THE USE OF HEART RATE INDICES AND SUBJECTIVE QUESTIONNAIRES IN THE DETERMINATION OF FATIGUE IN MOTOR-MANUAL TREE FELLING AND DELIMBING OPERATIONS IN NEW ZEALAND EXOTIC PLANTATION FORESTS

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ABSTRACT

This study assessed the use of heart rate indices and subjective questionnaires in the determination of fatigue in motor- manual tree felling operations in New Zealand exotic plantation forests.

The research design consisted of a causal study utilising an amalgamation of both observational and ex post facto data collection techniques employing a cross sectional case study approach within a field study research environment.

Findings from the research indicate that motor-manual tree felling and delimbing are tasks not necessarily analogous with excessively high levels of fatigue, even though the physiological measures categorised motor-manual felling and delimbing as being moderate to heavy workload tasks. Chronic fatigue was avoided, and acute fatigue mitigated by the effective use of the fallers self-pacing mechanism, combined with both structured and spontaneous rest breaks analogous with the work method adopted by motor-manual fallers. Consequently, production was not negatively affected by the progression of the working day. Poor work postures commonly adopted by the fallers encourage the progressive development musculo-skeletal damage. Hazards encountered by the subjects followed national trends for felling and trimming. Significant decreases in thermal comfort and sensation ratings occurred, accompanied by an increase in the skin wettedness rating and higher thermal regulation ratings for the majority of the fallers. No discernible increase in mental fatigue could be identified during the study. The ambient thermal environment and work site terrain had minimal effect on the subjects performance levels or physiological and psycho-physiological loadings.

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Of all those that I must thank, by far the most important and special of all to me is that of my wife Pam. I thank her for the endless and undying support over the last two years. Without which, none of the work could have been started, let alone completed.

All that I can say now is, that enough is enough, and here endith my progression up the ladder of Academia, its now time for deer stalking!!.

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CHAPTER 1: INTRODUCTION TO COMMERCIAL FORESTRY

1.0 Introduction

This chapter begins with a brief history of plantation forestry in New Zealand, the resource and the labour force. It then outlines the current and future labour requirements for both current and projected harvesting trends within the industry. The final section outlines past and present ergonomic research relating to manual forestry work in New Zealand.

1.1 New Zealand Commercial Forestry

Forestry is one of the oldest occupations known to New Zealanders. Even before the whaling and sealing colonies were established during the late 1700's and early 1800's, Europeans had been involved in the extraction of *Agathis australis* (Kauri) poles for use as ship spars. Before European settlement, the indigenous forest was an important aspect of the culture of the Polynesian (Maori) population which inhabited New Zealand from ca 1000 AD. They harvested the forest for fuel wood, shelter and, using fire, cleared areas for the purpose of raising food crops.

Commercial, or plantation, forestry commenced at the beginning of the 20th century. It was recognised that the indigenous forests could not provide the lumber requirements of the rapidly growing colony. Plantation forestry boomed during the great depression of the 1930's, when large scale planting of predominantly *Pinus radiata* was undertaken to provide gainful employment for the large number of people who were jobless during this period. This was the first evidence of the importance of plantation forestry to the nation and the employment opportunities it could provide.

In 1995, New Zealand contained 1,308,000 hectares (ha) of exotic forestry of which 89.9% was planted in *Pinus radiata*, 5.1% Douglas Fir (*Pseudotsuga menziesii*) the remaining 5% consisted of a mixture of exotic softwoods (3%) and exotic hardwoods (2%) (Forestry Facts and Figures 1995). In April 1992 (latest available figures), only 16% of the total *Pinus radiata* resource fell into the clearfell age class of 25 + years old.

More significantly, a further 43% of the total *Pinus radiata* resource was between 5 to 10 years away from clearfell age class (Forestry Facts and Figures ,1995).

Between 1920 and 1990, the annual rate of new planting's peaked at approximately 57,000 ha per year up until the early 1980's when this rate decreased dramatically in line with both the standardisation of all land based production incentives (Le Heron 1985) and the economic recession instigated by the share market crash of 1987. Since the early 1990's an increased interest in forestry investments in the form of joint venture retirement and superannuation schemes, combined with the more traditional farm based woodlot establishments, has seen the rate of new planting's increase dramatically from around 17,000 ha per year in 1990 to an estimated 85,000 ha per year in 1995 (Forestry Facts and Figures 1995). The beneficial consequences of such a trend, in terms of the continuance of a viable wood fibre source for the forestry sector, are substantial.

1.2 The New Zealand Logging Workforce

In February 1994, there were 8548 people employed in the logging and silviculture workforces in New Zealand (Forestry Facts and Figures 1995). Current figures are unavailable on the exact distribution between these two groups. However, an indication can be gained from the previous year's figures which, for a total workforce of 7394 workers, placed 4552 in silviculture and 2842 in logging (Forestry Facts and Figures, 1994). The average $\pm$ (sd) age of the logging workforce in June 1995 was 31.4 ± 8.9 years. The average logging experience for the workforce was 8.4 years. Seventy six percent of the logging workforce had at least one training module (Byers, 1995a). The logging workforce is predominantly male, with only 1.5% of the workforce being female (Byers pers.comm, 1996). The logging workforce is comprised of two major ethnic groups consisting of 57% European and 41% Maori. Unlike the silviculture workforce, where Pacific Islanders accounted for 9% of the workforce, in logging they only accounted for 1.5% (Byers, 1995a).

1.3 Future Developments

Traditionally, employment within the timber harvesting sector of the forest industry has contained a significant component of manual work. More recently this started to change with the development of technological advances which enable the partial or full mechanisation of certain harvesting tasks. Many overseas forestry nations have mechanised a large proportion of their timber harvesting and processing operations, particularly in Scandinavia and the United States. Such moves have been assisted by available and appropriate technologies, favourable timber resources, agreeable topography and most importantly, the emergence of critical health and safety issues.

New Zealand's forest industry, while beginning to mechanise, still requires a large contingent of manual labour in order for it to function effectively. This will continue to be the case for the foreseeable future due to a relatively large proportion of the timber resource being established on steep and inauspicious terrain, and economy of scale constraints associated with the large production rates generated by mechanised operations. Nevertheless, timber production from New Zealand plantation forests has consistently increased over the last decade. In 1988 2504 logging workers produced 9,688,000 m^3 of timber. By 1994 the logging workforce had increased to 3369 and production to 15,937,000 m^3. In relative terms this means that in 1988 each person employed in logging produced 3, 869 m^3 of wood per annum. By 1994 this had increased to 4,730 m^3 per annum. Whilst some of this increased production would have been generated through the use of better technologies and increased production due to mechanisation, the majority can still be attributed to increased use of motor-manual systems, that is, a person using a chainsaw.

1.4 Manual Forestry Work

Manual forestry work has been categorised by many researchers as an occupation requiring moderate to heavy physical workloads (110-145 $bt.min^{-1}$), high rates of energy expenditure (7.5 - 10.0 $kcal.min^{-1}$) and oxygen consumption (1.5 - 2.0 $l.min^{-1}$) (Cristofolini et al., 1990; Fibiger and Henderson, 1982; Hagen, 1993; Harstela, 1990;

Henderson, 1984; Kirk and Parker, 1994b; Kukkonen-Harjula, 1984; Parker and Kirk, 1994; Seixas and Ducatti, 1995). Such work is often undertaken in inhospitable working environments, and in close proximity to potentially dangerous equipment and situations (Golsse and Rickards, 1990; Vik, 1984). The hazardous nature of the fallers work requires constant vigilance in order to prevent serious or fatal injuries from occurring. A multitude of factors need to be constantly monitored, observed and corrective action taken while working in forest harvesting operations. If any one of these factors are misread, neglected or incorrectly diagnosed, then the result for the forest worker can be serious injury or death.

This has been the case with forest harvesting operations globally. Similar research findings have been found in Scandinavia (Hagen et al., 1993; Kukkonen-Harjula, 1984), Europe (Van Loon, 1976), United States (Johnson and Tabor, 1987; Smith and Sirois, 1982; Smith et al., 1985; Smith et al., 1986; Smith and Thomas, 1993), Canada (Robinson et al., 1993; Trites et al., 1993), South America (Apud et al., 1990; Apud and Valdes, 1993; Apud and Valdes, 1994; Seixas and Ducatti, 1995), Asia (Andersson, 1986), Africa (Abeli and Malisa, 1994), Australia (Henderson, 1984) and New Zealand (Gaskin, 1990; Kirk and Parker, 1993a; Kirk and Parker, 1994b; Kirk and Sullman, 1995; Parker and Kirk, 1993b; Vitalis et al., 1986) to name a few.

Most of New Zealand's forestry based ergonomics research has followed those directions identified by Gaskin in his review of past, present and future ergonomics research within New Zealand's forestry sector (Gaskin, 1986). This review laid the foundation for much of the subsequent nine years human factors based research within the industry. Consequently there has been extensive work undertaken to identify the *physical hazards* (Parker, 1991; Parker and Kirk, 1993b; Tapp et al., 1990), *accident type and frequency*, (Gaskin and Parker, 1992; Parker, 1994; Parker, 1995; Prebble, 1984; Slappendel et al., 1993), *physiological strain* (Gaskin, 1990; Kirk and Parker, 1993b; Kirk and Parker, 1994b, Kirk and Sullman, 1995; Parker and Kirk, 1993a; Vitalis et al., 1986;), *biomechanical loadings* (Gaskin, 1990; Gaskin et al., 1987; O'Leary, 1988), *socio-political factors* (Byers, 1994; Byers, 1995a; Byers, 1995b; Byers and Adams, 1995; Gibson, 1994) and *the role of personal protective equipment* (Kirk, 1992; Kirk, 1993; Kirk et al., 1992; Kirk and Parker, 1994; Prebble, 1981; Sullman, 1994) associated with forest harvesting operations.

However, the majority of these studies have traditionally utilised one single measure to determine the physiological or mental effort being exerted by the person undertaking the observed task. The work undertaken by Kirk and Parker (1994b) investigating the physiological workloads experienced in several sectors of the forest industry, gave an insight into the severity of workloads experienced by forest workers in New Zealand. The research by Kirk and Sullman (1995) took this work a step further and used a series of measures to determine the impact of physiological and psycho-physiological stressors on the safety, comfort, productivity and fatigue of hauler breaker-outs.

The objective of this thesis is to develop this research further by applying heart rate indices and subjective questionnaire protocols developed by Kirk and Sullman (1995) to motor-manual tree fallers in an attempt to determine fatigue in forest workers.

1.5 Summary

This chapter briefly outlined the history of plantation forestry in New Zealand, its resource and labour force. It then examined the current and future labour requirements for the industry. Past and present ergonomic research relating to manual forestry work in New Zealand was examined Chapter 2 identifies key issues pertaining to fatigue and reviews past and present research pertinent to each of these issues.

CHAPTER 2: LITERATURE REVIEW

2.0 Introduction

This chapter begins by discussing the concepts of muscular (physical) and general (mental) fatigue, their definitions and mechanisms for measurement. The chapter then reviews principal aspects which have been identified as impacting on worker fatigue. Thermal load, work environment, work rate, psychological state and physical capacity, are reviewed and key issues identified in conjunction with past and present research pertinent to each of these key areas.

2.1 Fatigue

As stated by Cameron (1974), fatigue is a concept which defies precise definition. It is a useful label for a generalised response to stress over a period of time, which has identifiable and measurable characteristics, but it has no explanatory value. The effects of fatigue may be either acute or chronic, or both, confined to the subjective state of the individual or extend into measurable aspects of their performance.

Fatigue is a very complex concept since it involves both physiological as well as psychological factors. Fatigue can be defined broadly into muscular (physical) fatigue and general (mental) fatigue. However, Mital et al., (1991) in their review of fatigue allowances suggested three fatigue categories; subjective, objective and physiological fatigue. Krueger's (1991) investigation into the effects of fatigue, sleep deprivation and rest pauses on sustained military performance also used a third category of fatigue, namely that of phasic fatigue. Krueger defined phasic fatigue as short term fatigue resulting from prolonged vigilance work.

The majority of researchers however, appear to use the more generic physical and general fatigue categories (Apud et al., 1972; Åstrand and Rodahl, 1986; Brzezinska, 1968; Grandjean, 1979; Grandjean, 1988; Mascord and Heath, 1992; Mital et al., 1991; Okogbaa et al., 1994; Rodahl, 1989; Rosa and Colligan, 1988). Physical fatigue is generally defined as being an acutely painful phenomenon, which arises in overstressed muscles, and is localised there. General fatigue, in contrast, is a diffused sensation which is accompanied by feelings of indolence and disinclination for any kind of activity (Grandjean, 1988). Both forms of fatigue are seen as being natural protective devices designed to prevent the body from overstraining itself as well as allowing time for the body's recuperative processes to take place (Apud et al., 1972; Åstrand and Rodahl, 1986, Grandjean, 1988; Rodahl, 1989).

The quantitative measurement of fatigue has been of interest to ergonomists and industry alike for many years (Brzezinska, 1968; Grandjean, 1979; Radjef, 1972; Rosa and Colligan, 1988; Mascord and Heath, 1992; Mital et al., 1991). Ergonomists have investigated the relationships between fatigue and the level of stress so as to develop ways of improving work methods and conditions in order to make such tasks less demanding on the worker. Industry on the other hand wishes to know the relationship between fatigue and worker output and the influence of working conditions and methods. Ideally the sole objective of these two groups should be the development of work methods and conditions which provide an efficient level of worker productivity without detrimentally effecting either the workers safety, comfort or long term health.

Actual measurement of fatigue presents one serious limitation in that to date there is no way of directly measuring the extent of fatigue itself in absolute terms (Apud et al., 1972; Grandjean, 1988; Radjef, 1972). There is no absolute measure of fatigue, comparable to that of energy consumption, expressed in kilojoules. All the experimental work carried out so far has merely measured certain manifestations or "indicators" of fatigue (Grandjean, 1988). As a consequence, several of these "indicators" must be measured simultaneously at set intervals throughout the period in which the task is being undertaken. Once this has been done, the level of fatigue can be concluded from these indicators. A key indicator which must be included in any assessment of fatigue is a person's subjective feeling of fatigue. As stated by Grandjean (1988), a measurement of physical factors needs to be backed up by subjective feelings before it can be correctly assessed as indicating a state of fatigue.

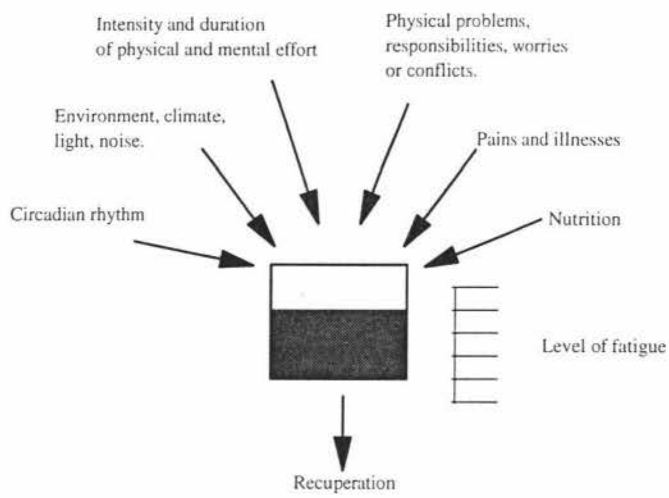
Grandjean (1988) states that the six most commonly used methods of fatigue measurement are:

1. Quality and quantity of work performed.
2. Recording of subjective impressions of fatigue.
3. Electroencephalography (EEG).
4. Measuring subjective frequency of flicker-fusion of eyes.
5. Psychomotor tests.
6. Mental tests.

Fatigue can be caused by a number of factors (Figure 1) and is usually the result of an amalgamation of several factors which occur during the working day or week. Closely linked with the concept of fatigue is that of recuperation. A strong emphasis must be placed on the fact that stress and recuperation must balance out over the 24-hour period, and that neither of these should be carried over to the next day. If rest is unavoidably postponed until the following evening, this can be done only at the expense of well-being and efficiency (Grandjean, 1988). Such a phenomenon is not uncommon within the forest industry due to the hard physical nature of the work, harsh working environment, long working days (12 - 14 hours/day), extended working weeks (5.5 - 6 days/week) and associated short recuperation time (1 - 1.5 days/week). As a consequence, the potential for workers to develop symptoms of chronic fatigue abound.

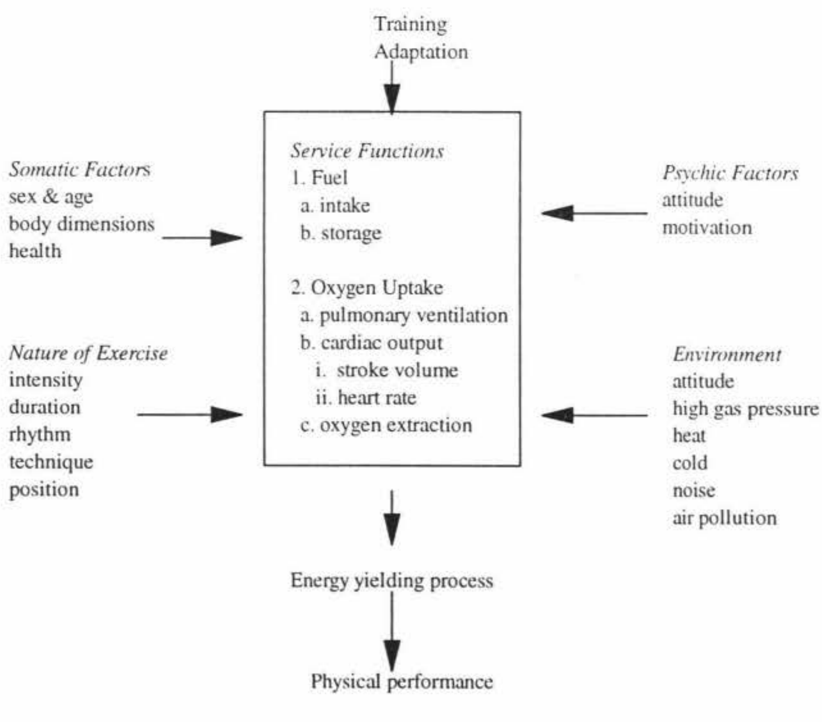
There are numerous physical, environmental and psychological factors which effect a person's ability to perform physically in their work environment (Figure 2). The relationship between the work load and work capacity is affected by a complicated interplay of many factors, both internal and external, which must be taken into consideration (Åstrand and Rodahl, 1986; Okogbaa et al., 1994). By far the most important of these factors in relation to the task of tree felling are; thermal load, physical work environment, work rate, psychological state and physical ability.

Figure 1: Combined Effect of Everyday Causes of Fatigue.



(Source: Grandjean, 1988)

Figure 2: Factors Affecting Physical Performance.

