Record)

8. How certain are you of your falling direction.

* CARD

10. Are there any alternative directions open to you.
(Did/did not) mention other alternatives.

1 2 3

What if anything could GO WRONG

* (Record).

11. Reasons *(if possible)*
   * Tree itself
   * Other trees
   * Conditions/Terrain/Wind

12. How much RISK do you feel there is in falling this tree.

 * (CARD)

13. Out of tree itself, other trees, wind and conditions:
 What is major reason or reasons for this level of risk?

14. How much experience do you have with this type of tree

 * (CARD).

16. Could you describe how AWKWARD this tree is as regards putting in the front and back cuts.

 * (CARD)

17. How much experience do you have with this type of tree

 (1) very little
 (2) several times before
 (3) a great deal

17. Is there anything in particular you will be watching for as tree falls.

/////// AFTER Fall \\\\\\\\\

18. How did that go.

 (Concrete reasons).

 * (CARD - which description)

19. Did you change your mind about anything?

 When you were cutting
 When the tree was going down.

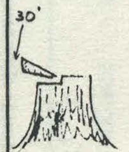
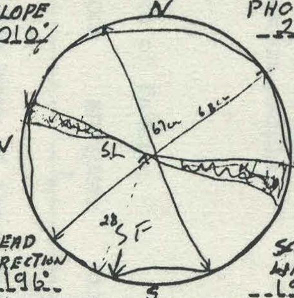
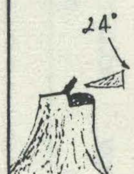
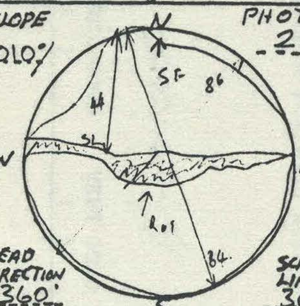
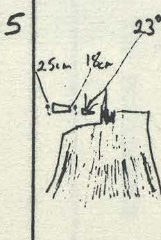
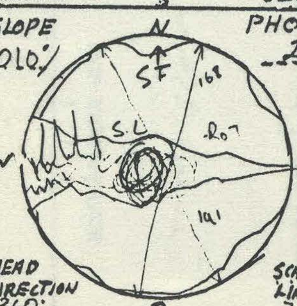
20. Right back at the start what was the first thing you thought about in relation to this tree.

 At any time did you think about where you would go if anything went wrong. *(first tree only)*

2. Tree and stump measurement pro-forma

FILL IN ALL PARTICULARS FOR X TREES ONLY — OTHERS JUST SPECIES, TREE NO. AND STUMP DIAM. FALLERS 30

CUTTER NO - 23 SHEET NO. - 3 DATE - 14-5-82 PHOTO NO - 20

SPECIES PLUS TREE NO.	STUMP DIAM.	STUMP HEIGHT FRONT	STUMP HEIGHT BACK	SCARF DEPTH	HINGE (FROM FRONT) HEIGHT LEFT	HEIGHT CENT	HEIGHT R	WIDTH LEFT	WIDTH CENT	WIDTH R	DIAGRAM OF SCARF WEDGE ANGLE PLUS STUMP OVERCUT LEFT OR RIGHT	DIAGRAM + DEGREES (SCARF LINE = SL, SCARF FACE = SF, HEAD DIRECTION = HD, DEFECT = D, PHOTO = P, GROUND SLOPE RELATIVE NTH = S)	ANGLES FROM BACK OF STUMP	MID DIAM	LENGTH	CROWN DEPTH	VOLU
CROWN TOP / 4X	67 / 68	54	59	28	–	–	–	7	2	10	 30° / FROM LEFT	SLOPE 010% / PHOTO 27 /  HEAD DIRECTION 196 / SCARF LINE 196	SCARFLINE L = 0° UP DOWN / SCARF FACE UP = DOWN = 2° / BACK CUT L = 4° UP DOWN / TO SCARF = 5° UP DOWN	49	16	10	3.0c
CROWN TOP 8	50				STEP HEIGHT 8	6	5										
CROWN TOP / 6X	84 / 86	69	81	44	–	31	–	10	13	8	 24° / FROM RIGHT	SLOPE 010% / PHOTO 28 /  HEAD DIRECTION 360 / SCARF LINE 360	SCARF LINE L : 5° UP DOWN / SCARF FACE UP = 1° DOWN = / BACK CUT L = 1° UP DOWN / TO SCARF = 1° UP DOWN	72	9.5	26	3.1
					STEP HEIGHT 17	12	9										
CROWN TOP / 5X	168 / 191	87	100	80	–	58	48	–	11	15	 23° / 25cm 18cm	SLOPE 010% / PHOTO 29 /  HEAD DIRECTION 360 / SCARF LINE 360	SCARF LINE L = 2° UP DOWN / SCARF FACE UP = DOWN = 0° / BACK CUT L = 3° UP DOWN / TO SCARF = 1° UP DOWN	14	26	18	11.1c
7X	70	check			STEP HEIGHT 14	22	22										
5X	80																

3. Observer-instructor's skill rating form

CSIRO DIVISION OF FOREST RESEARCH
Tasmanian Hardwood Faller Project
C/- Mel Henderson (062) 812801

CONFIDENTIAL
Final Comments of Bush Instructor

Name .... Date .... Time ....
Subject No. .... Instructor Initials ....
Total sample Selected trees

It is possible that the faller being studied has a drastically "off" day at the time of the study. To aid later interpretation of other information it is necessary to have an expert opinion on the fallers performance during this particular day.

1. For each of the job elements listed below we would like you to think of a faller who represents the best end of the scale and a faller who represents the worst. Place their initials in the brackets provided.

   Could you then mark (✓) todays faller on each scale in relation to the performance of these top and bottom people.

   Elements

   Planning the pattern of falling — Selectively HPR Team

VERY POOR	POOR	ADEQUATE	FAIRLY GOOD	VERY GOOD	TOP PERFORMANCE
( )	( )	( )	( )	( )	( )

   Preparation around the base of the trees

VERY POOR	POOR	ADEQUATE	FAIRLY GOOD	VERY GOOD	TOP PERFORMANCE
( )	( )	( )	(✓)	( )	( )

   Assessing the trees natural lean

POOR	ADEQUATE	TOP PERFORMANCE ( )
( )	(✓)	( )

   Putting in his fronts

TOP PERFORMANCE	VERY GOOD	FAIRLY GOOD	ADEQUATE	POOR	VERY POOR
( )	(✓)	( )	( )	( )	( )

   Avoiding danger as the tree falls

TOP PERFORMANCE	VERY GOOD	FAIRLY GOOD	ADEQUATE	POOR	VERY POOR
( )	( )	(✓)	( )	( )	( )

   Trimming

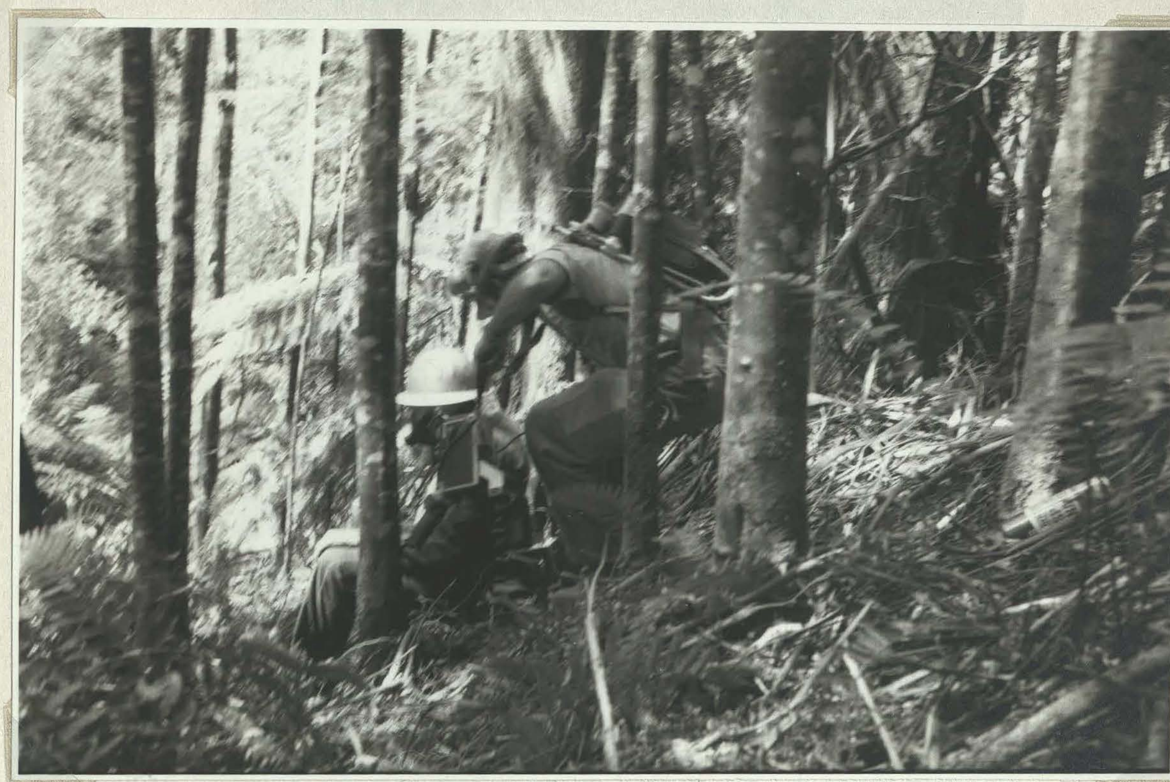
POOR	ADEQUATE	TOP PERFORMANCE
( )	(✓)	( )

   Condition of his saw as regards cutting efficiency

VERY POOR	POOR	ADEQUATE	FAIRLY GOOD	VERY GOOD	TOP PERFORMANCE
( )	(✓)	( )	( )	( )	( )

Appendix 23

Examples of tree density and working conditions in the study.



Appendix 24

Details of each subjects S-trees

Sno	S-Tree	Length	Volume	diam	Fall time	Scarf Angle ^{0}	Scarf depth % Dia.	Certainty of chosen direct
1	1	19.0	.80	30.0	5.11	23.0	.	
1	2	17.0	10.00	110.0	5.47	.	.	
1	3	18.0	10.00	121.0	6.04	.	.	20
1	4	15.0	5.00	77.0	5.34	.	.	40
1	5	30.0	14.70	140.0	7.84	15.0	.	40
1	6	24.0	12.60	110.0	3.92	11.0	.	60
1	7	.	.	.	5.24	.	.	60
2	5	14.0	8.80	130.0	5.36	24.0	.	80
2	4	15.0	8.30	110.0	6.48	21.0	.	80
2	2	21.0	12.70	131.0	.	13.0	.	100
3	1	21.0	2.10	51.0	6.60	31.0	.	100
3	2	19.0	1.30	41.0	4.64	30.0	.46	100
3	3	11.0	2.00	74.0	.	20.0	.36	100
3	4	18.0	1.60	50.0	.	22.0	.54	80
3	5	20.0	1.80	62.0	6.89	23.0	.48	40
3	6	10.0	9.10	110.0	5.73	22.0	.53	100
3	7	15.0	4.10	86.0	.	20.0	.36	100
3	8	20.0	3.20	61.0	5.37	.	.51	80
4	1	18.0	3.60	69.0	5.64	18.0	.46	60
4	4	15.0	4.20	87.0	.	7.0	.48	50
4	5	23.0	7.10	90.0	.	6.0	.48	40
4	3	20.0	8.30	95.0	8.12	.	.	50
4	2	23.0	7.10	90.0	7.01	19.0	.44	95
4	6	6.0	4.50	117.0	5.25	12.0	.38	100
4	8	18.0	3.80	88.0	.	13.0	.48	
4	7	18.0	7.10	125.0	5.60	6.0	.50	-
5	1	26.0	17.90	122.0	5.95	18.0	.68	80
5	2	31.0	33.00	182.0	9.97	27.0	.55	90
5	3	38.0	86.70	285.0	9.47	19.0	.	80
6	1	15.0	6.60	114.0	4.34	27.0	.37	80
6	2	10.0	3.20	109.0	.	24.0	.09	-
6	3	6.0	4.90	132.0	.	12.0	.43	-
6	4	8.0	4.30	90.0	3.10	18.0	.72	100
6	5	7.0	3.80	113.0	5.47	.	.	20
6	6	8.0	3.30	87.0	5.70	17.0	.53	100
6	7	16.0	14.60	.	6.81	.	.	40
6	8	8.0	2.10	117.0	5.67	.	.	60
7	6	18.0	2.30	69.0	.	25.0	.33	40
7	3	12.0	2.30	68.0	5.67	24.0	.38	60
7	1	12.0	2.80	67.0	5.60	25.0	.45	60
7	2	8.0	2.90	89.0	6.24	14.0	.27	80