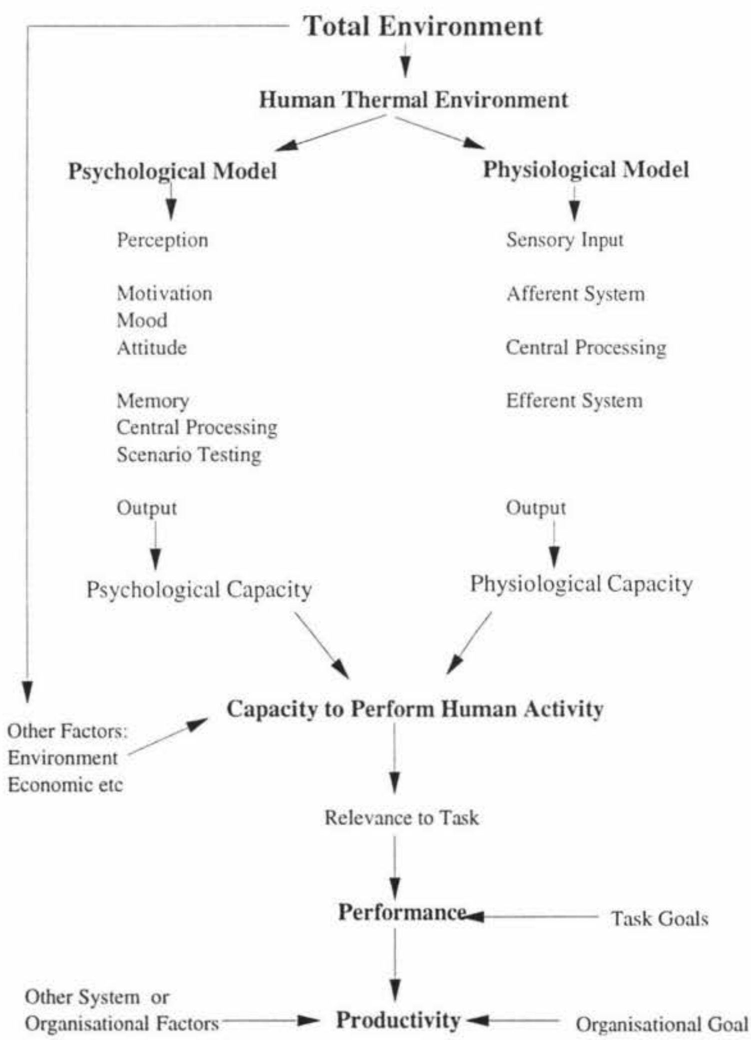


(Source: Åstrand and Rodahl, 1986)

2.2 Thermal Load.

The primary concern for forest workers in terms of thermal strain is heat stress. The worker usually has only a relatively small degree of control over this factor. The thermal load on the other hand, exerts a large degree of control over the forest worker in terms of safety, comfort, productivity and fatigue levels (Figure 3).

Figure 3: Model for Considering the Effects of the Thermal Environment on Human Activity, Performance and Productivity.



(Source: Parsons, 1993)

2.2.1 Effect of heat on performance.

When exposed to whole body heating, the human body must maintain a core temperature of 37^{o} Celsius. This is achieved by raising skin temperature via increased blood flow to the skin, by accelerating heart rate and by enlarging cardiac output. The change in blood routeing reduces the amount of blood that can be supplied to muscles and internal organs. If muscles must work in a hot environment, their raised metabolic requirements and heat output further increase demands on the cardiovascular system (Kroemer, 1991). Increasing deep body temperature creates competition for blood between working muscles and the skin. Consequently, fatigue and exhaustion from heavy work will occur sooner, and recovery will take longer, in a hot environment than a cool one (Sanders and McCormick,1992). This influence has been shown to have a detrimental effect on work rate and overall productivity of the worker (Andersson, 1986; Smith and Rummer, 1988; Smith and Sirois, 1982; Sirios and Smith, 1985; Smith et al., 1986).

While fatal and/or even severe cases of heat strain are rarely reported in the New Zealand forest industry, the overall effect of undertaking hard physical work under hot conditions on worker safety, comfort and productivity is relatively unknown in New Zealand. As stated by Smith and Sirois (1982), there is a large body of literature concerning heat stress in general, but little directed specifically at forest harvesting tasks.

The detrimental effect of heat stress on productivity within the forestry sectors of other countries has received some attention (Andersson, 1986; FAO, 1974; FAO 100, 1992; Smith and Rummer, 1988; Sirios and Smith, 1985; Smith and Sirois, 1982; Smith and Thomas, 1993; Smith et al., 1986). In some cases, it has been suggested that it may in fact be more economical to temporarily shut down the harvesting operation than continue to operate at a reduced productivity (and thus higher unit cost) level while increasing worker long-term accumulated fatigue (Smith and Sirois, 1982). Work by Smith and Rummer (1988) indicates that logging crew productivity as a whole, and the productivity of motor-manual tree fallers in particular, can experience productivity decreases of 5 to 15 percent when wet bulb globe temperatures (WBGT) exceed 26 °C. Surprisingly, mechanical tree harvesting operations also noted a 2 to 3 percent decrease in productivity once the WBGT exceeded 26°C.

In terms of safety, Smith and Rummer (1988) noted that approximately half of the workers in their study increased their level of unsafe behaviour once the WBGT exceeded 26°C. More alarming though was the finding that those workers who were exposed to the most direct sun, tended to neglect their personal protective equipment under the hotter conditions.

The impact of heat on perceptual motor tasks and mental/cognitive tasks is more difficult to define, and research into these areas often report contradictory findings (Ramsey, 1995). The review undertaken by Ramsey (1995) categorised this area of research into two distinctive categories, (a) mental or simple tasks, and (b) perceptual motor tasks. The review revealed that a loss of performance was not commonly observed for mental tasks and simple perceptual motor tasks undertaken in hot environments (Chiles et al., 1972; Grether et al., 1971; Lewis et al. 1983; Meese et al., 1981; Nunneley et al., 1978; Poulton and Kerslake, 1965; Ramsey et al., 1975; Ramsey and Pai, 1975).

The impact of heat on the performance of perceptual motor tasks however, showed a significant decrease once wet bulb globe temperatures reached the 30°C - 33°C range. Such a trend was evident for tracking tasks (Chiles et al., 1972; Duchon and Hudock, 1989; Grether et al., 1971; Lewis et al., 1983; Ramsey et al., 1975; Ramsey and Pai, 1975; Razmjou and Kjellberg, 1992; Wyon et al., 1979), vigilance tasks (Duchon and Hudock, 1989; Grether, 1973; Mortagy and Ramsey, 1973; Poulton and Edwards, 1974; Ramsey and Kwon, 1988;), and complex or dual tasks (Andersson, 1986; Chiles et al., 1972; Fine and Kobrick, 1978; Grether et al., 1971; Mackie and O'Hanlon, 1976; Poulton and Edwards, 1974; Smith et al., 1986; Vitalis et al., 1994). Ramsey (1995) stated quite correctly, that complex or dual tasks are more difficult and demanding than perceptual motor skills, and thus come closest to representing typical industrial and military work tasks. Such performance decrements are of concern, particularly with regard to the complex or dual tasks, as forest work requires constant vigilance in order to prevent serious or fatal injuries from occurring.

2.3 Physical Work Environment.

The significance of the physical work environment in terms of its impacts on work productivity, safety and health is illustrated by the lack of control forest workers have over their work environment. Slappendel et al., (1993) in their review of factors effecting work related injury among forest workers, specifically identified climate, terrain, flora, and lighting as being variables which can affect the safety and productivity of people at work in the forest.

The full impact of nature's elements, whether it be cold snow or intense sunshine, can to some degree be mitigated by the wearing of either more or less clothing or through the provision of shelter or shade. Mitigating the impact of ground slope on the other hand is often impractical, both physically and logistically. Consequently it is this aspect of the physical work environment which often has the greatest impact on the worker.

Slope has shown to be an important factor in effecting worker productivity (Apud and Valdes, 1994; Vik, 1984), workload (Fibiger and Henderson, 1984; Kirk and Parker, 1994b; Trewin and Kirk, 1992; Wenbin et al., 1989) and safety (O'Leary, 1992). One major New Zealand forest company alone directly attributes 25% of its 1991 lost time accidents to steep and difficult terrain (O'Leary, 1992).

In steep terrain the use of equipment which is of the correct weight and design is of paramount importance (Tatsukawa, 1994). Tatsukawa (1994) found that working efficiency increased, and cardiac strain decreased, when smaller lighter chainsaws were used for tree delimbing on steep terrain, rather than heavier medium sized chainsaws. A reduction in localised muscular fatigue in the upper limbs was also noted when the lighter smaller chainsaw were used. Imatomi (1994) showed how an individual's physiological capabilities can be effectively integrated into effective forest harvest planning. Similar work was undertaken by Apud and Valdes (1994) when extensive field evaluations found that the number of trees that could be manually planted per hour of work was positively correlated to the average cardiac frequency, and negatively associated to ground slope. The result of this work was the development of two equations for the estimation of output on ground with different slopes. The equations were based on the understanding that output is determined by the difficulty of the work object, the ground conditions, the climate and the workload that the worker may sustain without fatigue.

Imatomi (1994) showed that increasing slope directly resulted in a decrease in worker performance within limits of physiological load. Consequently this relationship was used to determine the most efficient road placement for the harvesting of the compartment. Wenbin et al., (1989) also showed that slope played an important role in the attainment of maximum physiological efficiency and that such efficiency increased as ground slope approached zero degrees.

2.4 Work Rate.

If a person works at a rate beyond their aerobic capacity, their heart rate, pulmonary ventilation, blood lactic acid and body temperature continue to rise throughout the period of exercise at a rate roughly proportional to the intensity of the work. The person becomes fatigued and there is a limit to the time they can work (Durnin and Passmore, 1967).

There has been considerable work undertaken to determine the "optimal" working pace. During steady state work, sufficient oxygen is supplied to the working muscles by the aerobic metabolism and lactic acid does not exceed resting levels. If the work level intensifies and the aerobic metabolism can no longer supply all the required energy requirements, anaerobic metabolism commences and supplies the additional energy requirements. The negative aspect of this anaerobic contribution is that lactic acid accumulates within the working muscles. This lactic acid is subsequently removed through oxidation during the following recovery period (Durnin and Passmore, 1967).

As a consequence of earlier work undertaken by Apud et al.,.(1989); Astrand, (1967); Astrand and Rodahl, (1986); Evans et al., (1980); Levine et al., (1982) and Michael et al., (1960), it is now generally accepted that a worker undertaking hard physical labour should not exceed on average, 40 per cent of their estimated maximal oxygen uptake (Vo_{2max}) for an eight hour shift. A prime example of this philosophy being applied in a work situation can be seen within the Chilean forest industry. As a direct result of forest industry based ergonomic research into factors effecting human performance (Apud et al., 1972; Valdes and Apud, 1994), the industry has accepted that, as an average for an eight hour working shift, cardiovascular load should not exceed 40% of the workers Vo_{2max} (Apud and Valdes, 1994).

When allowed to choose their own working pace, subjects have been shown to choose between 35% (Johansson and Ljunggren, 1989), and 45% (Evans et al., 1980; Levine et al., 1982) of their estimated maximal oxygen uptake. Work undertaken by Vik (1984) investigated several different forest harvesting tasks, and clearly showed that the body maintains an internal equilibrium whilst encountering different stressors, such as slope and difficult terrain, by decreasing work output. Smith et al., (1985) also found that subjects modified their work behaviour when subjected to hotter environmental conditions so as to keep their physiological stress at a tolerable level. Vogt et al., (1983) suggested that workers have the natural ability to set a work pace in response to increased thermal stress that results in the maintenance of their average heart rates in a relatively narrow range. They termed this phenomenon *constant strain behaviour* and suggested that the increase in environmental heat load is compensated by a decrease of muscular work. Smith and Rummer (1988) also recorded this phenomenon whilst studying heat stress effects on forest workers in harvesting operations.

2.5 Psychological State.

2.5.1 Perception of Physiological Demands

Motivational factors and perception of effort play an important role in determining individual capacity for physical work (Gamberale, 1990). Borg (1982) suggested that the perceived exertion rating integrated different information, including signals elicited from the peripheral working muscles and joints, the cardiovascular and respiratory organs and the central nervous system. Hence the perception of exertion gives vital feedback to a person about their state of health and allows them to modify their work pace accordingly.

Subjective reaction to physical work can only be measured indirectly through the use of self-reported techniques and are often used to a compliment objective physiological measures such as heart rate (Aunola et al., 1979; Costa et al., 1989; Genaidy et al., 1990; Johansson and Borg, 1993; Johansson and Ljunggren, 1989; Roscoe, 1993). In fact Borg (1985) stated that when considering the relative strain of an individual, the perception of exertion was in many cases, as reliable and relevant as physiological measures. Fleishman and Hogan (1978) found good agreement between rated exertion in different work tasks and the metabolic consumption of energy. The same findings have been found by other researchers studying people undertaking a variety of tasks (Capodaglio et al., 1995; Gamberale, 1972; Johansson and Borg, 1993; Ulmer et al., 1977). As pointed out by Capodaglio et al., (1995), several quantitative psychophysical methods have been developed to measure perceptual intensities during exercise (Borg, 1970; 1982, 1986). By far the most commonly used quantitative psychophysical methods are Borg's rating of perceived exertion (RPE) (Borg, 1970) and 10-point category-ratio (CR-10) scale (Borg, 1982).

Several researchers have successfully applied subjective ratings when studying work-related stress over a wide variety of occupations and applications (Aunola et al., 1979; Bru et al., 1994; Costa et al., 1989; Garg and Saxena, 1979; Genaidy et al., 1990; Jianghong and Long, 1994; Johansson and Borg, 1993; Johansson and Ljunggren, 1989; Karhu et al., 1977; Kihlberg et al., 1994; Kirk and Sullman, 1995; Ljungberg et al., 1982; Öberg, 1994; Roscoe, 1993). In the majority of these cases the main goal of these studies has been to arrive at norms for acceptable workloads (Johansson and Borg, 1993).

2.5.2 Discomfort Survey's

Putz-Anderson (1988) identified musculoskeletal disorders as the prime disablers of working adults. Pain and discomfort, like perceptions of exertion, provide essential warnings which alert to damage, disease and the limitations of the body (Chaffin and Andersson, 1984). A linear relationship between length of exertion and musculoskeletal pain or discomfort has been found to exist (Corlett and Bishop, 1976). Musculoskeletal pain and discomfort are therefore good indicators of over-exertion and fatigue. Stressors on the musculoskeletal system which are beyond the adaptive capacity of the individual lead to the inflammatory processes of the body taking over in the affected muscles and/or joints. If the exertion which causes pain or discomfort is continued daily, adaptation may occur (Chaffin and Andersson, 1984). If however, the demands (stress) placed on the musculoskeletal system are outside the homeostatic limits of the body (stress response mechanisms), adaptation will not occur and the inflammatory processes (strain) of the body will take over (Chaffin and Andersson 1984). Hence the perception of pain and discomfort in muscles and joints allows a person to receive information about their body's state of well being and adjust their behaviour (work rate) accordingly.

Discomfort surveys are often used in ergonomics (Bru et al., 1994; Stuart-Buttle, 1994; Johansson, 1994; Legg et al., 1995; Ryan, 1989; Yu et al., 1988;). A common approach is to use a modified Corlett and Bishop's (1976) body diagram, the Nordic Musculo-skeletal Questionnaire (NMQ) (Johansson, 1994), or a hybrid body part discomfort survey or questionnaire (Bru et al., 1994; Legg et al., 1995; Stuart-Buttle, 1994). Their relative ease of application, minimal disruption to the worker and inexpensive nature of musculo-skeletal and discomfort surveys aids their use by researchers in applied settings (Bru et al., 1994; Johansson, 1994; Kirk and Sullman, 1995; Legg et al., 1995; Stuart-Buttle, 1994).

While there have been studies which have assessed musculoskeletal loads and incidence of disease via the use of BPD and HSE questionnaires in other industries (Johansson, 1994, Putz-Anderson 1988, Stuart-Buttle, 1994) there has been, to date, limited attempts to do so with forest workers in New Zealand (Ford, 1995; Kirk and Sullman, 1995).

2.6 Physical Capacity.

2.6.1 Oxygen Consumption

Traditionally, in order to accurately determine the physiological cost of an activity, oxygen consumption (Vo_2) has been measured. In many applied field settings however, the measurement of Vo_2 is difficult, and in some cases impractical (Rodahl 1989, Apud et al., 1989; Astrand and Rodahl 1986; Montoliu et al., 1995; Imbeau et al., 1995). The development of relatively small portable Vo_2 measurement devices such as the PK Morgan Ltd oxylog have improved the situation and enabled the measurement of Vo_2 in some work situations (Becker et al. 1983; Fordham et al., 1978; and Goldsmith et al., 1978).

However, not all the associated problems of field Vo_2 measurement have been completely resolved by this development. The measurement of Vo_2 with such equipment requires the subject to carry the equipment on their person while breathing through a mask while attempting to undertake their normal working tasks. The result is often discomfort, interference and distraction for the subject, typically resulting in lost productivity, and in extreme situations, the collection of non-representative data (Apud et al., 1989; Astrand and Rodahl, 1986; Imbeau et al., 1995; Keawplang et al., 1993; Montoliu et al., 1995; Vitalis et al., 1986).

Due to the difficulties associated with the direct measurement of Vo_2, an effective and popular alternative often used is the estimation of Vo_2 from the subject's heart rate (Aunola et al., 1979; Imbeau et al., 1995; Montoliu et al., 1995; Van Der Beek and Frings-Dresen et al., 1995; Vitalis, 1987). This approach is based on the linear relationship between increases in oxygen consumption and heart rate during submaximal dynamic physical work (Imbeau et al., 1995). Typically, the relationship between heart rate and oxygen consumption is established for each individual in a laboratory cycle ergometer or treadmill test. Then, heart rate measurements taken in the field are compared to the data derived from the laboratory testing to estimate oxygen consumption (Andersson, 1986; Imbeau et al., 1995). Whilst not as accurate as direct measurement, this method provides an effective estimation of oxygen consumption with an accuracy of ± 15% (Rodahl, 1989; Rodahl et al, 1974).

Traditionally there has been some discussion relating to the applicability of the use of a cycle ergometer based test for estimating an individuals Vo_{2max} when that individuals work task involves the use of both the leg and upper body muscle groups. The work undertaken by Astrand and Saltin (1961) showed quite clearly that (a) cycling a bicycle ergometer in a sitting position, (b) simultaneous arm and leg work on bicycle ergometers, (c) running on a treadmill and (d) skiing, all exhibited similar heart rates and Vo_{2max} readings. The three tasks which differed significantly were those of (a) swimming and (b) cycling in a supine position and (c) arm cranking of a cycle ergometer. Swimming and cycling in a supine position produced a Vo_{2max} level approximately 15% lower than that achieved when cycling a bicycle ergometer in a sitting position. Arm cranking of a cycle ergometer produced a Vo_{2max} that was approximately 70% of that obtained when cycling.

Many of the tasks encountered in forest harvesting operations require the use of both the leg and upper body muscle groups (i.e. breaking-out, felling and delimbing and skid work). Consequently, the use of the cycle ergometer test to determine the relationship between heart rate and oxygen consumption for application in applied forestry situations, has been extensively adopted worldwide (Andersson, 1986; Abeli and Malisa, 1994; Andersson, 1986; Apud et al., 1989; Apud and Valdes, 1994; Henderson, 1984; Kirk and Parker, 1994b).

2.6.2 Heart Rate

In situations where the direct measurement of Vo_2 has not been undertaken, the application of subjects heart rates to a series of heart rate indices can provide an effective and accurate estimation of task severity. This concept has been used in a variety of occupations, including cane cutters (Vitalis, 1987), factory workers (Aunola et al., 1979), surgeons (Becker et al., 1983), nurses (Fordham, et al., 1978), steelworkers (Vitalis et al., 1994) and tree pruners (Kirk and Parker, 1996).

One key consideration which favours of the use of heart rate is the fact that unlike oxygen consumption, which solely measures energy expenditure, heart rate has the ability to measure the total strain being experienced by the subject (Astrand and Rodahl, 1986; Grandjean, 1980; Le Blank, 1957; Lamert, 1972; Rodahl et al., 1974; Rodahl, 1989; Vitalis, 1987; Vitalis et al, 1994). Previous research has raised questions regarding the validity of using oxygen consumption alone to measure the physiological strain of a task (Astrand et al., 1968; Grandjean, 1980; Sato and Tanaka, 1973; Sanchez et al., 1979).

The true value and applicability of heart rate as a measure of task strain can best be seen in the work undertaken by Rodahl et al., (1974) which investigating the physical strain sustained by Norwegian coastal fishermen. Rodahl et al., (1974) stated that the use of continuous heart rate monitoring gave a better indication of stress than any other parameter that involves samples. They suggested that the continuous recording method overcame the difficulties associated with the measurement of tasks which occur intermittently, and accurately reflected the true work situation. In conclusion the authors stated that such an approach, when combined with direct observation, provided an effective tool for the accurate estimation of the physical strain resulting from workloads of varying intensities.

A large proportion of the tasks encountered within clearfell forest harvesting operations present the same parameters as those experienced by Rodahl et al., (1974), (i.e. harsh working conditions and workloads of varying intensities and duration's). Consequently, the use of continuous heart rate recording, combined with direct observation, to determine the strain of specific tasks has gained considerable favour within the forestry sector (Abeli and Malisa, 1994; Apud and Valdes, 1994; Gaskin and Guild, 1989; Kirk and Parker, 1994b; Kirk and Sullman, 1995; Parker and Kirk, 1994; Seixas and Ducatti, 1995; Sirois and Smith, 1985; Smith and Thomas, 1993; Tatsukawa, 1994).

2.6.3 Energy Expenditure.

The use of the estimated energy expenditure approach gained early recognition due to work undertaken by Passmore and Durnin (1955; 1967), and has subsequently been used extensively by researchers in the field of work physiology (Apud and Valdes, 1993; Apud et al., 1989; Astrand and Rodahl, 1986; Frings-Dresen et al., 1995; Grandjean, 1980; Gun and Budd, 1995; Imbeau et al., 1995; Montoliu et al., 1995; Reilly and Thomas, 1979; Rodahl, 1989). "An accurate assessment of oxygen consumption (Vo_2) provides important information for determining the energy expenditure requirements of work and thus, has been used extensively" (Astrand and Rodahl, 1986). The basis for this is that the calorific value of oxygen is 4.8 kcal. That is, when one litre of oxygen is consumed by the human body, there is, on average, a turnover of 4.8 kcal of energy (Grandjean, 1980). With this knowledge, one can determine an individual's energy consumption by simply multiplying their oxygen consumption by 4.8.

The measurement of energy expenditure, and in particular an individual's "work calories", has several purposes within the physiological and psycho-physiological context. An estimate of an individuals daily energy expenditure is important for both the calculation of their energy needs, and their level of physical activity. As stated by Grandjean (1988), "work calories indicate the level of bodily stress, and in relation to heavy work they can be used to assess the level of effort, to work out necessary rest periods, and to compare the efficiency of different tools and different ways of arranging the work".

An individual's daily energy expenditure can be broken down into three broad categories; basal metabolism, leisure calories and work calories (Grandjean, 1980). By determining the combined energy expenditure obtained from these three categories, an individual is able to determine approximately how strenuous or "difficult" their occupation is in relation to others in terms of energy consumption. Of particular interest to physiologists is the "work calories" component of the equation, as it is this portion that tends to exhibit the greatest influence on an individual's total 24 hour energy expenditure. As stated by Astrand and Rodahl (1986), there are three commonly accepted ways that energy expenditure estimates can be made;

(1) The 24 hour recording of heart rate by telemetric device,

(2) Estimation based on time-activity data and measurements of the energy cost of all pertinent activity,

(3) The assessment (by food weighing) of daily food intake required to maintain body weight.

All three methods are of equal accuracy and reliability, with an error of no more than 15 percent (Rodahl, 1960). The use of detailed direct observation time study methods, in conjunction with known task energy expenditure rates, enables the calculation and estimation of daily energy expenditures for observed subjects (Fibiger and Henderson, 1982; Frings-Dresen et al., 1995; Hagen et al., 1993; Henderson, 1984; Nwuba and Kaul, 1987). The estimation of daily and hourly energy expenditure rates has been used effectively by previous researchers working in applied forestry situations (Cristofolini et al., 1990; Fibiger and Henderson, 1982; Golsse and Rickards, 1990; Maleta and Sood, 1984; Nwuba and Kaul, 1987).

2.7 Summary

This chapter has reviewed much of the relevant literature pertaining to the ergonomic techniques and concepts utilised in this study. Their ability to judiciously determine the impact of both physiological and psycho-physiological stressors in applied field settings with minimal disruption to the subjects has been detailed. The following chapter describes the concepts and processes associated with the harvesting of timber from New Zealand exotic plantation forests.

CHAPTER 3: DESCRIPTION OF THE EXPERIMENT

3.0 Introduction

This chapter describes the concepts and processes associated with the harvesting of timber from New Zealand exotic plantation forests. The fallers daily timetable, the felling, delimbing and timber extraction processes used, and the methods and equipment used by the fallers are described. A description of the type and purpose of each felling cut is given as well as an explanation of the various delimbing techniques used during the study.

3.1 Daily Time Table in the Field.

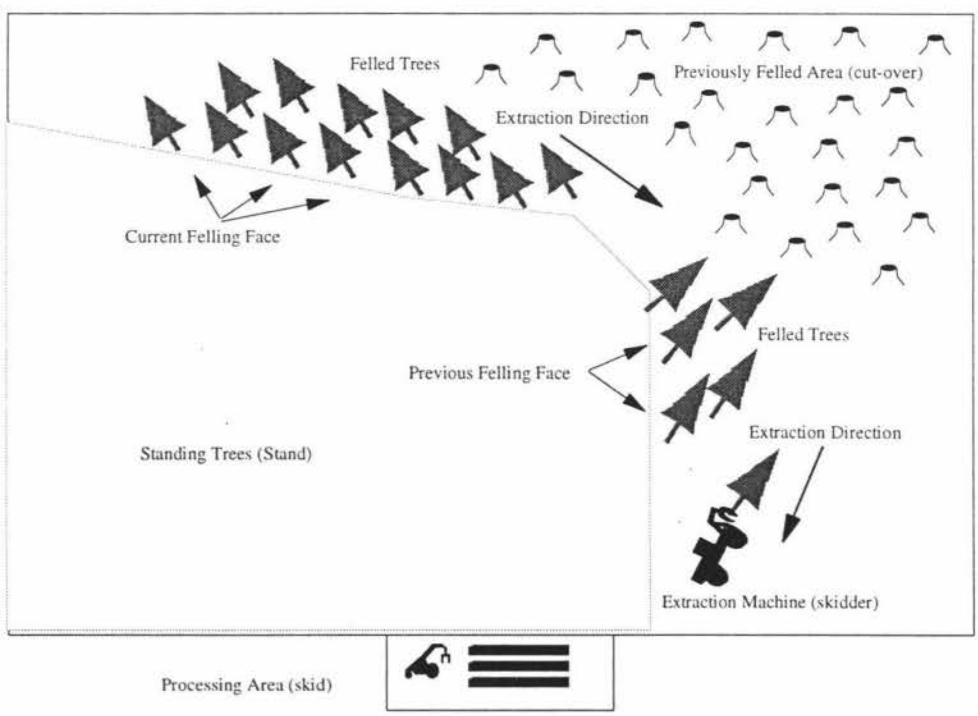
All of the fallers worked from approximately 07:00 hours until 15:30 hours. Each faller was met at their work site by the researcher before they commenced work at approximately 06:30 hours. The crews tended to arrive slightly early so that they could organise themselves before starting work 07:00 hours. During this time the subjects were fitted with the Pe3000 heart rate monitors and the time study computers were brought on-line but not started. Once the subject indicated that he was ready to start work for the day, both the heart rate monitor and the time study programme were started simultaneously.

Subjects one - four stopped at 11:30 hours in order to have their 30 minute lunch break whilst subjects five and six stopped at 11:00 hours to have their one hour lunch break. The subjects continued to wear the heart rate monitors during this lunch break. At the end of the day each faller would walk out to the nearest road where they would be picked up by the crew vehicle and taken back to the main skid. Once at the main skid, the heart rate monitors and time study programmes were stopped and the heart rate monitors removed from the subjects.

3.2 Operational Planning.

The fallers were given a daily quota of trees which had to be felled and delimbed. This quota was known as the fallers "daily target". The entire forest compartment within which the crew as a whole were working was split between the crew's fallers, usually four men. Each faller was assigned an area of forest within this compartment in which they alone worked (Figure 4). The fallers were kept separated from one another by a distance of at least two full tree lengths, in order to meet the legal safety requirements stipulated by the Department of Labour. Whilst being far enough away from each other to ensure safety, each faller was within visual sight of at least one other faller. In this way the fallers were able to visually check on one another should assistance or aid be required.

Figure 4: Plan View of Felling Face Layout and Operation.



Each faller would start the day by walking from the nearest road or skid into their forest area to reach their particular felling face. This typically involved walking a distance of approximately 30 to 40 meters. During this time the faller would carry their chainsaw as well as one fuel and one oil container. These containers had a combined weight of approximately 6 kg, depending on their particular size and configuration. Upon reaching the felling face the faller would typically undertake a quick maintenance check of his saw chain, (i.e check chain sharpness and tension), followed by refuelling of the chainsaw. Once these procedures were completed the chainsaw would be started and allowed to warm up for approximately 30 to 60 seconds. The faller would then appraise the trees in the immediate vicinity before finally selecting one and felling it.

The trees were directionally felled in a systematic manner so as to ensure that once on the ground, the trees lay in such a way as to expedite their extraction by the skidder from the cutover to the landing. The edge of this felling area was called the "felling face" (Figure 4), and the systematic felling of the trees along this face was termed "working a face". Each faller established at least two felling faces within their area so that if wind direction should unexpectedly change, or operational circumstances require it, they could move to their alternative felling face and continue working.

Figure 5: Faller Working the Felling Face.

3.3 Felling Equipment.

The fallers main felling tools were the chainsaw, felling hammer and felling wedges. The chainsaws used were high performance 88 - 92 cc professional models from the Husqvarna and Stihl product range. They weighed 8.4 - 8.6 kilograms (kg) (fully fuelled and oiled), operated 46 - 56 centimetre (cm) length saw bars fitted with 3/8 pitch saw chain. Each faller wore a felling belt which contained several compartments holding plastic felling wedges, a chainsaw file, small chainsaw spanner, at least one wound dressing and a felling hammer (Figure 6).

Figure 6: Faller Wearing His Helmet, Ear Protectors, Protective Legwear and Felling Belt.

The approximate weight of the felling belt complete with two wedges, one file, one spanner, one wound dressing and one felling hammer was 2.6 kg. Each faller wore the belt around their waist with the compartments sitting at the rear of the body to allow unrestricted movement whilst still providing easy access to the wedges and hammer. As well as a felling belt, each faller wore a pair of cut resistant chainsaw leggings (chaps) weighing on average 1.5 kg, and a safety helmet fitted with ear muffs and eye visor weighing 0.6 kg.

3.4 Timber Extraction

Each crew had a dedicated timber extraction machine called a "skidder" (Figure 7). The skidder serviced all of the crew's fallers by removing freshly felled and delimbed stems from the felling faces. The skidder extracted the stems from the felling face to a nearby processing area called a "skid" (Figure 8). At the skid, skid workers processed the stems into individual log types depending on the specific market demands at that time.

Figure 7: Grapple Skidder Extracting Felled and Delimbed Stems From The Cutover.

As a result of this work method, the fallers had little time in which to build up a buffer of felled and delimbed stems, as the skidder would alternate between the fallers continually throughout the day removing the wood as quickly as it accumulated. This resulted in that a steady production pressure being exerted on the fallers throughout the day.

Figure 8: Freshly Felled and Extracted Stems on the Skid Awaiting Processing.

3.5 The Mechanics of Tree Felling.

The felling of the trees, involved the correct placement of three basic components, the scarf, hingewood and backcut (Figure 9). The function of the scarf is to control the tree's direction of fall. The hingewood also helps control the tree's direction of fall as well as preventing the tree from twisting or breaking sideways when falling. The backcut removes the wood from the back side of the tree to leave the hingewood and allow the tree to fall forward in the intended direction (Figure 10). Just prior to the tree striking the ground, the hingewood completely breaks, thus entirely severing the stem from the stump of the tree.

Figure 9: Cross Sectional View of Tree Felling Cuts

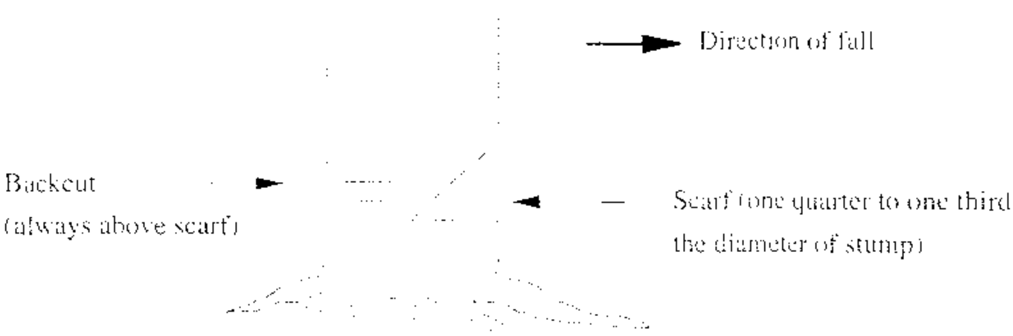
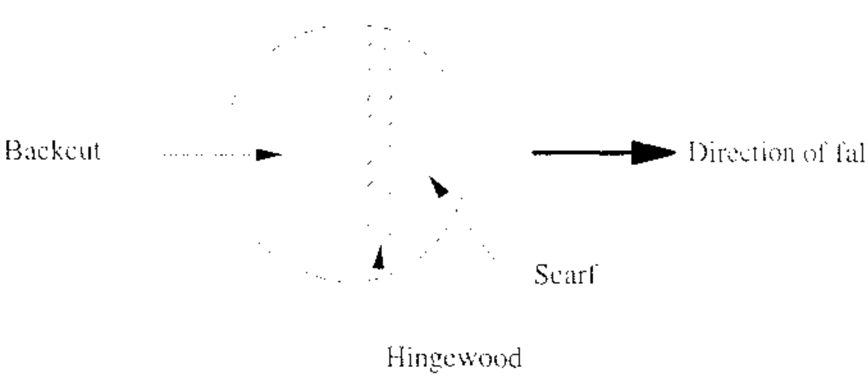


Figure 10: Plan View of Tree Felling Cuts



3.6 Delimbing Methods

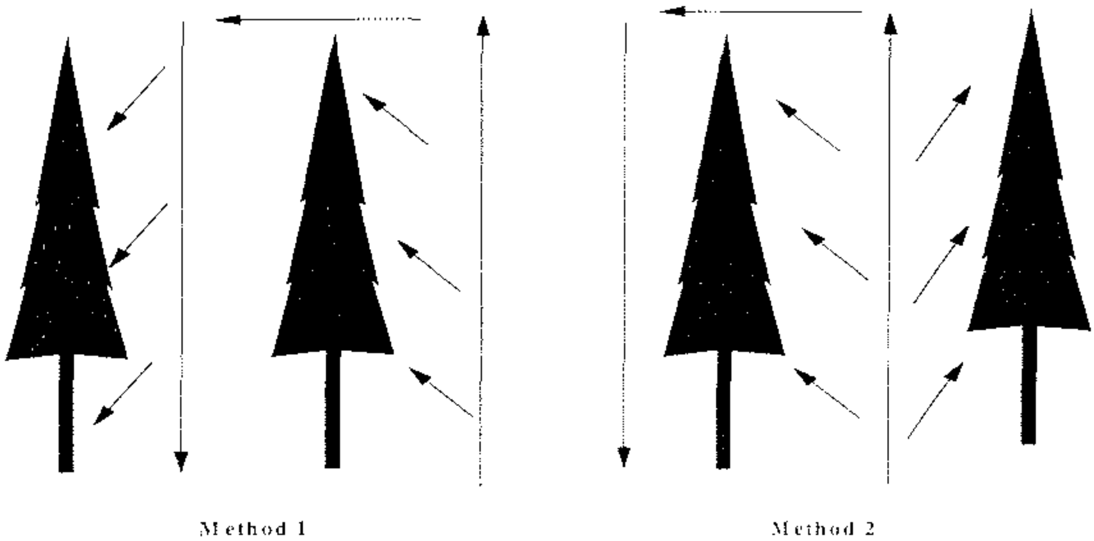
Once felled, the faller would either walk along on top of the stem, or beside it on the ground, removing the branches from the stem with the chainsaw as they were encountered. This action is commonly known as "delimbing" or "trimming" the tree. The posture adopted by the faller during this delimbing phase is that of heavily bent forward in a stooped nature incurring trunk inclination at angles of 90 to 100° (Figure 11).

Figure 11: Poor Posture Adopted During Delimbing of the Stem.

In some instances the faller would fall two trees in quick succession. In these cases the faller would delimb both stems together at the same time using one of two methods (Figure 12). Method 1 involved delimbing one stem from the base to the top, then returning the same way delimbing a second stem from the top to the base of the stem. Method 2 involved working between two closely placed stems delimbing alternatively between the two as he progressed from the base to the top of the stem. In this manner the faller would return to their original starting point with minimal unnecessary and non productive walking, and would be ready to fell the next tree.

The fallers would work in this way until their chainsaw needed refuelling. Refuelling was done at the work site. The fallers continually moved their fuel and oil containers along the felling face as they worked. Such refuelling breaks tended to provide the faller with short two to three minute rest breaks in which, as well as refuelling the chainsaw, they would usually have either a quick drink, sharpen their saws chain, or carry out routine saw maintenance such as chain tensioning.

Figure 12: Faller Delimbing Methods.



3.7 Summary

This chapter has described the concepts and processes associated with the harvesting of timber from New Zealand exotic plantation forests in relation to the current study. The following chapter describes the research design, the procedure for subject selection and the methods used for data collection and analysis.

CHAPTER 4: METHODOLOGY

4.0 Introduction

This chapter outlines the research design, the procedure for subject selection and the methods used for data collection and analysis. The methodology section has been formulated in such a manner as to enable other researchers to successfully repeat the research, even if they are unfamiliar with the forest industry.