Sno	S-Tree	Length	Volume	diam	Fall time	Scarf Angle ^{0}	Scarf depth % Dia.	Certainty of chosen direct
7	4	19.0	3.60	66.0	6.04	20.0	.42	60
7	5	15.0	3.80	79.0	.	.	.	40
7	7	16.0	2.60	80.0	.	21.0	.40	20
8	1	21.0	7.60	100.0	5.39	18.0	.55	-
8	2	22.0	10.70	144.0	6.69	22.0	.51	-
8	3	14.0	7.60	125.0	4.67	17.0	.43	-
8	4	22.0	8.80	106.0	.	19.0	.49	-
8	5	20.0	7.60	115.0	.	18.0	.57	80
8	6	25.0	11.20	130.0	5.22	14.0	.	80
8	7	24.0	19.90	151.0	5.39	19.0	.40	60
8	8	20.0	15.20	118.0	6.82	7.0	.25	60
9	1	17.0	3.60	95.0	4.25	11.0	.26	99
9	2	10.0	2.60	85.0	5.52	13.0	.45	90
9	3	11.0	2.60	74.0	5.51	13.0	.32	90
9	4	18.0	5.40	92.0	6.34	11.0	.41	90
9	5	18.0	3.00	84.0	6.52	12.0	.43	90
9	6	15.0	4.60	89.0	5.68	10.0	.45	80
9	7	15.0	3.00	90.0	3.52	6.0	.39	100
9	8	12.0	6.10	121.0	5.80	5.0	.20	80
10	1	10.0	3.10	93.0	6.03	28.0	.31	-
10	3	16.0	3.70	85.0	5.85	42.0	.29	-
10	4	12.0	2.00	63.0	3.48	40.0	.33	-
10	5	15.0	2.80	.	3.13	36.0	.	-
10	6	9.0	3.00	100.0	.	22.0	.41	20
10	7	11.0	2.50	80.0	3.89	37.0	.23	80
10	8	15.0	13.20	.	.	41.0	.	40
10	9	16.0	14.60	107.0	5.24	.	.	-
11	No field data collected							
12	1	45.0	10.90	100.0	9.09	11.0	.61	40
12	2	46.0	36.50	146.0	8.88	8.0	.22	40
12	3	46.0	9.60	87.0	9.39	12.0	.61	40
13	1	46.0	18.30	105.0	1.54	17.0	.23	80
13	2	46.0	11.00	117.0	6.54	27.0	.30	80
13	3	45.0	18.70	126.0	7.82	20.0	.34	60
13	4	55.0	85.20	352.0	8.79	14.0	.20	60
13	5	59.0	24.20	143.0	2.56	16.0	.45	80
13	6	54.0	13.30	100.0	.	25.0	.30	-
14	1	.	14.00	119.0	5.90	17.0	.19	80
14	2	.	11.00	82.0	.	.	.	40
14	3	45.0	12.60	128.0	.	17.0	.32	80
14	4	22.0	8.80	113.0	.	17.0	.19	80

(cont.) Appendix 24

Sno	S-Tree	Length	Volume	diam	Fall time	Scarf Angle ⁰	Scarf depth % Dia.	Certainty of chosen direct
14	5	.	.	.	6.89	.	.	80
14	6	.	10.60	157.0	9.98	.	.	80
14	7	48.0	23.90	185.0	.57	.	.	80
15	1	45.0	8.10	95.0	8.06	.	.	20
15	2	42.0	5.20	.	7.85	.	.	40
15	3	69.0	30.30	193.0	.	.	.	20
16	1	26.0	2.10	72.0	4.45	39.0	.40	40
16	2	31.0	2.50	65.0	5.27	32.0	.54	50
16	3	25.0	1.70	55.0	4.86	35.0	.46	100
16	4	28.0	1.70	47.0	5.25	36.0	.41	100
16	5	34.0	2.30	69.0	5.13	29.0	.41	100
16	6	28.0	7.00	90.0	6.21	25.0	.33	80
16	7	32.0	2.90	78.0	8.03	30.0	.36	80
16	9	28.0	2.30	57.0	.	31.0	.35	-
17	1	26.0	8.40	130.0	4.24	15.0	.36	70
17	2	34.0	16.40	170.0	4.79	24.0	.33	80
17	3	40.0	34.20	135.0	5.53	15.0	.38	100
17	4	29.0	3.10	80.0	3.48	13.0	.43	80
17	5	22.0	1.60	70.0	.	19.0	.57	90
17	6	22.0	1.70	72.0	5.39	.	.	100
17	8	25.0	2.50	62.0	5.98	20.0	.56	60
17	9	34.0	16.50	140.0	9.09	18.0	.36	50
18	1	45.0	43.50	295.0	8.30	30.0	.47	80
18	8	33.0	14.50	125.0	5.51	30.0	.36	80
18	4	47.0	25.10	330.0	5.06	27.0	.27	70
19	1	20.0	1.70	70.0	4.29	25.0	.54	100
19	2	22.0	4.50	105.0	3.49	25.0	.35	100
19	3	21.0	7.00	135.0	5.45	18.0	.	100
19	4	21.0	1.00	65.0	6.99	25.0	.48	100
19	5	26.0	4.90	120.0	9.55	27.0	.45	100
19	6	21.0	2.90	90.0	6.82	25.0	.57	100
19	7	28.0	8.90	135.0	7.53	11.0	.38	100
19	8	21.0	2.40	90.0	5.54	20.0	.36	100
19	9	24.0	3.80	100.0	8.29	25.0	.42	100
20	1	46.0	7.40	65.0	.	25.0	.48	70
20	2	36.0	3.50	70.0	.	20.0	.29	75
20	8	52.0	11.20	80.0	.	18.0	.53	75
20	3	48.0	6.20	90.0	.	15.0	.47	80
20	5	34.0	3.40	78.0	6.22	25.0	.46	75
20	6	38.0	3.70	65.0	8.15	20.0	.42	85
20	4	41.0	4.90	70.0	.	25.0	.46	85