4.1 Research Design

The research design consists of a causal study utilising an amalgamation of both observational and ex post facto data collection techniques employing a cross sectional case study approach within a field study research environment.

4.1.1 Limitations

The data were collected under field conditions from a relatively small group of subjects who were performing their normal felling and delimbing activities. Every effort was made to ensure that data collection did not interfere with the subjects' production performance. Although the data were obtained as precisely as possible, they are nevertheless limited both with respect to sample size and experimental control. In spite of these limitations, the data should be representative of the actual task demands experienced by New Zealand forest workers undertaking the tasks of motor-manual tree felling and delimbing in New Zealand plantation forests.

4.2 Subjects

Six full time professional fallers working in clearfell logging operations. Each faller was observed continuously for one complete working week (5 days).

4.2.1 Weight

The subjects weight was measured before the commencement of the estimated aerobic capacity (Vo_2max) test using a Hanson mechanical scale positioned on a hard flat concrete surface. The subject was barefooted and wore minimal light weight clothing (shorts and a singlet), suitable for undertaking the Vo_2 max test. The protocol described by Wilson et al., 1993 was adhered to with the subjects being asked to stand directly over the scale while the weight reading was being taken. The subjects were then asked to step off the scale, and the process repeated one further time. The correction factor of 0.5 kg was subtracted from the readings to take account of the clothing worn (Wilson et al., 1993). Naked weights were not obtained as they were considered by the researcher to be non-sociably acceptable in this case.

4.2.2 Stature:

The subjects stature was also recorded before the commencement of the estimated aerobic capacity (Vo_2 max_{est}) test using a protocol modified from that described by Wilson et al., (1993). Since the researcher did not have access to an anthropometer, a plastic tape measure was attached vertically to a hard flat concrete wall. The tape measured 5 meters in length and contained 1 millimetre increments. The subjects were asked to remove their footwear and stand with both feet firmly together. The back of the heels, buttocks, shoulders and back of the head touched the wall. The head was held straight with the subject looking directly forward, ensuring that the Frankfort plane was horizontal. The subject was then asked to stand up as tall as they could and a small (10 X 4 centimetre) spirit level was placed on top of the subjects head and held level. The point at which the tape measure and spirit level met was taken as being the subject height.

4.2.3 Body Mass

Body Mass Index (BMI); was derived using the equation:

$$BMI = \frac{\text{Body Mass (kilograms(kg))}}{\text{Height}^2 \text{ (metres(m))}}$$

Duboi's Surface Area (DSA); was derived using the equation:

$$DSA = 0.203 * W^{0.425} * H^{0.725}$$

Where W = Weight (kg) and H = Height (m).

4.3 Sample Size

4.3.1 Felling Cycles

Felling cycles were based on data obtained from a previous study of fallers undertaking tree felling and delimbing (Kirk and Parker, 1994a). The previous study observed a mean cycle time for the felling and delimbing of a single tree of 7.2 $\pm$ 1.1 min/tree.

Using the minimum sample size formula in Harnett (1982).

$$n = \frac{\sigma^2 z^2_{\alpha/2}}{D^2}$$

Where:

n = sample size
σ^2 = standard deviation of the population.
z^2 = the level of statistical significance to the estimate.
D^2 = maximum acceptable difference between the sample mean and the true mean.

The standard deviation figure obtained from the Kirk and Parker, 1994a study, which observed tree fallers working in the same forest as the present project under simular terrain and tree characteristics, was applied to the Harnett 1982 formula. A 0.999 confidence interval and 0.3 minute (18 second) maximum acceptable difference were also included. The result being a sample size of 52 trees/subject/day.

The subjects standard working day was 0700hrs until 1600hrs, with a total of one hour for food and rest breaks. This leaves a total of eight hours are available for data collection. To allow for late starts and early finishes, the trees felled and trimmed /day figure has been calculated based on seven productive hours/day. Taking the seven productive hours (420 minutes) and dividing it by the mean value of 7.2 minute/tree, a total daily figure of 58 trees/day is achieved. This is then multiplied by five working days resulting in 291 cycles/subject.

As can be seen, the five day of observation period/subject satisfied the criteria for the minimum sample size calculation.

4.3.2. Heart Rate Recordings.

Heart rate recordings were measured at 1 minute intervals. If this is multiplied by seven productive hours/day a total of 420 heart rate recordings/subject/day is obtained. If this figure is then multiplied by five working days a total of 2100 recordings/subject is obtained.

4.4 Subject Recruitment

Priority was given to the recruitment of subjects who have previously voluntarily participated in LIRO Human Factors research projects. Participation of the subjects in the project was on a voluntary basis with the subject being provided with adequate and appropriate information about what their participation involved. The subject had the right to decline to participate in the project, or withdraw from participation at any time, without penalty of any kind and without providing reasons (Appendix A). Potential subjects were contacted by the researcher on a one to one basis in complete discretion and informed of the projects details and what was required of them if they so chose to consent to being involved with the project (Appendix B). The equipment to be used in the project was shown and demonstrated to each subject at this time and any subsequent questions answered. Complete confidentiality of the subjects identity was guaranteed during the project and during any subsequent write-up and publication of the findings.

Once this process has been completed, each subject was asked to sign the consent form (Appendix A) after having it thoroughly explained. Each subject was also given an information sheet detailing the researchers involved, the objective of the study and detail of the subjects involvement and rights during the study. Special care was taken to ensure that the subject fully understood the consent form since the forestry workforce has traditionally contained a high degree of illiteracy within it.

4.5 Ethical Approval

The research plan received ethical approval from the Massey University Human Ethics Committee. The main ethical concern in the research was the minimisation of harm to the research subjects. This concern was accounted for by ensuring that there was no way to identify what data was associated with any individual subject. As established protocol was adhered to, there was no concerns about the submaximal exercise testing to establish the estimated Vo_2max of the subjects'.

4.6 Physiological Responses

4.6.1 Heart Rate

4.6.1.1 Working Heart Rate (Hr_w)

Working heart rate was measured at one minute intervals for the entire working day, including rest breaks, using a hard-wired Polar Electro Sport Tester Pe3000 (Pe3000) portable heart rate monitor (Figure 13). The Pe3000 consists of a pericardial heartbeat capturing-transmitting unit in a 2.5 centimetre wide chest band and a receiver-storage unit similar to a digital wrist watch. This system has been validated in several studies (Karvonen et al. 1984; Leger and Thivierge, 1988; Vogelaere et al. 1986) and used extensively in New Zealand (Gaskin and Guild, 1989; Kirk and Parker, 1994a; Kirk and Parker, 1994b; Parker et al, 1993; Parker and Kirk, 1993b; Kirk and Sullman; 1995), as well as overseas studies (Montoliu et al. 1995; Smolander et al. 1995; Van der Beek and Frings-Dresen et al., 1995). The Pe3000 had been hard-wired using double insulated coaxial shielded cable so as to eliminate the electrical interference generated by the chainsaw (Parker, 1992) which distorts the transmitted heart rate readings causing erroneous heart rates to be recorded by the monitor. The Pe3000 monitor was placed into a small plastic waterproof container in order to protect it from the ambient climatic and harsh working conditions. This plastic container had a clear plastic lid which enabled the researcher to see the monitor and tell if it was recording correctly. This container was then placed within a small canvas army issue ammunition pouch which was then attached to the subjects felling belt at the waist located in the small of the subjects back.

The purpose of doing so was to make the entire Pe3000 heart rate recording unit fully self contained and unobtrusive to the subject (Figure 14). Since the Pe3000 monitor could be accessed from behind the subject while they continued working, regular inspections of the Pe3000 could be made by the researcher with minimal disruption to either the subject or their work pattern.

The result was a low impact heart rate measurement system which did not require the subject to stop working in order for their heart rate to be recorded. This would not have been the case had the palpitation method been used as such a method would of required the subject to momentarily interrupt their normal work routine so as to allow the researcher to record their heart rate (Vitalis, 1981). Added to this, is the possibility of incurring inaccuracies which Cumming and Glenn (1977) found were inherent with the use of this method

Figure 13: Pe3000 Portable Heart Rate Monitor, Protective Case and Carry Pouch.

4.6.1.2 Resting Heart Rate (HR_r)

Resting heart rates for each subject were obtained prior to the Vo_2 max test. Upon arrival at the testing laboratory the subjects were asked to sit in a comfortable chair whilst the researcher described the procedure that they would be required to undertake in order to obtain their estimated Vo_2 max. After approximately 15 minutes the subjects were attached to the heart rate monitoring equipment whilst they remained seated. The subjects were then asked to remain seated without moving, drinking coffee or tea or smoking for a further ten minutes. The last ten minute period was recorded as being their resting heart rate since they had been in a sitting posture with minimal movement for a period of approximately 15 minutes prior to the commencement of the measuring period. Whilst acknowledging that true resting heart rate should be measured while the subject is asleep, such measurements were not possible during this research project due to the subjects not agreeing to such a measure.

Figure 14: Faller Wearing Pe3000 On His Belt In The Carry Pouch

4.6.1.3 Percent Heart Rate Range (%HRR)

Percent heart rate range was determined by applying the formula:

$$\%HRR = \frac{HR_w - HR_r}{HR_{max} - HR_r} * 100$$

Where: HR_w = average working heart rate.

HR_r = resting heart rate as defined above.

HR_{max} = maximum heart rate was estimated by using the standard formula of HRmax = 220 - Age.

(Source: Vitalis, 1987)

4.6.1.4 Work Pulse (HR_{wp})

Work pulse was calculated using the formula:

$$HR_w - HR_r$$

(Source: Grandjean, 1988)

4.6.1.5 50% Level of Heart Rate Reserve (50% $_{Level}$)

50% level of heart rate reserve was determined using the formula:

$$HR_r + \frac{HR_{max} - HR_r}{2}$$

(Source: Lammert, 1972)

4.6.1.6 Ratios of HR_w/HR_s (Ratio)

Ratios of working heart rate divided by resting heart rate were obtained using the formula:

$$\frac{HR_w}{HR_s}$$

(Source: Diament et al., 1968)

4.6.2 Calibration of Heart Rate Monitors

The Pe3000s to be used in the study were tested to see if they were working within an acceptable margin of error. This margin of error was set at an 85% signal to noise ratio. Calibration experiments were performed by comparing the output of the two available PE 3000s with that of a 3-lead clinical electrocardiogram (ECG) machine during exercise on a cycle ergometer.

4.6.3 Aerobic Capacity

4.6.3.1 `Estimated Oxygen Uptake (Vo_{2est})

Estimated oxygen uptake values in litres per minute ($l.min^{-1}$) were derived by applying each subjects mean Hr_{work} value rate recording to their workload/oxygen uptake (Vo_2) relationship obtained via cycle ergometry testing (Åstrand and Rodahl, 1986).

4.6.3.2 Estimated Aerobic Capacity ($Vo_2\ max_{est}$)

Each subjects aerobic capacity ($Vo_2\ max_{est}$) in litres per minute ($l.min^{-1}$) was estimated using the submaximal direct method using a "Cateye Ergociser" EC-1500 cycle ergometer (Åstrand and Rodahl, 1986) (Figure 15). A heart rate monitor was attached to the subjects right ear lobe and the subject was then asked to sit on the bike for five minutes with no load and zero revolutions per minute (rpm). The subject then commenced pedaling at a cadence of 60 rpm and the level of resistance increased in three stages until the subjects heart rate attained a steady state within the 120 - 140 beats per minute ($bt.min^{-1}$) range (Apud et al, 1989). Heart rate (HR) and energy expenditure (Watts) were recorded during the final steady state condition and applied to the Åstrand and Ryhming nomogram once they had been corrected for age (Åstrand and Rodahl, 1986).

4.6.3.3. Relative Estimated Aerobic Capacity ($Vo_{2rel}\ max_{est}$)

Relative estimated aerobic capacity was derived using the equation:

$$V_{O_2}\ max\ ml.min^{-1}.kg^{-1} = \frac{V_{O_2}\ max\ (l.min^{-1})\ x\ 1000}{Body\ Mass\ \ (kg)}$$

4.6.3.4 Estimated Energy Expenditure

Estimated energy expenditure was derived from each subjects heart rate recordings using the workload/oxygen uptake (Vo_2) relationships obtained via cycle ergometry testing (Åstrand and Rodahl, 1986). Estimated mean Vo_2 figures derived from the cycle ergometry tests were multiplied by 4.8 and 20 in order to obtain the mean kilocalorie per minute (kcal min^{-1}) and kilojoules per minute (kJ. min^{-1}) values. These min^{-1} values were then multiplied by the time spent at work in minutes to obtain an estimation of energy expenditure for the working period for each subject.

Figure 15: Cateye Ergociser EC-1500 Cycle Ergometer

4.7 Production

4.7.1 Cycle Times

Cycle times were obtained through the use of a "Husky Hunter" field computer programmed with the continuos time study program (Siwork3). Siwork 3 is a Turbo/Pascal language program specifically developed for work study and data collection. (Rolev, 1990). The time taken by each subject to undertake a pre determined task was recorded on the Husky Hunter field computer in centiminutes by one observer at the work site.

4.7.2 Percentage Time per Task

Each subjects mean time per task was divided by the subjects mean cycle time in order to obtain the percentage of the day spent undertaking each particular task.

4.7.3 Time Study Elements

Task.	*Description.*
Walk In	Walk from the gang vehicle to the work site.
Select	Clear path to, and around, selected tree and prepare escape route.
Fell	Fell tree (scarf, backcut, sloven).
Trim	Trim any branches from stem.
Refuel	Refuel chainsaw petrol and oil
Maintain	Sharpen and tighten sawchain and other related chainsaw parts
Odel	Delays attributed to operational interference (e.g. machine interference).
Pdel	Delays caused by the subject themselves (e.g. toilet breaks).
Mdel	Delays caused by machinery breakdowns.
Walk Out	Walk from work site to gang vehicle.
Lunch Break	Main meal break of the working day

4.7.4. Volume/Day

The average stem volumes were obtained from the stands "method for the assessment of recoverable volume, by log types, in plantation forests (MARVL) data which was obtained from the forest owners. The number of trees felled per day by each faller were then multiplied by the associated stem volume to obtain a tree volume in cubic metres (m^3) felled per hour and per day by each subject.

4.8 Terrain

4.8.1 Ground Slope

Ground slope was measured in degrees using a sunnto inclinometer to determine the predominant ground slope of the working area in which the faller is working. The researcher stood at the stump of the tree previously felled by the subject. The inclinometer was raised to the researchers eye, a point on the next tree to be felled was selected that approximated the researchers own eye height, and a reading was taken from the inclinometer.

4.8.2 Undergrowth Hindrance

Undergrowth hindrance was determined subjectively by the researcher using the same rating system as outlined in (Kirk and Parker, 1994b) with 1 = low hindrance and 4 = extreme hindrance.

4.9 Hazards

4.9.1 Hazardous Felling and Delimbing Techniques

Hazardous felling and delimbing techniques as defined by Östberg (1980), and later modified by Parker and Kirk (1993b), were used to determine hazard type and frequency of occurrence. The researcher personally observed when an unsafe act or situation occurred and duly noted so using the note pad function of the Husky Hunter field computer.

4.9.2 Hazard Ratios

Hazard ratios per 100 stems were calculated using the formula:

$$\frac{\text{Hazards}}{\text{Stems}} = \frac{x}{100}$$

4.10 Psycho-physiological Measures

4.10.1 Rate of Perceived Exertion (RPE)

Rate of perceived exertion was measured using the "Borg Scale" questionnaire (Appendix C) in an attempt to match the subjective rating of exertion with the objective physiological rating as measured by heart rate (Borg, 1985). Each subject was asked to state their RPE at the end of every fifth felling and delimbing cycle during the working day based on a fifteen point Likert scale (Figure 16). The anchors for the scale were six (no exertion at all) and twenty (maximal exertion). At the same point that the RPE question was asked, the subjects corresponding heart rate was recorded from the Pe3000 heart rate monitor being worn by the subject. The heart rate was then assigned to the subjects RPE response using the note pad function of the Husky Hunter field computer.

The data was then transformed to give the variables, predicted RPE and actual RPE. Predicted RPE was derived by multiplying the rating given by the subject by a factor of ten in order to obtain the corresponding RPE (i.e. RPE of 12 equated to a heart rate of 120 bt.min^{-1}). Actual RPE was derived from the subjects heart rate record for that same epoch which had been divided by a factor of ten in order to derive the corresponding RPE on the Borg scale (i.e. a heart rate of 130 bt.min^{-1} equates to a RPE of 13). Correlation coefficients were then calculated for the two variables, predicted RPE and actual RPE, in order to determine how closely the subjects predicted RPE correlated to the actual RPE over the period of the working day.

Figure 16: Faller Undertaking Psycho-Physiological Tests.

4.10.2 Self Assessment of Fatigue

Self assessed fatigue was measured at one hourly intervals throughout the working day, as well as at the start and end of the working day, using a series of six fatigue related questions (Appendix D). Each question comprised of a seven point Likert scale. The subject was asked the six questions in a sequential manner with the subject stating their self assessed level of fatigue at that particular point in time.

4.10.3 Body Part Discomfort (BPD)

Body part discomfort was determined at one hour intervals throughout the working day according to a method modified from Corlett and Bishop (1976) (Appendix E). The subject was shown the body part diagram and asked if they currently felt any discomfort in any of the body part segments shown in the diagram. If the subjects responded affirmatively, they were then asked to identify which segment was experiencing discomfort and to give the discomfort a severity rating. The severity rating consisted of a four point scale with the anchors zero (minimal discomfort) and four (unbearable discomfort). In an attempt to remove any non-work related bias with the responses, the subject was asked if the discomfort was the result of a non work activity (i.e. rugby training, hunting).

4.10.4 Perceived Thermal Comfort and Sensation

Perceived thermal comfort and sensation was measured using a standard questionnaire at one hour intervals throughout the working day (Appendix F). Each subject was asked to rate their perceived thermal comfort on a four point Likert scale with the anchors of one (very uncomfortable) and four (not uncomfortable). The subject was then asked to rate their perceived thermal sensation on a nine point Likert scale with the anchors of one (very hot) and nine (very cold).

4.10.5 Skin Wettedness

Skin wettedness was measured using an eight point Likert scale at one hour intervals throughout the working day. The anchors for the scale were one (more dry than normal) and eight (sweat running off in many places) The subject would be shown the scale and asked to rate their degree of skin wettedness at that particular point in time (Appendix F).

4.10.6 Thermal Regulation

Thermal regulation was measured using a seven point Likert scale at one hour intervals throughout the working day. The anchors for the scale were one (vigorously shivering) and seven (heavily sweating). The subject would be shown the scale and asked to state their degree of thermal regulation for that particular point in time (Appendix F).

4.10.7 Digit Symbol Substitution (DSS)

Mental fatigue was measured at one hour intervals throughout the working day using the Digit Symbol Substitution (DSS) test technique used by Kirk and Sullman (1995). The DSS test technique consisted of six separate sheets comprising eight double rows. Each double row was segmented into fifteen individual columns. The top segment of each column contained a symbol and the corresponding lower segment a blank space in which the subject wrote the matching number (Appendix G). The order in which the subjects were given the test sheets was predetermined using the random numbers obtained from Eton random number tables (Quinn, 1974). A dice was rolled in order to randomly determine both the starting column and row within the table. Once the starting point was selected the digits zero, seven, eight and nine were omitted from the possible choices since there were only six test sheets to randomise. The digits, one to six inclusive, were then selected from the remaining random numbers. The requirement was for each subject to be shown one test sheet every hour for eight hours over a period of five working days.

Instances where the same digit was encountered sequentially within the random number tables resulted in the second number being ignored. The reason being that it was felt that if a subject was shown the same test sheet twice in a row, there would be some learning bias within the results. This being that the subject would have retained some of the digit/symbol relationships from the previous test undertaken only one hour previously.

Each subject was given one test sheet and had the process explained to them by the researcher. The subject was then allowed to carry out a practice run on the top row of the test in order for them to gain some familiarity with the technique. Once this test row was completed, the subject was given two minutes in which to attempt to complete as many rows of the test sheet as possible. This protocol was then repeated for the remaining seven tests of the day. The number of digit symbol substitutions attempted was divided by the number of correct digit symbol substitutions attained in order to derive a percentage correct figure for each test and subject.

4.11 Ambient Thermal Environment

To ensure comparisons of workload could be made between days, dry bulb, wet bulb and globe bulb temperature were recorded on the felling face as near as practically possible to the faller throughout the day. The CR-21 weather station was set up at least 30 minutes prior to the arrival of the crew so as to allow the probes to acclimatise to the ambient thermal environment. Dry bulb (t_a), natural wet bulb (t_{nwb}) and globe bulb (t_g) temperature were used to calculate the wet bulb globe temperature (WBGT) and relative humidity (RH) for each day of the study. The WBGT formula WBGT = $0.7\ t_{nwb} + 0.2\ t_g + 0.1\ t_a$ (Botsford, 1971; Parsons, 1993) for outdoor use was used Relative humidity was determined from the wet and dry bulb temperature readings off the CR-21 weather station. Relative humidity was calculated using relative humidity tables (Anon, 1944).

4.11.1 Calibration of CR-21 Weather Station

The CR-21 weather was calibrated by the National Institute of Water and Atmospheric Research Ltd (NIWA) and found to be operating with an acceptable degree of accuracy (i.e. $\pm$ 0.2°C) for all three temperature probes.

4.11.2 Summary

This chapter has outlined the research design, the procedure for subject selection and the methods used for data collection and analysis. The following chapter presents the results of data collection and analysis.

CHAPTER 5: RESULTS

5.0 Introduction

This chapter presents the results of data collection and analysis. Firstly the subjects physical characteristics and physiological responses will be presented. Then the results of the production study will be detailed The chapter will conclude with the subjective responses and the thermal environment. The interpretation of the results will be presented in the discussion and conclusions will be presented in Chapter 7.

5.1 Subjects

5.1.1 Physical Characteristics

Table 1: Subjects Physical Characteristics.

Subject	1	2	3	4	5	6	Mean ± S.D.
Age (Years)	24	23	30	42	27	22	28 ± 7.5
Weight (kg)	79	76	86	100	89	67	82.8 ± 11.4
Height (cm)	180	190	166	171	179	173	176.5 ± 8.4
BMI	24	21	31	34	28	22	26.7 ± 5.2
Pondural Index	0.41	0.45	0.37	0.37	0.40	0.43	0.41 ± 0.03

Key:

Body Mass Index = $\frac{W}{H * H}$

20 = under weight
20 -25 = correct weight
25 - 30 = over weight

Pondural Index = $\frac{Height(m)}{\sqrt[3]{Weight(kg)}}$

1 = Lean

0 = Obese

The fallers had a mean ± standard deviation (sd) age of 28 ± 7.5 years, weighed 82.8 ± 11.4 kilograms (kg) and were 176.5 ± 8.4 centimetres (cm) tall. In terms of somotypes, subjects two and six possessed ectomorphic, subjects one and five, mesomorphic and subjects three and four endomorphic body shapes.

5.2 Physiological Responses

5.2.1 Heart Rate Indices

Table 2: Mean Daily Heart Rates at Work and Rest (mean ± S.D.)

Subject	n	Working Heart Rate (bt.min-1)	Work Pulse (bt.min-1)	Heart Rate Range (%)	Resting Heart Rate (bt.min-1)	Ratio	HRw/50% Level
1	1805	113.9 ± 9.9	44.5	35.1	69.4 ± 1.2	1.64	0.8 ± 0.08
2	1471	105.1 ±12.2	37.9	29.1	67.2 ± 0.9	1.56	0.77 ± 0.07
3	1814	110.6 ± 10.9	45.3	36.4	65.3 ± 1.5	1.69	0.83 ± 0.09
4	1425	105.1 ± 11.4	35.7	32.8	69.4 ± 2.0	1.51	0.76 ± 0.25
5	2405	98.4 ± 10.9	30.5	24.4	67.9 ± 1.1	1.45	0.73 ± 0.07
6	2487	110.5 ± 16.1	42.5	32.6	68.0 ± 0.9	1.62	0.81 ± 0.05
Mean		107.3 ± 5.5	39.4 ± 5.8	31.7 ± 4.4	67.9 ± 1.5	1.58 ± 0.1	0.78 ± 0.03

n = sample size

The subjects had a mean ± (S.D.) working heart rate of 107 ± 5.5 $bt.min^{-1}$, work pulse of 39.4 ± 5.8 $bt.min^{-1}$, heart rate range of 31.7 ± 4.4 %, resting heart rate of 67.9 ± 1.5 $bt.min^{-1}$, ratio of 1.58 ± 0.1, and working heart rate/50%level of 0.78 ± 0.03.

Table 3: Mean Working Heart Rate; Morning (AM) versus Afternoon (PM) (mean ± S.D.).

Time	Subjects					
	1	2	3	4	5	6
AM	111.0 ± 14.3	105.3 ± 18.0	107.4 ± 14.6	97.4 ± 11.8	93.2 ± 13.4	105.5 ± 17.4
PM	118.3 ± 15.6	104.7 ± 16.8	116.3 ± 16.1	114.6 ± 12.9	104.8 ± 14.6	117.3 ± 17.8
Significant Difference*	Yes (p = 0.000)	No (p = 0.479)	Yes (p = 0.000)	Yes (p = 0.000)	Yes (p = 0.00)	Yes (p = 0.000)

* One way ANOVA (Bonferroni Pairwise Comparisons of Means)

Five of the six subjects experienced significantly ($p < 0.01$) higher mean working heart rates in the afternoon (PM) work period , compared to the morning (AM) work period.

5.2.2 Aerobic Capacity and Oxygen Consumption

Table 4: Estimated Aerobic Capacity and Estimated Mean Oxygen Consumption During Work.

Subject	1	2	3	4	5	6	Mean ± S.D.
Estimated Vo_2max ($l.min^{-1}$) *	4.6	4.6	4.5	4.2	6.0	4.8	4.8 ± 0.63
Estimated Vo_2max ($ml.kg^{-1}.min^{-1}$) *	58.0	60.5	44.3	42	67.4	71.6	57.3 ± 12.0
Estimated Oxygen Uptake during Work ($Vo_2.l.min^{-1}$)	1.7	1.6	1.5	1.7	1.3	1.4	1.5 ± 0.2

* = Age Corrected according to Åstrand & Rodahl (1986)

The mean estimated aerobic capacity and estimated mean oxygen consumption during work was 57.3 ± 12.0 millilitres per kilogram per minute ($ml.kg^{-1}.min^{-1}$) 1.50 ± 0.2 litres per minute ($l.min^{-1}$) respectively.

Figure 17: Predicted Oxygen Uptake ($l.min^{-1}$)

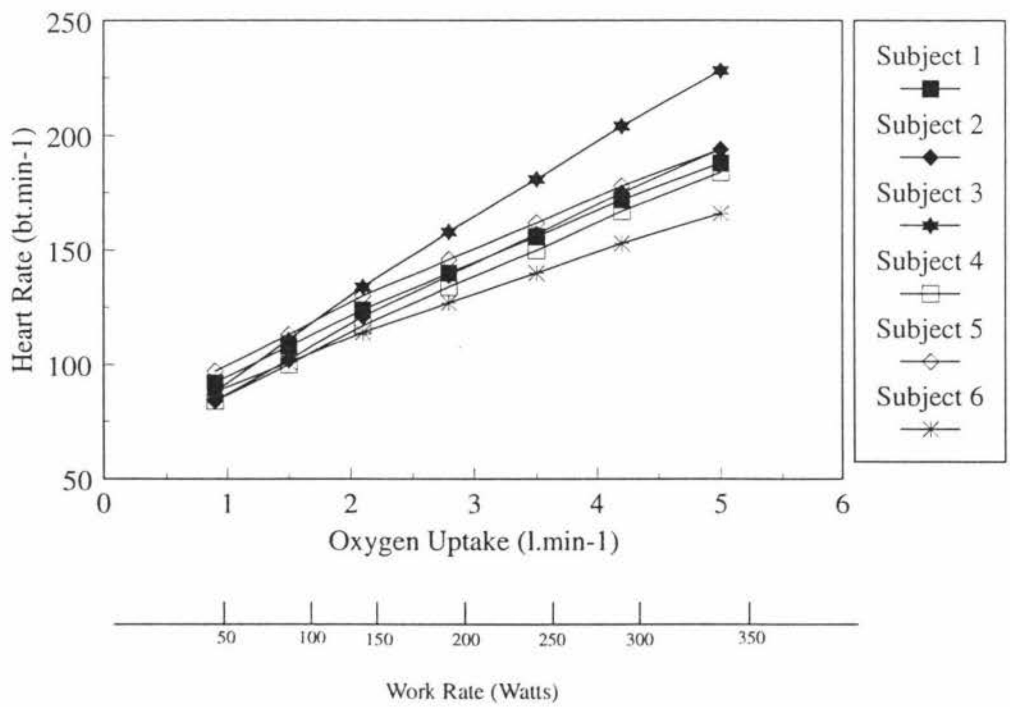


Table 5: Predicted Workload/Oxygen Uptake Relationships.

Work Rate (Watts)	O_2 Uptake ($l.min^{-1}$) *	Heart Rate ($bt.min^{-1}$)					
		Subject 1 [1]	Subject 2 [2]	Subject 3 [3]	Subject 4 [4]	Subject 5 [5]	Subject 6 [6]
50	0.9	92	84	88	84	97	88
100	1.5	108	102	111	100	113	101
150	2.1	124	121	134	117	130	114
200	2.8	140	139	158	134	146	127
250	3.5	156	157	181	150	162	140
300	4.2	172	175	204	167	178	153
350	5.0	188	194	228	184	194	166

* Source: Astrand and Rodahl (1986)

1 $R^2 = 0.88$ 4 $R^2 = 0.89$
2 $R^2 = 0.87$ 5 $R^2 = 0.97$
3 $R^2 = 0.80$ 6 $R^2 = 0.97$

5.2.3 Energy Expenditure

Table 6: Mean Estimated Rates of Energy Expenditure.

Subject	Working Day (minutes)	Work Vo_2 ($l.min.^{-1}$)	Work Energy Expenditure ($kcal.min^{-1}$)	Daily Work Energy Expenditure* (kcal)
1	519	1.7	8.2	4235.0
2	517	1.6	7.7	3970.6
3	496	1.5	7.2	3571.2
4	489	1.7	8.2	3990.2
5	495	1.3	6.2	3088.8
6	497	1.4	6.7	3339.8
Mean ± S.D	502 ± 12.6	1.5 ± 0.2	7.4 ± 0.8	3699.3 ± 439

* = based on an average working day of 8.4 hours.

Results show a mean ± standard deviation per minute estimated energy expenditure rate for the working day of 7.4 ± 0.8 kilocalories per minute ($kcal .min^{-1}$) and 30.8 ± 3.3 kilojoules per minute ($kJ. min^{-1}$). Total estimated work expenditure for the working day was 3699.3 ± 439 kcal and 15488.2 ± 1837 kJ. The average working day consisted of 502 ± 12.6 minutes or alternatively, 8.4 hours.

5.3 Production

5.3.1 Cycle Times

Table 7: Mean Total Cycle Time Per Stem, Morning (AM) versus Afternoon (PM).

Subject	AM	PM	Significant Difference*
1	11 minutes 42 seconds n = 80	10 minutes 17 seconds n = 52	No
2	10 minutes 34 seconds n = 83	12 minutes n = 47	No
3	13 minutes 4 seconds n = 68	13 minutes 17 seconds n = 39	No
4	13 minutes 2 seconds n = 57	13 minutes 1 second n = 31	No
5	12 minutes 13 seconds n = 82	11 minutes 14 seconds n = 72	No
6	9 minutes 29 seconds n = 104	6 minutes 44 seconds n = 109	Yes

* 95% Confidence Level
n = sample size

Subjects one to five experienced no significant change in mean cycle time per stem relative to time of day. Subject six had significant decrease in cycle time during the afternoon (pm) time period compared with the morning (am) period (Table 6).

5.3.2 Percentage Time per Task.

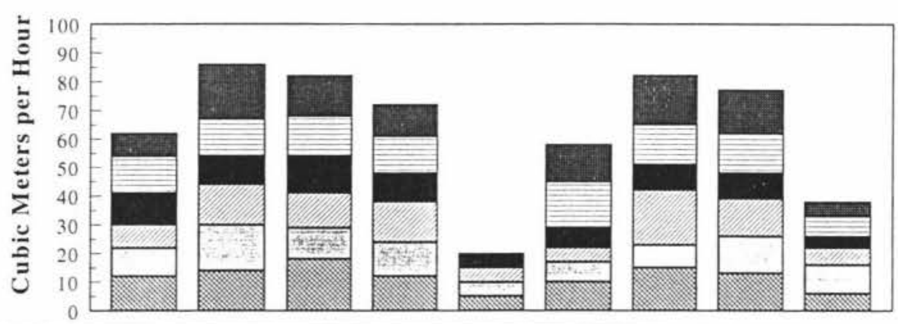
Table 8: Percentage of Day Undertaking Each Task.

Task	Subject						
	1	**2**	**3**	**4**	**5**	**6**	**Mean ± S.D.**
Walk In	3	2	5	2	1	3	3 ± 1.4
Select	6	6	5	4	11	8	7 ± 2.5
Fell	20	19	23	16	19	11	18 ± 4.1
Delimb	37	33	34	41	40	37	37 ± 3.2
Refuel	4	5	6	3	5	7	5 ± 1.4
Repairs	4	4	6	5	1	3	4 ± 1.7
Personal Delay	10	7	2	7	3	7	6 ± 3.0
Operational Delay	5	11	5	7	4	6	6 ± 2.5
Mechanical Delay	0	3	1	4	1	1	2 ± 1.5
Walk Out	3	2	2	1	1	1	2 ± 1.0
Lunch Break	8	9	11	10	14	16	11 ± 3.1

The subjects spent most of their working time undertaking the tasks of delimbing (37 ± 3.2%), felling (18 ± 4.1%) and selecting the next tree to fell (7 ± 2.5%). The lunch break accounted for 11 ± 3.1% of the entire working day.

5.3.3 Volume per Day

Figure 18: Average Daily and Hourly Production in Cubic Metres (m^3).



Time	7 - 8	8 - 9	9 - 10	10 - 11	11 - 12	12 - 13	13 - 14	14 - 15	15 - 16
Subject 1	12	14	18	12	5	10	15	13	6
Subject 2	10	16	11	12	5	7	8	13	10
Subject 3	8	14	12	14	5	5	19	13	6
Subject 4	11	10	13	10	5	7	9	9	4
Subject 5	13	13	14	13	0	16	14	14	7
Subject 6	8	19	14	11	0	13	17	15	5

Table 9: Mean Hourly Production ($m^3/hr \pm$ S.D.); Morning (AM) vs Afternoon (PM).

Time	**Subjects**					
	1	**2**	**3**	**4**	**5**	**6**
AM	14.0 ± 2.8	12.3 ± 2.8	12.0 ± 2.8	11.0 ± 1.4	13.3 ± 0.5	13.0 ± 4.7
PM	11.0 ± 3.9	9.5 ± 2.6	10.8 ± 6.5	7.3 ± 2.4	12.8 ± 3.9	12.5 ± 5.3
Significant Difference*	No (p = 0.26)	No (p = 0.19)	No (p = 0.74)	Yes (p = 0.03)	No (p = 0.81)	No (p = 0.89)

* One way ANOVA (Bonferroni Pairwise Comparisons of Means)

A two sample t-Test comparing morning production against afternoon production (Table 7) revealed that while all six subjects experienced a reduced hourly production rate in the afternoon, only that of subject four was statistically significant (p = 0.03).

5.4 Terrain

Crew one had a mean hindrance rating of 1.3 ± 0.5 and a mean slope recording of 1.6 ± 0.8 °. Crew two had a mean hindrance rating of 1.5 ± 0.7 and a mean slope recording of 2.0 ± 1.3 °. While crew two did experienced both statistically steeper slope recordings and hindrance ratings ($p < 0.05$) than crew one, both crews overall terrain rating was minimal adverse slope with low hindrance.

5.5 Hazards

Figure 19: Mean Hazard Type and Percentage Occurrence.

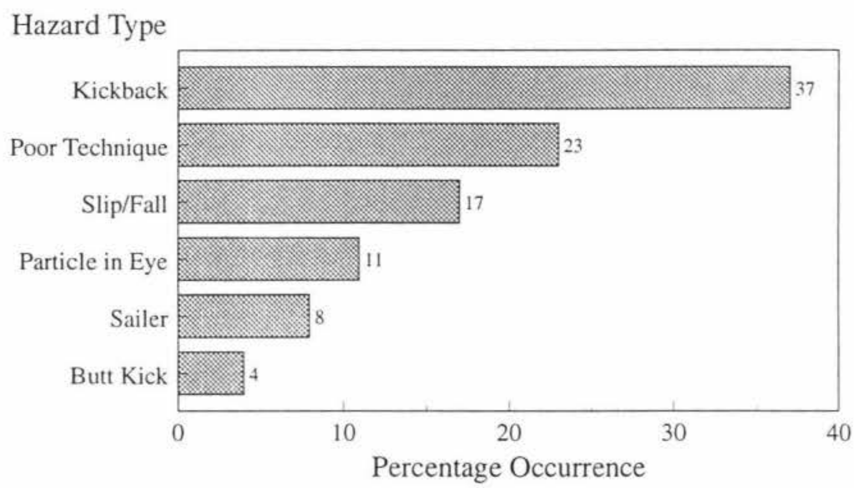


Table 10: Mean Weekly Hazard Ratio, Frequency and Location.