(cont.) Appendix 24

Sno	S-Tree	Length	Volume	diam	Fall time	Scarf Angle ⁰	Scarf depth % Dia.	Certainty of chosen direct
20	7	52.0	11.20	112.0	.	25.0	.36	80
21	2	28.0	3.50	80.0	7.78	25.0	.31	60
21	1	32.0	3.80	85.0	.	28.0	.40	60
21	4	26.0	2.90	75.0	.	.	.43	40
21	5	32.0	3.30	105.0	7.29	30.0	.22	60
21	3	28.0	2.90	90.0	6.94	30.0	.28	70
21	6	29.0	5.30	100.0	.	24.0	.55	5
22	1	25.0	5.50	124.0	4.67	28.0	.44	90
22	2	24.0	1.10	63.0	4.04	35.0	.43	90
22	3	29.0	1.90	62.0	4.38	36.0	.42	90
22	4	26.0	7.20	85.0	4.85	38.0	.49	95
22	5	19.0	2.40	65.0	3.61	37.0	.34	90
22	6	25.0	1.40	78.0	6.78	38.0	.49	-
22	8	32.0	4.00	80.0	4.10	35.0	.54	80
22	7	26.0	9.40	135.0	6.35	35.0	.39	60
23	2	47.0	6.20	93.0	5.55	35.0	.38	75
23	3	37.0	4.70	106.0	8.32	26.0	.47	50
23	4	26.0	3.00	68.0	5.56	30.0	.42	50
23	5	44.0	11.10	191.0	9.86	23.0	.44	50
23	6	36.0	3.80	86.0	5.29	24.0	.52	50
23	7	.	3.00	70.0	6.70	.	.	50
23	8	.	3.00	80.0	5.05	.	.	100
24	1	.	7.00	125.0	.	.	.	-
24	2	39.0	12.60	105.0	8.90	18.0	.56	-
24	3	31.0	4.50	108.0	4.89	.	.	90
24	4	37.0	15.20	164.0	5.84	.	.	-
24	5	38.0	8.60	122.0	.	.	.	80
24	6	35.0	5.60	81.0	6.47	.	.	90
24	7	36.0	14.40	205.0	.	18.0	.38	80
24	8	23.0	12.90	163.0	5.26	21.0	.39	-
24	9	43.0	21.70	20.0	.	11.0	.42	80
24	10	27.0	3.10	70.0	.	.	.	-
25	1	42.0	46.20	310.0	7.25	.	.	100
25	2	37.0	16.30	233.0	8.16	.	.	100
25	3	45.0	31.60	220.0	.	.	.	-
25	4	21.0	1.60	220.0	.	.	.	-
25	5	22.0	1.40	66.0	.	.	.	-
25	6	45.0	45.50	280.0	9.25	.	.	100
25	7	40.0	31.20	202.0	.	.	.	100
26	1	23.0	1.60	78.0	4.74	20.0	.45	50
26	2	24.0	1.20	57.0	5.12	20.0	.46	100
26	3	37.0	3.80	71.0	5.28	18.0	.45	-

(cont.) Appendix 24

Sno	S-Tree	Length	Volume	diam	Fall time	Scarf Angle ^{0}	Scarf depth % Dia.	Certainty of chosen direct
26	4	29.0	2.10	80.0	5.01	25.0	.50	25
26	5	28.0	1.50	80.0	4.50	23.0	.	100
27	1	45.0	20.0	320.0	9.61	12.0	.47	80
27	2	43.0	15.40	220.0	6.93	18.0	.35	80
27	3	43.0	11.50	110.0	5.90	13.0	.45	80
27	4	46.0	16.00	210.0	5.91	13.0	.26	80
27	5	36.0	13.60	153.0	6.81	13.0	.56	80
27	6	51.0	22.40	162.0	7.67	15.0	.29	50
28	1	33.0	1.80	90.0	4.01	43.0	.40	50
28	2	24.0	3.90	95.0	5.46	48.0	.51	10
28	3	27.0	7.40	150.0	5.92	42.0	.36	50
28	4	26.0	5.78	105.0	7.52	35.0	.45	50
28	5	26.0	1.40	64.0	5.19	43.0	.55	60
28	6	22.0	1.30	62.0	.	33.0	.33	50
28	7	29.0	3.80	107.0	6.24	38.0	.34	50
28	8	31.0	10.10	137.0	9.42	.	.41	-
29	2	29.0	1.60	70.0	6.21	27.0	.45	87
29	3	28.0	3.00	88.0	4.57	18.0	.53	78
29	1	26.0	2.00	62.0	5.58	23.0	.48	98
29	4	29.0	2.50	75.0	8.36	10.0	.24	70
29	5	27.0	2.30	84.0	5.50	.	.	95
29	7	27.0	2.70	65.0	5.48	18.0	.42	99
29	6	25.0	2.30	79.0	4.45	.	.	96
29	9	24.0	6.60	95.0	4.80	1.0	.52	98
29	8	28.0	7.00	129.0	4.67	1.0	.45	96
30	1	31.0	2.50	70.0	4.89	21.0	.46	75
30	2	32.0	8.90	120.0	5.55	19.0	.39	60
30	3	36.0	12.90	158.0	8.26	14.0	.28	60
30	4	40.0	14.50	160.0	7.94	12.0	.34	-
30	6	35.0	3.30	62.0	.	18.0	.53	70
30	7	40.0	22.60	195.0	8.85	15.0	.54	70
30	8	38.0	14.80	130.0	5.40	.	.47	98
30	5	42.0	15.70	127.0	6.38	18.0	.48	80
31	1	16.0	3.10	102.0	4.48	13.0	.59	75
31	2	22.0	2.00	113.0	3.77	24.0	.40	90
31	3	25.0	2.20	100.0	6.78	25.0	.20	50
31	4	18.0	.80	70.0	4.07	23.0	.41	90
31	5	28.0	10.00	208.0	.	25.0	.57	-
31	6	24.0	5.60	99.0	4.48	20.0	.48	90
31	7	8.0	.50	90.0	1.44	.	.	100
31	8	22.0	1.20	110.0	4.33	.	.28	90
32	2	26.0	3.90	80.0	4.88	.	.	-