Subject	1	2	3	4	5	6	Mean ± S.D
Mean Daily Production (m^3)	105	92	96	78	104	102	96.2 ± 10.2
Felling Hazards per 100 stems	7.1	5.5	11.6	0	4.9	0.7	4.9 ± 3.9
Delimbing Hazards per 100 stems	19.1	13.4	12.5	5.5	5.3	5.3	10.1 ± 5.2
Total Hazards per 100 stems	26.2	18.9	24.1	5.5	10.2	6.0	15.2 ± 9.1
Felling Hazards (%)	27	30	48	0	48	12	27.5 ± 19.2
Delimbing Hazards (%)	73	70	52	100	52	88	72.5 ± 19.2

An average production of 96.2 ± 10.2 m^3 generated an average 15.2 ± 9.1 hazards per 100 stems with 27.5 ± 19.2% of the hazards occurring in the felling phase and 72.5 ±

19.2% occurring in the delimbing phase of the operation. The most frequently occurring hazard was kickback, followed by poor technique and slip/fall hazards.

Table 11: Hazard Ratio (Hazards/100 stems) : Morning (AM) vs Afternoon (PM)*

Time	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	Subject 6
AM	33.7	13.3	18.4	5.4	12.4	8.6
PM	28.4	14.1	24.1	5.0	7.3	3.1
Significant Difference	No (p = 0.74)	No (p = 0.90)	No (p = 0.64)	No (p = 0.94)	No (p = 0.07)	No (p = 0.10)

* One way ANOVA (Bonferroni Pairwise Comparisons of Means)

A two sample t Test revealed that only subjects five and six experienced any significant different between morning (am) and afternoon (pm) hazard frequency. While subjects one, five and six experienced lower hazard ratios in the afternoon periods, these decreases were not statistically significant ($p > 0.05$).

5.6 Psycho-physiological Measures

5.6.1 Rated Perceived Exertion

Table 12: Mean Daily Rated Perceived Exertion (RPE) (Pearsons Correlation).

Time	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	Subject 6
AM	0.7874	-0.0350	0.5722	0.6655	0.5950	0.7205
PM	0.7423	0.2865	0.5887	-0.1875	0.6148	0.3323
Significant Difference 95% Level*	no	no	no	yes	no	yes
Complete Day	0.7878 n = 28	-0.0115 n = 30	0.7521 n = 23	0.3533 n = 25	0.6424 n = 51	0.6417 n = 40

* One way ANOVA (Bonferroni Pairwise Comparisons of Means)

Subjects one, three and five were able to effectively rate their level of perceived exertion throughout the working day. Whilst subjects four and six ability decreased as the day progressed. Subject two consistently showed an inability to correctly rate his level of perceived exertion.

5.6.2 Subjective Fatigue Ratings

The results for the self assessment of fatigue questionnaire shows that the subjects felt more weary (83%), tense (66%), weaker (100%) and more exhausted (83%) in the afternoon (PM), compared with the morning (AM). Only two of the six subjects (33%), felt more sleepy and bored in the afternoon (PM), compared with the morning (AM).

Table 13: Weekly Average Fatigue Trends, Morning (AM) vs Afternoon (PM).

Subject	Question	1	2	3	4	5	6
1	AM	1.5	4.5	1.4	6.0	1.0	5.3
	PM	2.1	5.6	2.0	5.6	1.0	4.4
Significant Difference#		No	No	Yes*	No	No	Yes*
2	AM	2.4	5.6	2.6	5.5	2.1	5.9
	PM	4.1	6.0	4.3	3.6	3.3	4.9
Significant Difference#		Yes**	No	Yes**	Yes**	Yes**	Yes**
3	AM	2.8	5.7	1.5	5.5	1.1	4.9
	PM	4.3	4.2	3.7	3.7	1.6	4.9
Significant Difference#		Yes**	Yes**	Yes**	Yes**	Yes*	No
4	AM	2.8	5.8	2.6	5.4	1.00	7.00
	PM	4.2	4.0	4.2	4.2	1.00	7.00
Significant Difference#		Yes*	Yes**	Yes**	Yes**	No	No
5	AM	2.6	6.4	2.9	4.9	1.05	4.0
	PM	4.2	5.3	4.4	2.8	1.0	4.0
Significant Difference#		Yes**	Yes**	Yes**	Yes**	No	No
6	AM	4.6	4.0	4.4	3.9	4.5	4.4
	PM	5.2	3.4	4.9	3.2	4.7	4.2
Significant Difference#		Yes**	Yes**	Yes*	Yes**	No	No

One way ANOVA (Bonferroni Pairwise Comparisons of Means)

* 95% Confidence Interval ** 99% Confidence Interval

Key:

Question 1:
FRESH 1 2 3 4 5 6 7 WEARY

Question 2:
TENSE 1 2 3 4 5 6 7 RELAXED

Question 3:
STRONG 1 2 3 4 5 6 7 WEAK

Question 4:
EXHAUSTED 1 2 3 4 5 6 7 VIGOROUS

Question 5:
WIDE AWAKE 1 2 3 4 5 6 7 SLEEPY

Question 6:
BORED 1 2 3 4 5 6 7 INTERESTED

5.6.3 Body Part Discomfort

Figure 20: Subject 1 Mean Weekly Discomfort and Severity Rating.

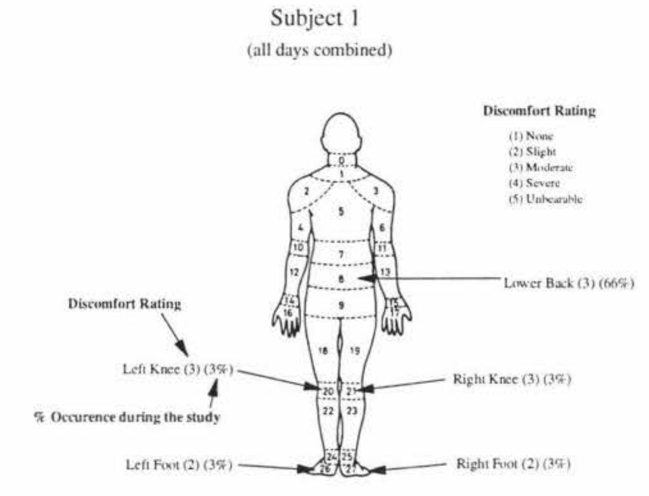


Figure 21: Subject 2 Mean Weekly Discomfort and Severity Rating.

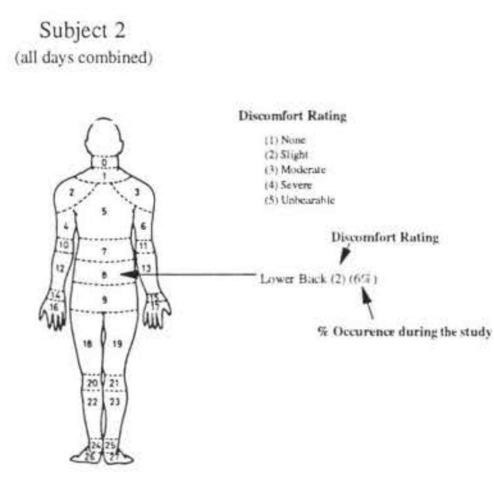


Figure 22: Subject 3 Mean Weekly Discomfort and Severity Rating.

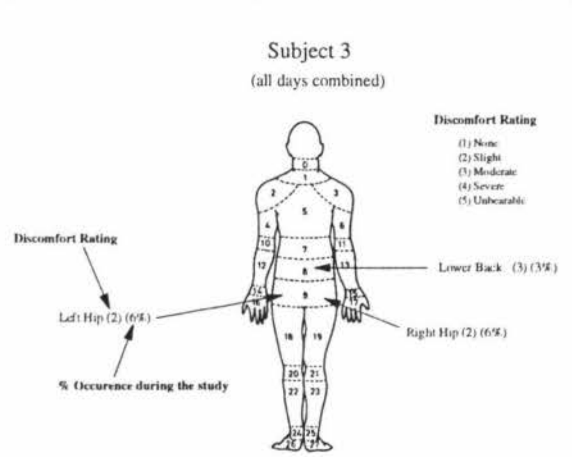


Figure 23: Subject 4 Mean Weekly Discomfort and Severity Rating.

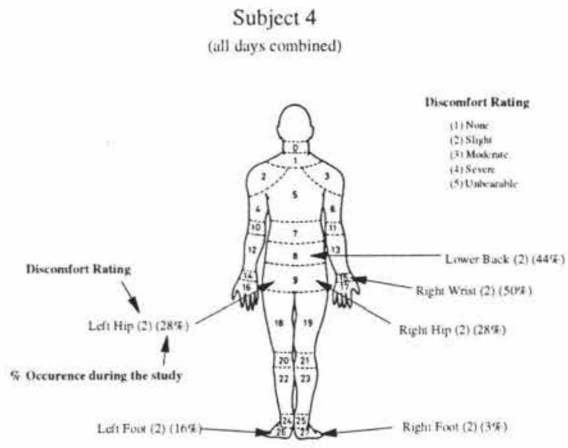


Figure 24: Subject 5 Mean Weekly Discomfort and Severity Rating.

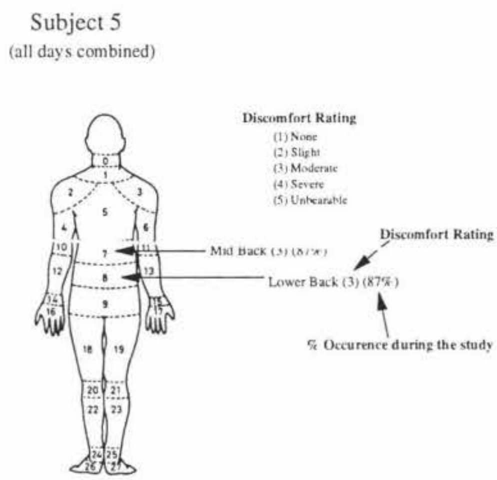
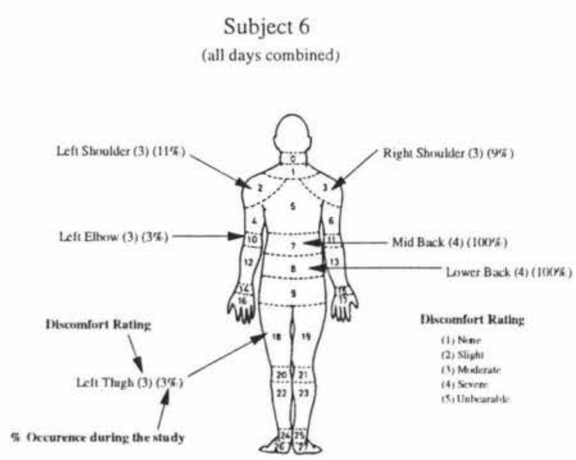


Figure 25: Subject 6 Mean Weekly Discomfort and Severity Rating..



The lower back (segment 8), was the most frequently recorded body part experiencing discomfort (26 %), followed by the hips (segment 9), (14 %), upper back (segment 7) (9%) and the ankle (segments 26 and 27) (9 %). Severity ratings were predominantly slight (49%) to moderate (43%), with only eight percent being ranked as severe.

5.6.4 Thermal Comfort

Figure 26: Mean Weekly Thermal Comfort Ratings

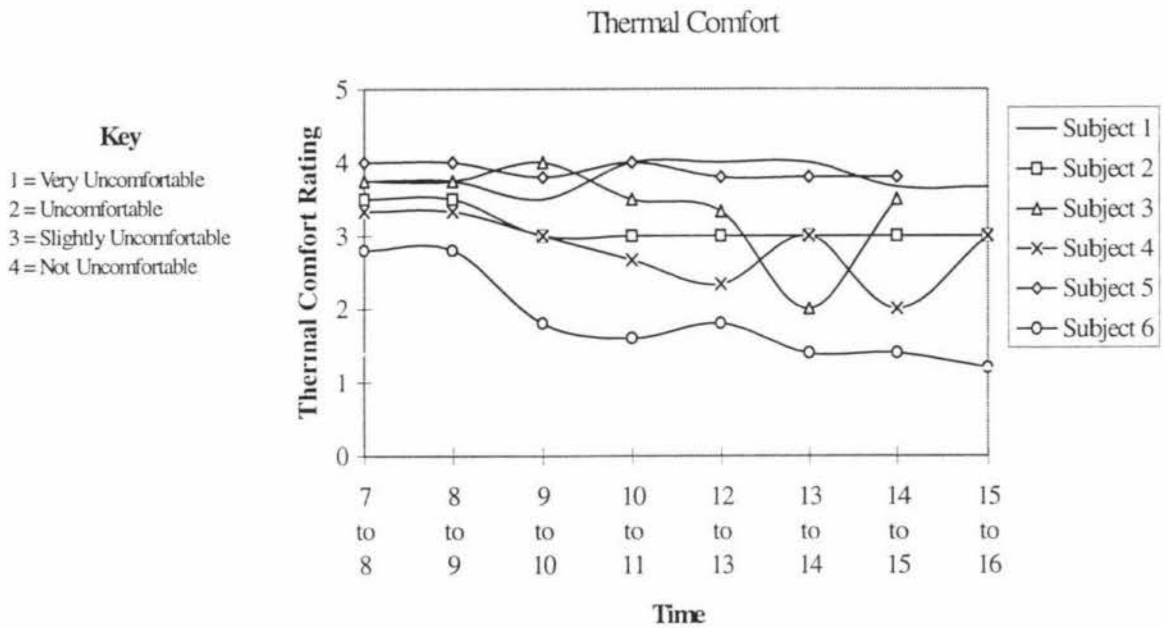


Table 14: Mean Weekly Thermal Comfort Ratings, Morning (AM) versus Afternoon (PM) (mean ± S.D.)

Subject	AM	PM	Significant Difference#
1	3.8 ± 0.8	3.8 ± 0.4	No
2	3.8 ± 0.6	3.8 ± 0.4	No
3	3.8 ± 0.6	2.7 ± 0.9	Yes **
4	3.1 ± 0.5	2.4 ± 0.9	Yes **
5	4.0 ± 0.2	3.8 ± 0.4	No
6	2.3 ± 0.9	1.5 ± 0.6	Yes **

One way ANOVA (Bonferroni Pairwise Comparisons of Means

** 99% Confidence Interval

Table 14 shows that three of the six subjects (50%) experienced a significant ($p < 0.05$) decrease in their thermal comfort level as the day progressed.

5.6.5 Thermal Sensation

Figure 27: Mean Weekly Thermal Sensation Ratings

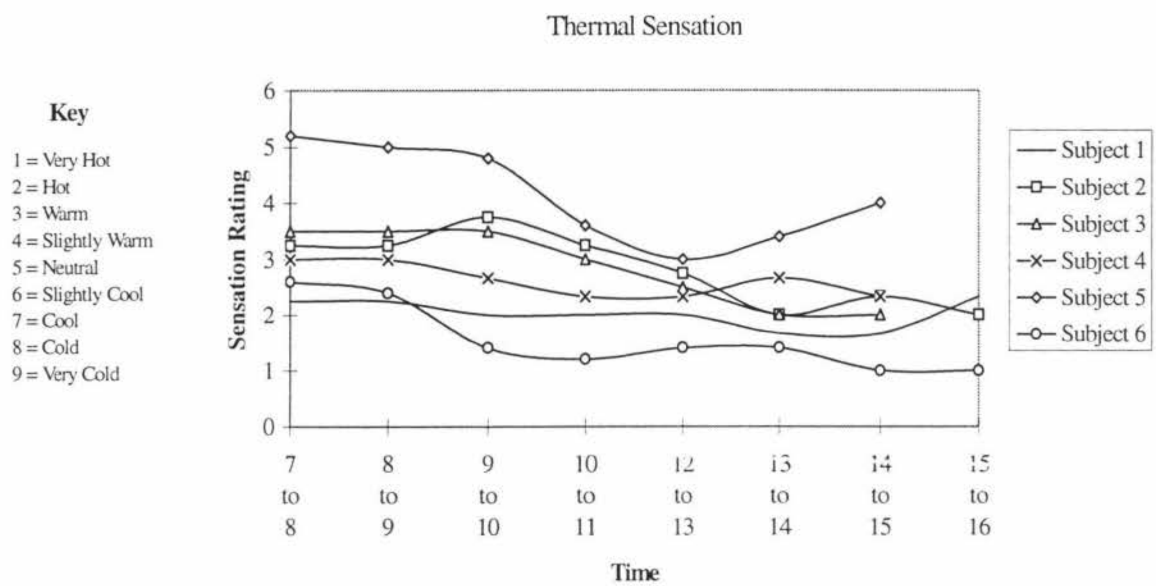


Table 15: Mean Weekly Thermal Sensation Ratings, Morning (AM) versus Afternoon (PM) (mean ± S.D.).

Subject	AM	PM	Significant Difference #
1	2.1 ± 0.3	1.9 ± 0.5	No
2	3.4 ± 0.8	2.3 ± 0.6	Yes **
3	3.4 ± 1.3	2.2 ± 0.6	Yes **
4	2.8 ± 0.5	2.4 ± 0.5	No
5	4.7 ± 1.2	3.5 ± 1.5	Yes **
6	1.9 ± 0.8	1.2 ± 0.4	Yes **

* One way ANOVA (Bonferroni Pairwise Comparisons of Means)

** 99% Confidence Interval

Table 15 shows that four of the six subjects (66%) experienced a significant ($p < 0.05$) increase in their thermal regulation as the day progressed, as a result of the subjects becoming hotter.

5.6.6 Skin Wettedness

Figure 28: Mean Weekly Skin Wettedness Ratings

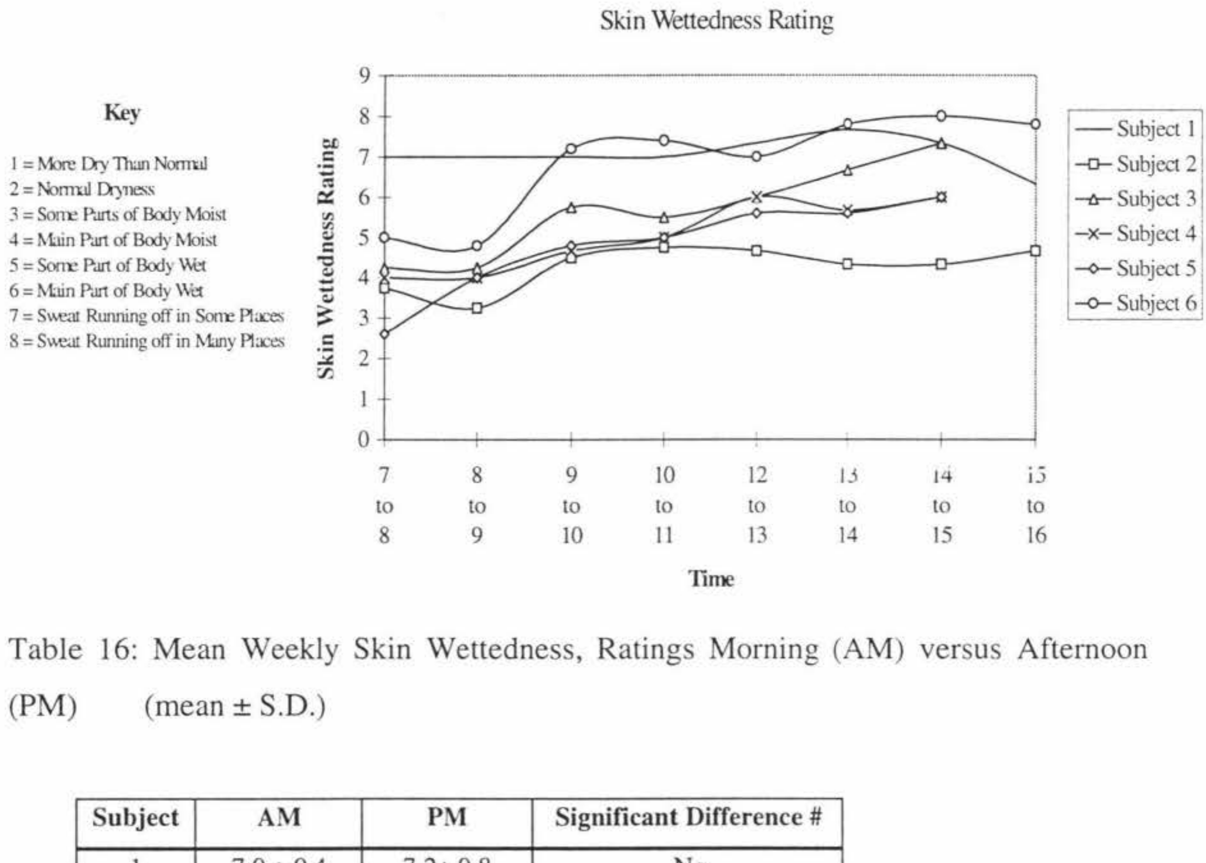


Table 16: Mean Weekly Skin Wettedness, Ratings Morning (AM) versus Afternoon (PM) (mean ± S.D.)

Subject	AM	PM	Significant Difference #
1	7.0 ± 0.4	7.2± 0.8	No
2	4.1 ± 1.3	4.5± 0.7	No
3	4.9 ± 1.1	6.6 ± 1.3	Yes **
4	4.4 ± 0.5	5.9 ± 1.5	Yes **
5	4.1 ± 1.7	5.7 ± 1.7	Yes **
6	6.1 ± 1.5	7.7 ± 0.7	Yes **

One way ANOVA (Bonferroni Pairwise Comparisons of Means)

** 99% Confidence Interval

Table 16 shows that four of the six subjects (66%) experienced a significant increase ($p < 0.05$) in their skin wettedness rating as the day progressed as a result of increased sweating.

5.5.7 Thermal Regulation

Figure 29: Mean Weekly Thermal Regulation Ratings

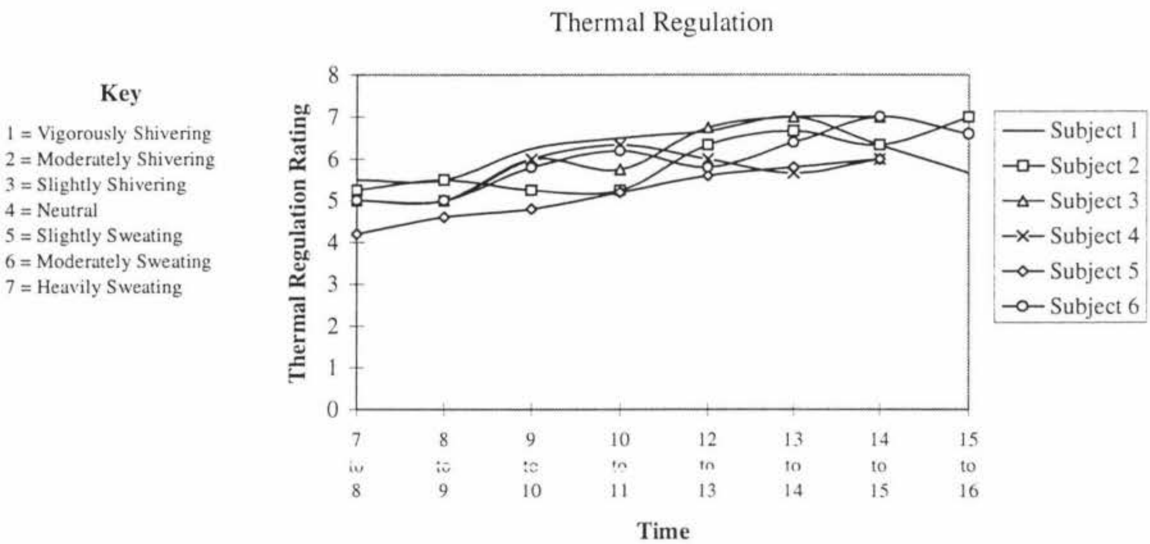


Table 17: Morning (AM) versus Afternoon (PM) Mean Weekly Thermal Regulation Ratings (mean ± S.D.)

Subject	AM	PM	Significant Difference #
1	5.9 ± 0.7	6.4 ± 0.9	No
2	5.3 ± 0.8	6.6 ± 0.5	Yes **
3	5.4 ± 0.8	6.9 ± 0.3	Yes **
4	5.6 ± 0.7	5.9 ± 0.9	No
5	4.7 ± 0.7	5.8 ± 0.8	Yes **
6	5.5 ± 0.8	6.5 ± 0.8	Yes **

One way ANOVA (Bonferroni Pairwise Comparisons of Means)

** 99% Confidence Interval

Table 17 shows that four of the six subjects (66%) experienced a significant change ($p < 0.05$) in their thermal regulation in the afternoon period (PM), through an increase in their sweat rating. The remaining two subjects experienced no such change.

5.6.8 Digit Symbol Substitution (DSS).

Figure 30: Subject 1 Mean Daily DSS Score

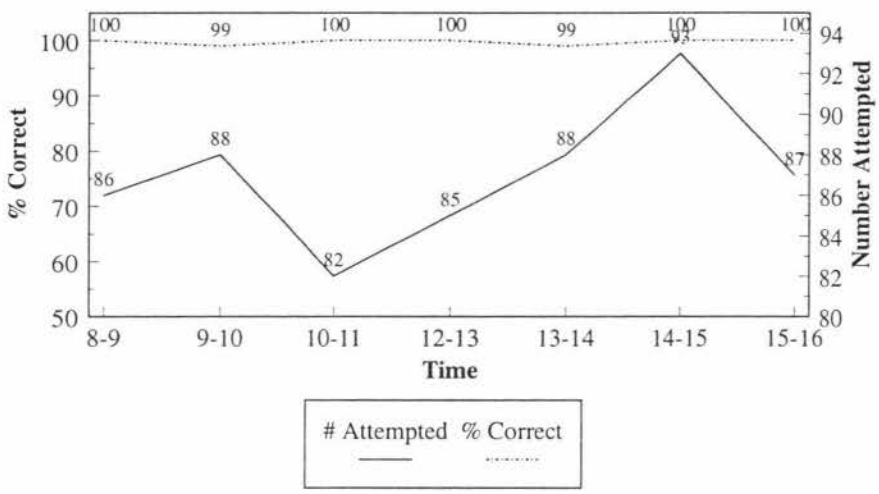


Table 18: Subject 1 Mean Daily DSS Score; Morning (AM) versus Afternoon (PM).

Subject 1	AM	PM	Significant Difference *
# Attempted	85 ± 3.0	88 ± 3.4	No (p = 0.3)
# Correct	85 ± 2.6	88 ± 3.5	No (p = 0.3)
% Correct	99.6 ± 0.6	99.7 ± 0.5	No (p = 0.85)

* One way ANOVA (Bonferroni Pairwise Comparisons of Means)

Figure 31: Subject 2 Mean Daily DSS Score

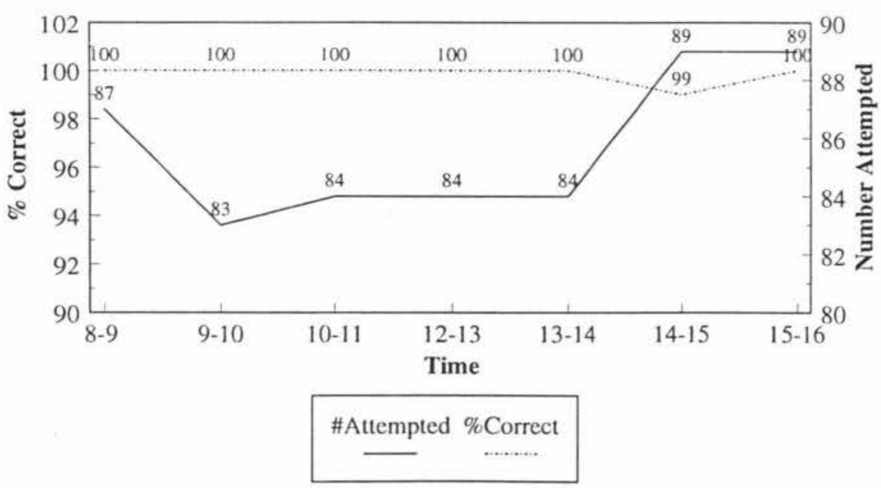


Table 19: Subject 2 Mean Daily DSS Score; Morning (AM) versus Afternoon (PM).

Subject 2	AM	PM	Significant Difference*
# Attempted	84.7 ± 2.1	86.5 ± 2.9	No (p = 0.4)
# Correct	84.7 ± 2.0	86.3 ± 2.6	No (p = 0.43)
% Correct	100.0 ± 0.0	99.8 ± 0.5	No (p = 0.44)

* One way ANOVA (Bonferroni Pairwise Comparisons of Means)

Figure 32: Subject 3 Mean Daily DSS Score

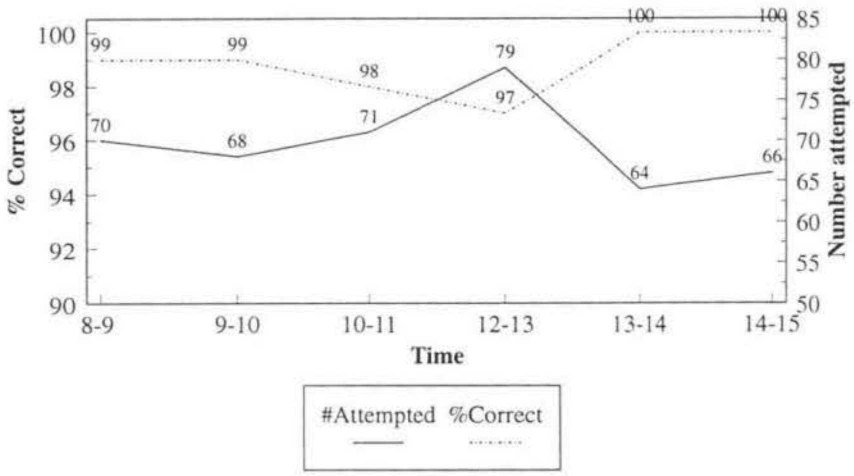


Table 20: Subject 3 Mean Daily DSS Score; Morning (AM) versus Afternoon (PM).

Subject 3	AM	PM	Significant Difference *
# Attempted	69.7 ± 1.5	67.3 ± 4.1	No (p = 0.41)
# Correct	69.0 ± 1.7	66.7 ± 3.1	No (p = 0.31)
% Correct	98.7 ± 0.6	99.0 ± 1.7	No (p = 0.78)

* One way ANOVA (Bonferroni Pairwise Comparisons of Means)

Figure 33: Subject 4 Mean Daily DSS Score

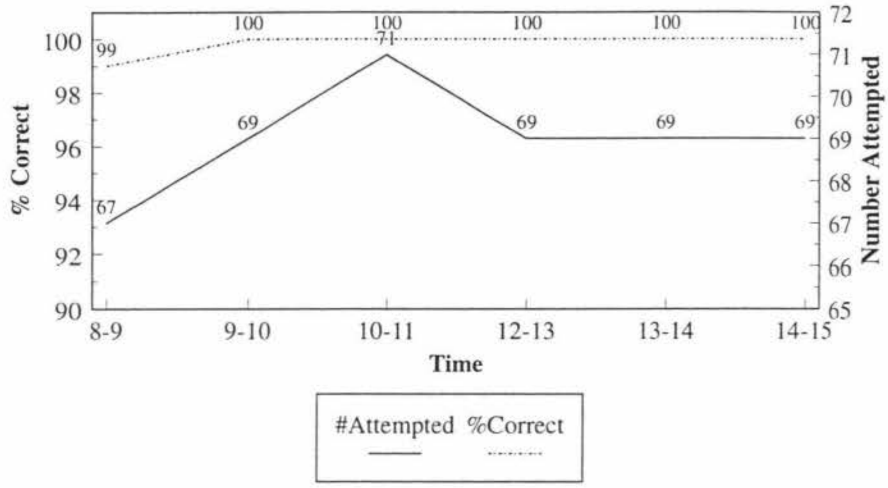


Table 21: Subject 4 Mean Daily DSS Score; Morning (AM) versus Afternoon (PM).

Subject 4	AM	PM	Significant Difference*
# Attempted			
# Correct	68.3 ± 2.0	68.3 ± 0.6	No (p = 0.07)
% Correct	99.3 ± 0.6	99.3 ± 0.6	No (p = 0.50)

* One way ANOVA (Bonferroni Pairwise Comparisons of Means)

Figure 34: Subject 5 Mean Daily DSS Score

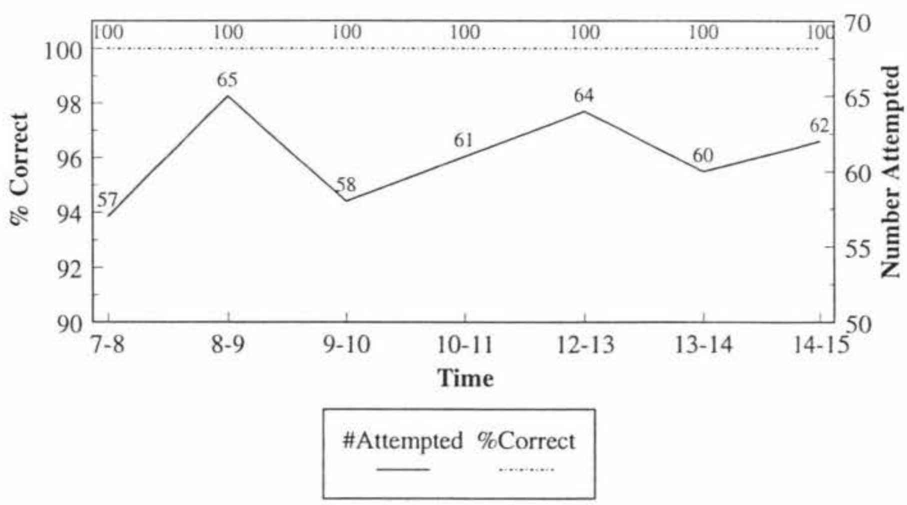


Table 22: Subject 5 Mean Daily DSS Score; Morning (AM) versus Afternoon (PM).

Subject 5	AM	PM	Significant Difference *
# Attempted	60.3 ± 3.6	62.0 ± 2.0	No (p = 0.49)
# Correct	60.3 ± 3.6	62.0 ± 2.0	No (p = 0.49)
% Correct	100.0 ± 0.0	100.0 ± 0.0	No (p = 1.00)

* One way ANOVA (Bonferroni Pairwise Comparisons of Means)

Figure 35: Subject 6 Mean Daily DSS Score

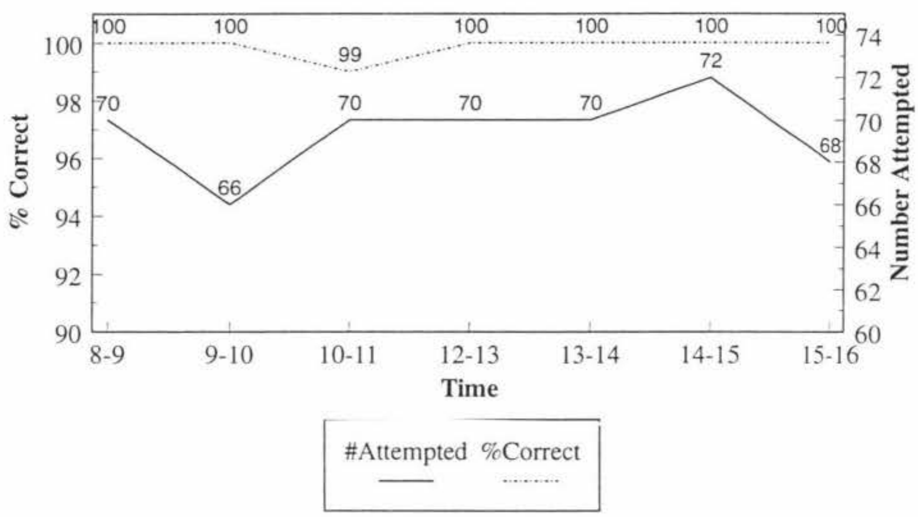


Table 23: Subject 6 Mean Daily DSS Score; Morning (AM) versus Afternoon (PM).

Subject 6	AM	PM	Significant Difference *
# Attempted	68.7 ± 2.3	70.3 ± 1.3	No (p = 0.30)
# Correct	68.0 ± 1.7	69.5 ± 1.3	No (p = 0.24)
% Correct	99.3 ± 0.6	99.2 ± 0.5	No (p = 0.84)

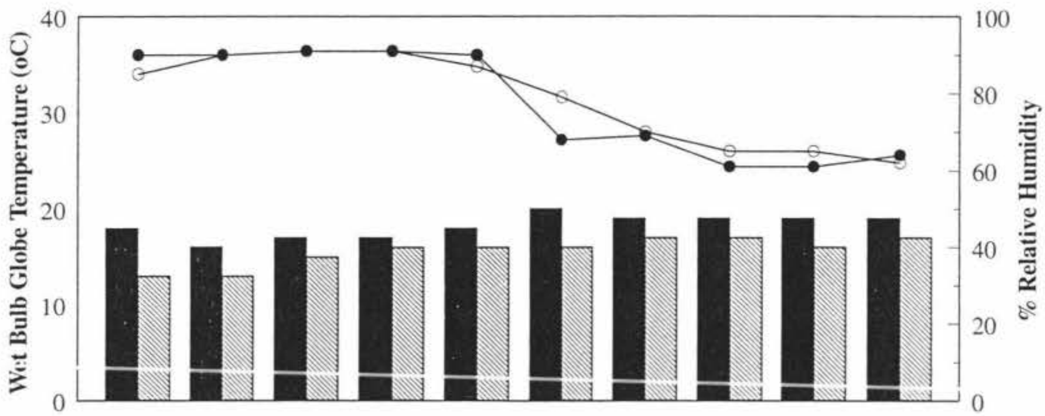
* One way ANOVA (Bonferroni Pairwise Comparisons of Means)

None of the six subjects experienced any significant change ($p > 0.05$) in either the number of digit symbol substitutions attempted, the number of correct answers gained or the percentage of correct answers as the day progressed.

5.7 Ambient Thermal Environment

The average wet bulb globe temperature (wbgt) for crew one was 18.2 ± 1.2°C (range 14.8 to 24.1), and 15.7 ± 1.4°C, (range 8.7 to 18.7°C) for crew two. The average relative humidity for crew one was 78 ± 11.2% (range 62 to 91%), and 77 ± 12.4%, (range 61 to 91%) for crew two.