Appendix 24

Sno	S-Tree	Length	Volume	diam	Fall time	Scarf Angle ⁰	Scarf depth % Dia.	Certainty of chosen direct
32	1	20.0	2.50	84.0	5.22	.	.	40
32	4	.	2.00	55.0	3.75	.	.	20
32	3	27.0	2.50	85.0	4.35	.	.	40
32	6	24.0	2.60	24.0	5.23	.	.	60
32	5	24.0	3.10	137.0	3.95	.	.	-
33	1	35.0	18.30	170.0	5.30	.	.	90
33	2	32.0	19.80	215.0	7.76	20.0	.28	70
33	3	31.0	3.80	90.0	3.57	.	.	90
33	4	35.0	14.70	144.0	.	16.0	.38	99
33	5	26.0	10.70	112.0	5.13	21.0	.27	100
33	7	25.0	6.00	116.0	4.36	24.0	.41	100
33	8	22.0	2.80	74.0	5.31	29.0	.47	100
33	9	25.0	8.80	105.0	.	.	.	100
33	10	36.0	17.40	107.0	5.29	18.0	.47	100
33	6	38.0	24.50	160.0	6.95	.	.	-
34	No field data collected							
35	1	52.0	16.90	145.0	.25	.	.	100
35	2	42.0	14.00	134.0	7.80	.	.	100
35	3	45.0	14.60	150.0	5.44	.	.	100
35	4	52.0	26.90	185.0	.	12.0	.45	100
35	5	54.0	16.70	110.0	.60	.	.	100
36	1	49.0	8.90	126.0	6.75	17.0	.60	50
36	2	41.0	4.70	116.0	7.82	28.0	.36	50
36	3	46.0	9.00	145.0	6.74	13.0	.34	40
36	5	45.0	7.70	105.0	.	.	.	50
36	6	45.0	6.00	127.0	6.63	18.0	.55	50
36	7	41.0	4.20	83.0	4.60	20.0	.45	60
36	8	44.0	4.40	80.0	.	.	.	60
36	9	43.0	8.90	97.0	.	20.0	.58	50
37	1	42.0	12.50	135.0	5.16	18.0	.48	95
37	2	36.0	3.30	72.0	5.04	28.0	.35	95
37	3	44.0	12.90	145.0	7.31	.	.28	70
37	4	40.0	5.10	100.0	5.87	15.0	.50	90
37	5	32.0	5.10	144.0	5.69	27.0	.28	90
37	6	32.0	3.70	75.0	4.39	30.0	.53	90
37	7	50.0	23.70	199.0	6.12	24.0	.35	100
37	8	39.0	3.90	83.0	6.39	20.0	.54	90
38	1	24.0	2.70	79.0	5.12	24.0	.51	75
38	2	27.0	4.60	95.0	4.79	14.0	.63	75
38	3	24.0	7.30	110.0	4.60	30.0	.32	75
38	4	29.0	6.50	105.0	7.59	24.0	.52	75
38	5	25.0	3.60	87.0	.	25.0	.40	90

(cont.) Appendix 24

Sno	S-Tree	Length	Volume	diam	Fall time	Scarf Angle ⁰	Scarf depth % Dia.	Certainty of chosen direct
38	6	26.0	2.10	71.0	6.69	16.0	.54	90
38	7	22.0	.90	63.0	3.95	23.0	.37	90
38	8	26.0	3.20	84.0	3.39	26.0	.27	90
39	1	36.0	3.70	80.0	5.13	34.0	.59	75
39	2	26.0	3.70	76.0	4.77	42.0	.48	75
39	3	26.0	2.30	70.0	5.68	28.0	.50	-
39	4	26.0	1.70	67.0	5.05	37.0	.60	50
40	1	43.0	8.10	107.0	6.78	18.0	.54	98
40	2	36.0	6.40	160.0	7.09	.	.	98
40	3	.	49.50	230.0	7.67	14.0	.30	98
40	4	33.0	5.40	99.0	.	20.0	.59	100
40	5	33.0	8.00	118.0	2.77	24.0	.47	100
40	6	40.0	21.70	197.0	8.86	18.0	.50	98
41	1	32.0	9.20	110.0	5.16	.	.	90
41	2	37.0	5.30	182.0	.	22.0	.40	100
41	3	30.0	19.10	228.0	5.96	.	.30	100
41	4	35.0	6.40	228.0	6.64	27.0	.27	-
41	5	31.0	8.60	167.0	4.54	10.0	.36	100
41	6	31.0	6.80	195.0	7.27	18.0	.44	90

Appendix 25

Distribution of the number of trees against 2 dimensions of rated defect: internal and circumference, and the uniformity of tree shape (n=260 trees)

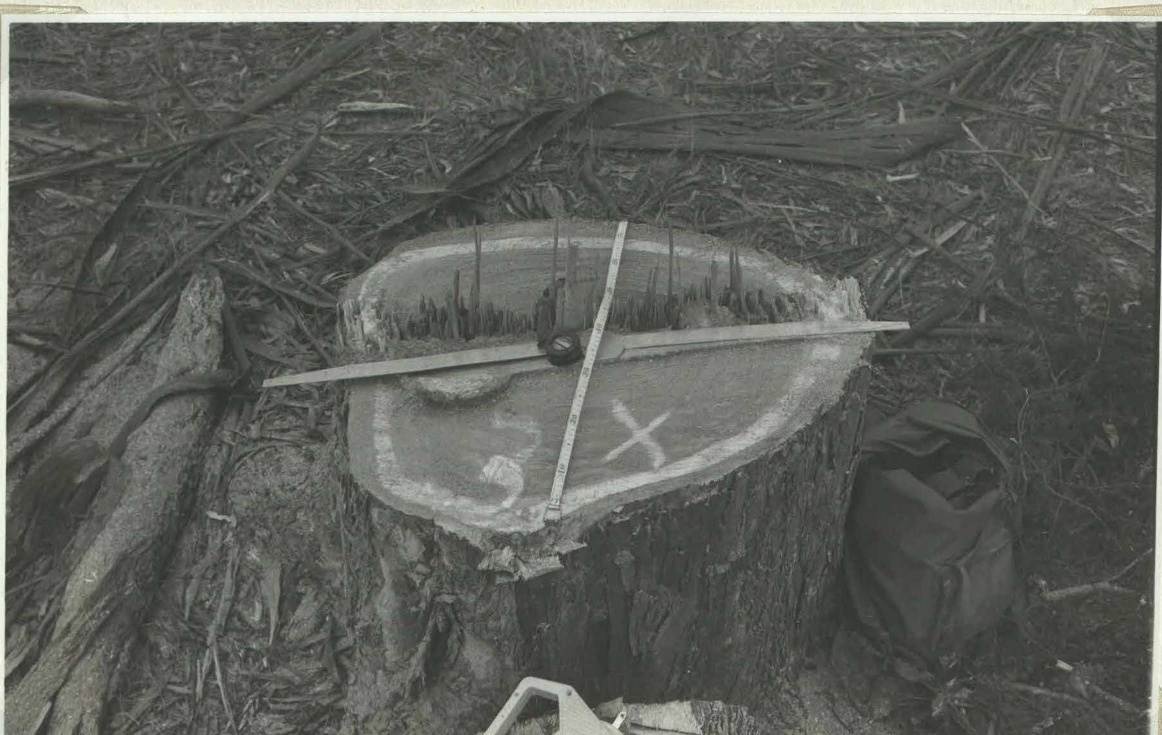
The gradings of the two dimensions of defect in the S-trees were distributed as in below. Close to half the trees (128 trees) were classified by two independent judges as having a noticeable degree of internal defective wood and decay, with 30 percent of the trees having at least two of the eight sectors of the tree classified as unsound. Only 22 of the 266 trees had half the tree stump, (four or more sectors), graded as defective. In terms of defective wood on the circumference of the tree a smaller number of trees, 75 or 30 percent were classified as having at least one sector of defect, with the complete distribution as shown in the central column of Table 20. The correlation between the subjective grading of internal defect and circumference defect was high (r = .83, n=260, p < .001). As can be seen in the table, the roundness of the trees circumference at stump height had a much more varied distribution across trees than the assessments of defective wood in the stump, with 165 or approximately 60 percent of the trees being judged as having more than half the stump uneven in shape, and less than ten trees having the sort of cylindrical circumference typically found in Australian softwood, such as pinus radiata.

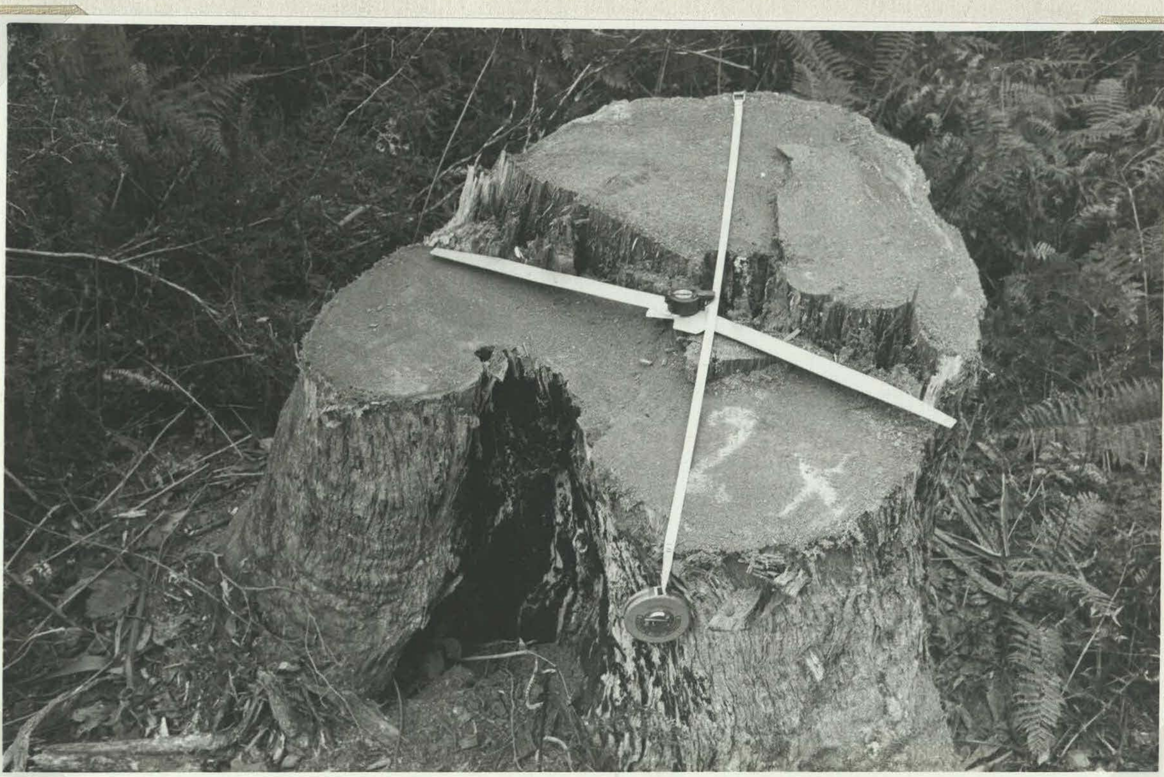
	Tree Stump Defect		Tree Stump Roundness
	Internal	Circumference	Un-even circumference
Sectors of tree affected	No trees	No trees	No trees
0 (no def)	132	185	-- (round)
1	54	42	10
2	39	17	17
3	13	11	32
4	13	4	33
5	7	1	47
6	2		51
7			44
8 (full defect)		23 (irreg)	

Though rudimentary, these classifications support the commonly held opinion that defect and irregular barrel shape are familiar problems for the hardwood tree feller.

Appendix 26

Examples of the tree stump qualities once the tree was cut





(cont.) Appendix 26

Appendix 27

Distribution of scarf type and dimensions used by the men (Overall n=266)

Scarf Type:
(Figure 3.1, p. 97-99)

	Frequency N	Percent
Conventional	120	57 %
V-shaped cut	48	23 %
Humbolt	41	20 %
Scarf under tree /not recorded	(57)	

Angle of scarf cut:

Angle	Frequency N	Percent
Up to 9^0	9	4 %
10 -- 19^0	77	38 %
20 -- 29^0	81	40 %
30 -- 39^0	30	15 %
40 -- 45^0	7	3 %
Above 45^0	1	-
Scarf under tree /broken	(61)	

Depth of scarf into tree as a proportion (%) of the mean stump diameter measurement:

	Frequency N	Percent
Up to one quarter depth	11	6 %
1/4 to 1/3	27	14 %
1/3 to 1/2	117	58 %
1/2 to 2/3	39	20 %
2/3 to 3/4	5	2 %
No definitive measure possible	(67)	

Appendix 28

Proportion of directions within the 4 quadrants of the compass for the chosen felling direction of the trees studied. (Proportions for the perceived natural lean in parenthesis) (n=246)

Directions - A quadrant analysis of points of the compass to determine if a prominent choice of felling direction existed, that is:

- Did the the tree fellers choose to fall significant proportions of the trees towards a particular point or quandrant of the compass?

Though there was a preponderance of trees chosen to be fallen to the north-west point of the compass it seems justified to conclude that this was a normal spread of chosen felling direction, and of the range of natural lean that would present themselves to tree fellers. Using forty five degree sectors, which is the most often used 8 way classification of a fall in the practical setting, these smaller segments still gave coverage to all points of the compass.

N

(34%) (27%)

34% **25%**

W E

(19%) (20%)

17% **24%**

S

Appendix 29

Frequency table of certainty for perceived natural lean and for the chosen direction of fall - In 10 point categories

Rated Certainty	Perceived natural Lean (Frequency) n=184	Chosen Felling Direction (Frequency) n=230
0 - 10	55	1
11 - 20	0	1
21 - 30	6	0
31 - 40	2	8
41 - 50	5	18
51 - 60	16	23
61 - 70	14	22
71 - 80	25	22
81 - 90	25	43
91 - 100	36	92

Error tress - main characteristics

In all, the felling of 266 S-trees were studied across the 39 field data subjects. Four of the subjects had 9-10 S-trees for study, with 70 percent of the group having 6-8 S-trees. Five subjects had only 3 S-trees, albiet mainly of larger diameter. The main characteristics of the S-trees that were felled are given in the secondy table. In terms of diameter some fifty percent of the trees were between 50 to 100 cms in butt diameter and forty two percent between 101 and 200 cms butt diameter, while the three largest S-trees were over 320 cms in diameter. The most common tree height was 25-26 metres. The falling time was the average of three measurements taken from the video film of the felling episode

Error trees (n =135):

	X	SD	Range
Length (metres)	27.5	11.2	6 - 59
Volume (tonnes)	8.3	10.7	1 - 85
Diameter DBH (cms)	112.9	54.1	24 - 352
Falling time (seconds)	5.8	1.6	<2 - >9

All S-trees (n=266):

	X	SD	Range
Length (metres)	29.1	11.7	6 - 69
Volume (tonnes)	9.0	10.7	1 - 87
Diameter DBH (cms)	113.8	52.7	24 - 350
Falling time (seconds)	5.8	1.7	<2 - >9

All accurate trees (n=106):

	X	SD	Range
Length (metres)	32.2	11.6	8 - 69
Volume (tonnes)	10.7	11.5	1.- 87
Diameter DBH (cms)	119.0	52.4	47 - 320
Falling time (seconds)	6.0	1.8	1.77

Appendix 31

Details of the trees and subjects of the 8 backwards error trees i.e., trees that fell greater than 90^0 from the chosen direction of fall.

S No	Age	Exp	PWC l/min	Tree	Error	Cert	Risk	Awk	Pull	Scarf	Hght (M)	Vol (T)	Dia (cms)	Average Hr	Hrnett
4	44	29	4	3	180	50	0	0	zero	N	20	8	95	129	53
6	47	21	3	5	150	20	1	0	zero	N	7	4	113	129	58
7	19	1	4	5	155	40	1	4	5	N	15	4	79	122	43
14	31	1	5	6	109	80	1	2	zero	N	19	11	157	123	59
24	20	2	4	3	135	90	1	0	zero	N	31	5	108	110	40
25	36	16	5	7	121	100	-	-	30	N	40	31	202	123	67
29	24	3	4	6	113	96	0	1	5	N	25	2	79	98	44
31	40	22	4	7	180	100	1	2	zero	N	8	1	90	122	56

Legend:

S No	Subject identification number
Age	Subjects age in years
Exp	Subjects experience in full time tree felling.
PWC	Subjects VO_2 max Or PWC class in terms of l/min.
Tree	S-tree number in the subjects series.
Error	Felling error from the nominated direction.
Cert	Subjects certainty about achieving an accurate fall.
Risk	Risk of the fall.
Awk	Awkwardness of making the felling cuts.
Pull	The amount that the tree was pulled away from its perceived natural lean.
Scarf	Type of scarf used by the subject (all N normal conventional scarf)
Height	Height of the tree to the nearest metre.
Vol	The volume/weight of the tree to the nearest tonne.
dia	Mid-girth diameter of the tree.
Hr	Average heart rate cutting the tree.
Hr nett	Average heart rate nett cutting the tree.

Appendix 32

Correlation of physical stump measurements and felling error

	Fell	Scarf			Hinge Width		Hinge Height		Mean
	error	angle	depth	depth %	Left	Right	Left	Right	Tree dia
Fell error	--	-.08	.17	.08	.08	.15	.04	-.07	.00
Scarf angle		--	-.01						-.26***
depth			--	.36***					
depth %				--	-.17*				-.23***
Hinge width Left					--	.69***			.48***
Right						--	.34***		.45***
Hinge Height Left							--	.15*	.50***
Right								--	.35***
Tree dia.									--

* $p < .05$ ** $p < .01$ *** $p < .001$

Appendix 33

Main correlation matrix for the study

Legend:

Age	Subject age years and months.
Wt	Weight.
Ht	Height.
Exp	Experience full-time hardwood felling years and months.
Skill-1	Instructors rating on skill "preparing base of tree".
Skill-2	Instructors rating on skill "making the scarf".
Skill-3	Instructors rating on skill "control of saw - accuracy".
Skill-4	Instructors rating on skill "avoiding danger as tree falls".
Quota	Subject's current quota at the time of the study.
Hr-rest	Heart rate at rest.
Hr-Ave.	Average absolute heart rate in the field.
Hr-nett Ave.	Average heart rate nett.
VO_2 max	Predicted VO_2 max value.
..VO_2 field	Average energy expenditure (VO_2) in the oxylog tests.
..%-util VO_2	Percentage utilisation (VO_2) in oxylog tests.
Type-A	Score in Type-A measure of Jenkins Activity Survey.
Speed/Imp.	Score on speed and impatience measure of JAS.
Hard/driv'g	Score on hard-driving measure of JAS.
Fatalism	Score on fatalism/locus of control measure.
Ave. cert	Average certainty for chosen felling direction
Prop cert	Highest proportion of certainty value for felling direction.
Ave. Error	Average felling error in the field.
Prop Error	Highest proportion of felling error value.
P (A) S/1	P (A) signal detection score at stage 1 of the simulation test.

	Age	Wt	Ht	Exp	Skill-1	Skill-2	Skill-3
Age	1.0000	-.0172	.2898	.6985***	.2056	.1688	.1058
Wt	-.0172	1.0000	.5134***	.0058	.0019	.2303	.4387**
Ht	.2898	.5134***	1.0000	.1284	.1659	.2746	.3330
Exp	.6985***	.0058	.1284	1.0000	.1059	.2038	.2284
Skill-1	.2056	.0019	.1659	.1059	1.0000	.5496**	.4132**
Skill-2	.1688	.2303	.2746	.2038	.5496**	1.0000	.5017**
Skill-3	.1058	.4387**	.3330	.2284	.4132**	.5017**	1.0000
Skill-4	.0295	.2009	.1657	.1078	.4819**	.7839***	.5146***
Quota	.0544	-.0404	-.2675	.0053	.2343	-.1621	.1123
Hr-rest	-.0912	-.0857	-.1158	-.0168	-.1339	-.0627	-.1954
Hr-Ave.	.1209	-.1142	-.1329	.0604	.0558	-.1528	-.1230
Hr-nett Ave.	.1174	.0019	-.0001	.0550	.2220	-.1695	.0100
VO_2 max	-.2338	.5733***	.3673	-.0858	.0351	-.0442	.1632
VO_2 field	.2371	.5528***	.4720**	.1092	.2486	.3676	.4132**
%-util VO_2	.4163**	-.0104	.0988	.1373	.2649	.3470	.2513
Type-A	.2361	.0239	.1012	.1713	.2434	.2334	.0724
Speed/Imp.	.2312	.1369	.2157	.0966	.1443	.2130	-.0767
Hard/driv'g	.0415	.0929	.2279	-.0457	.1513	.3266	.3386
Fatalism	-.0431	-.3542	-.3176	-.1159	-.2059	-.5462**	-.4557**
Ave. certain	.2846	-.1346	.0113	.2570	.2040	.2220	-.0431
Prop certain	.1668	-.0527	.0938	.1174	-.0207	.1421	-.0538
Ave. Error	-.1053	.0638	-.0606	-.0834	-.3286	-.4332**	-.2362
Prop Error	-.2227	-.0637	-.1274	-.0344	-.4183**	-.1854	-.4134**
P (A) S/1	.2188	.1254	.3473	-.1130	-.2795	.1208	.0255
	Age	Wt	Ht	Exp	Skill-1	Skill-2	Skill-3

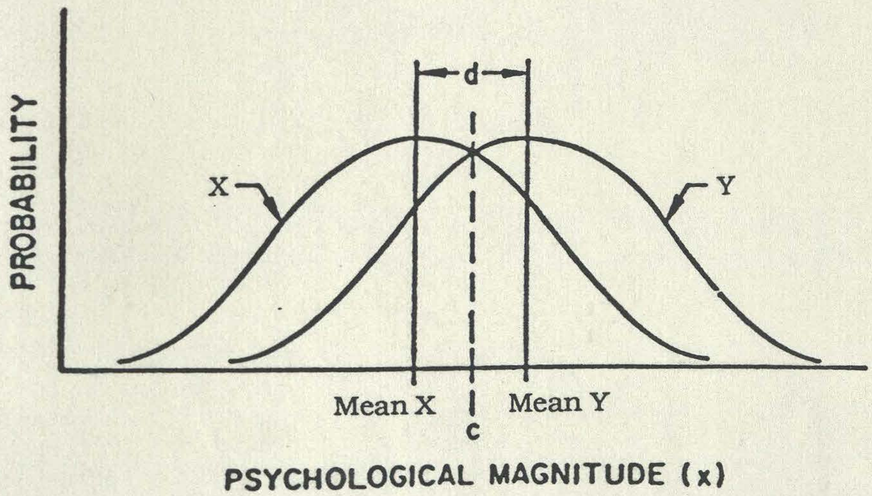
** $p < .01$ *** $p < .001$, N varies according to pair-wise deletion for missing data

Appendix 34

Diagram N & S+N distributions in the Theory of Signal Detection

P(A), the measure which indicates the ability of the operator to differentiate the S+N events from N alone.

(B), which refers to the decision criterion (or response bias) being employed by the operator in making the decision about the presence or absence of the signal.



Hypothetical distributions of the psychological magnitudes of two confusable stimili x and y. The distance between their means can be calculated from judgements on a forced choice rating sale as detailed in chapter four where d is the measure of discriminability. The dashed line, c, represents the ideal symmetrical decision criterion.