Figure 36: Mean Hourly % Relative Humidity and Wet Bulb Globe Temperature (wbgt)



Time	6:30	7:30	8:30	9:30	10:30	11:30	12:30	13:30	14:30	15:30
Crew 1 ■	18	16	17	17	18	20	19	19	19	19
Crew 2 ▨	13	13	15	16	16	16	17	17	16	17
Crew 1 -o-	85	90	91	91	87	79	70	65	65	62
Crew 2 -●-	90	90	91	91	90	68	69	61	61	64

The mean wbgt's for this study were 18.2 ± 1.2°C (range 14.8 to 24.1) for crew one, and 15.6 ± 1.5 °C (range 8.7 to 18.7 °C) for crew two. Mean relative humidity was 78.4 ± 11.2 % for crew one, and 77.1 ± 12.7 for crew two.

Table 24: Mean Hourly WBGT and Relative Humidity Morning (AM) versus Afternoon (PM).

Measure	Time	Crew 1	Crew 2
WBGT	AM	17.6 ±1.4	14.8 ± 1.5
	PM	19.0 ± 0.0	16.8 ± 0.5
	Significant Difference*	No	Yes
Relative Humidity	AM	88.1 ± 3.1	88.7 ± 5.2
	PM	67.7 ± 5.1	65.4 ± 3.4
	Significant Difference*	Yes	Yes

* 95% Confidence Level

Crew one experienced no significant ($p > 0.05$) increase in mean hourly WBGT, but did experience a significant ($p < 0.05$) decrease in mean hourly relative humidity as the day progressed. Crew two experienced a significant ($p < 0.05$) increase in WBGT and decrease in relative humidity as the day progressed (Table 22).

5.8 Summary

This chapter has presented the results of data collection and analysis. The following chapter will interpret these findings and discuss their significance in relation to both the current study and previous research findings.

CHAPTER 6: DISCUSSION

6.0 Introduction

This chapter will interpret the results and discuss their significance in relation to both the current study and previous research findings. Chapter 7 will present the conclusions of the research findings pertinent to each specific area examined, including suggested areas of future research identified during the course of this study.

6.1 Subjects

6.1.1 Height and Body Mass (BMI)

For comparative analysis the subjects were separated into two age class categories, 20 - 30 and 40 - 50. The 50th percentile New Zealand male in the 20 - 30 year old age group has a BMI of 24.3 (Wilson et al., 1993). The subjects in the 20 - 30 age category in the present study had a mean BMI of 25, indicating that they had healthy height to weight ratios. Both the body mass index (BMI) and pondural index has appeared to place subject 3 in the overweight category. However, this subject was of a solid muscular build, and relatively short in stature. These features would therefore tend to bias these particular indices. This phenomenon has been noted before when using BMI measurements. Wilson et al., (1993) noted that BMI measurements require careful interpretation to ensure that subjects with a high proportion of muscle and/or bones of greater density were not assigned erroneous BMI values.

The 50th percentile New Zealand male in the 20 - 30 year old age category has a mean height of 176.6 cm and mean weight of 75.9 kg (Wilson et al., 1993). The subjects within the 20 - 30 year category had a mean height of 178 cm and weight of 79.4 kg. This indicates that the subjects tended to be slightly taller and heavier than the average population.

The subject within the 40 - 50 year category had a BMI of 34, weighed 100 kg and was 171 cm tall. This placed him within the 95 percentile of the BMI range, 95th percentile of the weight and 20th percentile of the height classes for the 40 - 50 age class. Taking the podural index, height, weight and BMI measures into consideration, subject four was taller than, but slightly overweight for, his age class.

6.1.2 Summary

Based on the physical characteristics presented here, the subjects could be characterised as having, on average, a healthy weight for their height.

6.2 Physiological Measures

6.2.1 Heart Rate Indices

6.2.1.1 Working Heart Rate.

The overall mean daily working heart rate of 107.3 ± 5.5 beats per minute ($bt.min^{-1}$) (range 98.4 to 113.9) appears to be somewhat lower than working heart rates generally associated with such work. For example, Wencl (1971) 116 $bt.min^{-1}$, Kukkonen-Harjula (1984) 123 ± 4 $bt.min^{-1}$, Hagen et al., (1993) 138 ± 10 $bt.min^{-1}$, Fibiger and Henderson (1982) 138 $bt.min^{-1}$ and Henderson (1984) 133.8 ± 9 $bt.min^{-1}$. Only Nwuba and Kaul (1987) and Cristofolini et al., (1990) recorded a working heart rate that was lower than the current study, that being 98 ± 10 $bt.min^{-1}$ and 85.2 ± 18.5 $bt.min^{-1}$ respectively.

Several other forestry related studies did not state a single working heart rate figure, rather they partitioned working heart rate data into separate task related working heart rates such as chainsaw felling. Here again, there appears to be a degree of variation between studies. For example Apud et al., (1990) recorded a felling heart rate of 118 $bt.min^{-1}$, Bombosch (1994) 114 $bt.min^{-1}$, Kirk and Parker (1994a) 117 $bt.min^{-1}$, Maleta and Sood (1984) 124 $bt.min^{-1}$, Parker and Kirk (1994) 127 $bt.min^{-1}$, and Seixas et al., (1995) 117.6 $bt.min^{-1}$. When the same criteria was applied to the present study, a mean felling heart rate of 114.6 ± 6.5 $bt.min^{-1}$ was obtained. As previously shown, this figure was very similar to those recorded by other researchers.

This raises the question of how can the working heart rates be relatively lower, but task related working heart rates very simular, to those of previous studies?. The answer could be related back to what previous researchers have defined as "working heart rate". For example Wencl (1971) appears to have only measured working heart rate in four, rather than eight hour periods. Hagen et al., (1993) appear to have excluded meal and or rest breaks from their definition of working heart rate, as have Kirk and Parker (1994a). The exclusion of lower heart rates commonly associated with rest and meal breaks undoubtedly resulted in the generation of a higher working heart rate than would be the case if such data had been included. Kukkonen-Harjula (1984) included the task of snow shovelling in the subjects working heart rate. As stated by Smolander et al., (1995), snow shovelling is a strenuous physical work activity with an average heart rate of 141 ± 20 $bt.min^{-1}$. The inclusion of such a strenuous activity into the definition of working heart rate inevitably result in the calculation of a higher working heart rate figure than would be commonly recorded in studies where snow shovelling was not included.

This present study defined working heart rate as all of those activities which took place from the moment the worker started to walk into the forest to begin felling, up to and including, walking out to the roadside at the end of the working day. All activities which occurred in between these two events, including rest and meal breaks, were combined to calculate the subjects' working heart rates for the entire working period.

As can be seen in Table 3, there was a significant ($p < 0.01$) increase in working heart rates when the morning (am) and afternoon (pm) work periods were compared. However, there was only a minimal rise in ambient thermal environment in the afternoon, no significant change in productivity or cycle times and a significant increase in subjective fatigue ratings. The increased working heart rates have therefore been attributed to the subjects finding the work physically harder in the afternoon period as they worked to maintain their level of productivity in order to achieve their daily targets.

Compared to other occupations, tree felling and delimbing in the present study recorded working heart rates which were higher than those recorded for nurses 93 ± 10 bt.min^{-1} (Fordham et al., 1978), truck drivers 96 ± 13 bt.min^{-1} (Van Der Beek and Frings-Dresen et al., 1995), bricklayers 97 ± 15 bt.min^{-1} (Åstrand, 1967), steel workers 97 ± 13 bt.min^{-1} (Vitalis et al., 1994), carpenters 99 ± 11 bt.min^{-1} (Åstrand, 1967), and building labourers 102 ± 12.2 bt.min^{-1} (Åstrand, 1967), whilst being similar to coal miners 106 ± 18 bt.min^{-1} (Montoliu et al., 1995) but not as high as foundry workers 140 ± 11 bt.min^{-1} (Keawplang et al., 1993) or snow clearers 141 ± 20 bt.min^{-1} (Smolander et al., 1995).

Therefore, utilising the heart rate based workload categories formulated by Åstrand and Rodahl (1986), Grandjean (1988) and Rodahl (1989) place the current subjects mean working heart rate of 107.3 ± 5.5 bt.min^{-1} in the moderate to heavy workload category.

6.2.1.2 Relative Heart Rate at Work.

The relative heart rate at work index has, with increasing frequency, been used as an effective alternative to oxygen consumption to estimate the severity of a task and is taken to represent 'an analogous (to Vo_2) heart rate index of the cost of work' (Vitalis et al., 1994). The recommended index level for continuous physical work over an eight hour period ranges from 33% (NIOSH, 1981), to 45% (Evans et al., 1980; Levine et al., 1982), with the most frequently used being 40% (Apud et al., 1989). In this present study the mean relative heart rate was 31.7 ± 4.4%, (range 24.4 to 35.1). This figure falls within the recommended limits previously outlined and shows that the subjects were working at a sustainable pace. This compares to the occupations of nursing 26 ± 9% (Fordham et al., 1978), car assembly workers 21 ± 7% (Goldsmith et al., 1978), steelworkers 25 ± 14% (Vitalis et al., 1994), cane cutters 33 ± 5% (Vitalis, 1981) and foundry workers 37% (Aunola et al, 1979).

An explanation for the ability of the subjects to remain within the recommended limits for sustained physical work, is the fact that the task of tree felling and delimbing is largely a self paced task as the faller has a large degree of control over their own work pace. Montoliu et al., (1995) identified this effect when they investigated the cardiac strain of coal miners. They stated that due to the self-paced tasks associated with mining, the subjects were able to set for themselves the rates of work that they felt able to sustain day after day. The same can be said for the fallers in the current study.

Evans et al., (1980) however, found that when male and female soldiers were requested to work hard at self paced rates, they both chose a level equivalent to 45% of their Vo_{2max}. Other studies utilising male soldiers operating under the same criteria (Hughes and Goldmen, 1970; Soule and Levy, 1972), found that the level chosen represented 40 to 50% of the subjects Vo_{2max}. It should be noted however, that the self paced work rates chosen in these studies only had to be maintained for a period of two hours.

Levine et al., (1982) noted the short comings evident in the work undertaken by Evans et al., 1980), Hughes and Goldmen (1970) and Soule and Levy (1972), in terms of the short one to two hour test period, and extended the test period to three and a half hours. Their results involved the addition of a training factor into the analysis. Levine et al., (1982) recorded a significant difference between the trained and untrained subjects, with trained subjects selecting a work pace equivalent to 35%, and untrained 44%, of their Vo_{2max}. This finding was attributed to the fact that fit individuals may be limited by an inability to walk fast enough to maintain the same relative energy expenditure as unfit individuals.

Work undertaken by Myles et al., (1979) however, suggested that well trained subjects exercising at self paced intensities for prolonged periods of up to eight hours duration, such as the subjects in the current study, may reduce their energy expenditure to below 40% of their Vo_{2max}. This assumption is backed up by the findings of researchers investigating other forest industry activities in New Zealands exotic plantation forest industry. Other tasks studies, and percent relative heart rate recorded are; breaking-out (37%) (Kirk and Parker, 1994b; Kirk and Sullman, 1995), skid work (31%) (Parker et al., 1993), first lift pruning (29%), (Kirk and Parker, 1996), second lift manual pruning (39%) (Ford, 1995) and second lift chainsaw pruning (39%) (Ford, 1995). As can be seen, all of these tasks recorded percentage relative heart rate at work figures which lie between the recommended 30 to 40% limit. The fact that the majority of these tasks were undertaken for a period of at least eight hours, underscores the assumption made by Myles et al., (1979). Since these task were predominantly self paced with the incentive of high production rates equalling high financial reward, one could safely assume that the individuals studied were working at their highest sustainable pace.

A further effect on the percent relative heart rate adopted by the fallers was the impact of the frequent short rest breaks taken by the fallers during their working day, whilst they refuelled their chainsaws. As previously stated, the positive impact of both rest pauses and micro-pauses on worker fatigue and productivity have been well document (Alluisi and Morgan, 1982; Brzezinska, 1968; Krueger, 1991; Parker et al., 1993; Rosa and Colligan, 1988). This aspect will be discussed in greater detail in section 6.3.

6.2.1.3 Work Pulse

The average work pulse has been used as a guide in determining the limit of continuous performance. Karrasch and Muller (1951) stated that such a limit is reached when the average working pulse is 30 $bt.min^{-1}$ above the subjects resting heart rate. Grandjean (1988) on the other hand set this limit at 35 $bt.min^{-1}$ above the resting heart rate. The current study recorded a mean work pulse of 39.4 ± 5.8 $bt.min^{-1}$ (range 30.5 to 45.3). This figure exceeds both upper limits set by Karrasch and Muller (1951) and Granjean (1988). Therefore it can be said that according to the work pulse criteria, the subjects were working at the upper limit of continuous performance and the work could therefore be classified as heavy. Cristofolini et al., (1990) recorded a work pulse of 42.9 $bt.min^{-1}$ for Italian forestry workers. However, since this figure applied to subjects undertaking a range of forest harvesting tasks, it cannot be directly compared to the present study.

The accuracy and value of the index is questionable in that whilst other indices may classify the workload of a task as acceptable, the working pulse index will classify that same task as exceeding the acceptable limits. This was found with the subjects of this study as well as those of others. Whilst the percent relative heart rate figures of the following tasks fell within the acceptable limits, their associated work pulse figures exceeded the acceptable limits as defined by both Karrasch and Muller (1951) and

Grandjean (1988). For example, breaking-out (50) (Kirk and Parker, 1994b; Kirk and Sullman, 1995), skid work (45) (Parker et al., 1993), first lift pruning (44) (Hartsough and Parker, 1993), second lift manual pruning (42) (Ford, 1995) and second lift chainsaw pruning (41) (Ford, 1995). Therefore the researcher feels that the sensitivity, accuracy and therefore, value of this physiological strain index is questionable, and requires further evaluation.

6.2.1.4 Working Heart Rate/50% Level

As detailed by Vitalis et al., (1994), the 50% level is defined as being equal to the resting heart rate plus "heart rate"/2, where "heart rate" is the maximal heart rate minus the heart rate at rest. If a subject works at the 50% level, that is heart rate at work/50% level is equal to 1, their work is comparable to hard continuous work (Lammert, 1972). The current study's mean working heart rate to 50% level was 0.83 ± 0.04, placing it in the moderate to heavy work category. This finding is again comparable to other tasks of a self paced nature requiring continuous high performance for a period of at least eight hours. The result of the current study of 0.83 ± 0.04 compares favourably with the forestry tasks of breaking out 0.86 (Kirk and Parker, 1994b; Kirk and Sullman, 1995), skid work 0.83 (Parker et al., 1993) and first lift pruning 0.84 (Hartsough and Parker, 1993).

As with the work pulse index, the 50% level appears to lack a degree of sensitivity in that it appears to classify tasks of varying intensity as being the same, whilst other indices (Hrw, Ratio, %HRR) clearly identify them as being different in terms of physiological strain.

Therefore, the researcher questions the sensitivity with which the 50% Level heart rate index can accurate identify a difference between two physiologically demanding tasks, and suggests the use of more sensitive indices for the measurement of a task's physiological cost.

6.2.1.5 Ratio of Working Heart Rate to Resting Heart Rate

The overall mean for the ratio of working heart rate to resting heart rate in the current study was 1.58 ± 0.1, (range 1.51 to 1.69). This places the current tasks of felling and delimbing higher than steel workers 1.37 ± 0.23 (Vitalis et al., 1994), cane cutters 1.38 ± 0.12 (Vitalis, 1987), nurses 1.45 (Fordham et al., 1978) and car assembly workers 1.45 (Goldsmith et al., 1978), but lower than that recorded for open hearth workers 1.64 (Minard et al., 1971).

With regard to other forestry related tasks, the findings of the current study 1.58 ± 0.1, places the task of felling and delimbing higher than skid work (1.47) (Parker et al., 1993), but lower than breaking out 1.77 (Kirk and Parker, 1994b; Kirk and Sullman, 1995), and first lift pruning 1.62 (Hartsough and Parker, 1993; Kirk and Parker, 1996).

It should be noted that with the exceptions of Kirk and Parker (1996), Vitalis (1987) and Vitalis et al., (1994), all of the previous studies used sleeping heart rate to calculate the ratio figure. This was not possible in the current study due to the objections of the subjects. However, as pointed out by Vitalis et al., (1994), if sleeping heart rates were used, it would be expected that a slightly higher ratio figure would be produced.

6.2.1.6 Estimated Oxygen Consumption (Vo_2).

The estimation of Vo_2 from subjects heart rates, has been widely adopted for use where the nature of either the work environment, or the work itself, restricts or even prevents direct measurement of Vo_2 (Aunola et al. 1979; Vitalis 1987; Imbeau et al., 1995; Montoliu et al, 1995; Van Der Beek and Frings-Dresen et al., 1995). As previously mentioned, whilst not being as accurate as direct measurement, this method provided an effective estimation of oxygen consumption with an accuracy of ± 15% (Rodahl et al, 1974; Rodahl, 1989). This finding was further supported by Maas et al., (1989) who found that with combined static-dynamic work, such as felling and delimbing, a simple dynamic task such as the cycle ergometer test could be accurately used to predict Vo_2 from measured heart rate. Keawplang et al., (1993) also found that accurate estimations of Vo_2 could be made from heart rate if each subject was "calibrated", a finding supported by Nielsen and Meyer (1987).

The overall mean estimated Vo_2 ,based on working heart rate for the present study, was 1.50 ± 0.2 litres per minute ($l.min^{-1}$), with a range of 1.30 to 1.70 $l.min^{-1}$. As with the working heart rate figure, this Vo_2 figure appears to be lower than those recorded by other forestry researchers for the task of tree felling and delimbing. For example Fibiger and Henderson (1982) recorded a Vo_2 of 1.77 ± 0.1 $l.min^{-1}$, Hagen et al., (1993) 1.81 ± 0.1 $l.min^{-1}$, Maleta and Sood (1984) 1.87 ± 0.2 $l.min^{-1}$ and Kukkonen-Harjula (1984) 1.91 ± 0.31 $l.min^{-1}$. Only one other study recorded a similar Vo_2 to that of the present study, that being Henderson (1984), who recorded a Vo_2 of 1.33 ± 0.3 $l.min^{-1}$. However, the mean estimated Vo_2 for the tasks of felling and delimbing for the present study was 1.85 ± 0.2 $l.min^{-1}$, which is very similar to the figures obtained by Fibiger and Henderson (1982), Hagen et al., (1993), Maleta and Sood (1984) and Kukkonen-Harjula (1984). This suggests that these previous researchers may have reported "forestry work" as being solely the act of felling and delimbing, rather than all of the work elements which made up the subjects working heart rate as is the case with the present study. As previously discussed, the actual definition of the work task greatly impacts on the subsequent workload rating.

6.2.1.7 Estimated Energy Expenditure

An accurate assessment of oxygen consumption (Vo_2) provides important information for determining the energy expenditure requirements of work and thus, has been used extensively (Åstrand and Rodahl, 1986). The basis for this is that the calorific value of oxygen is 4.8 kcal or 20 kJ. That is, when one litre of oxygen is consumed by the human body, there is, on average, a turnover of 4.8 kcal or 20 kJ of energy (Åstrand and Rodahl, 1986; Grandjean, 1988). With this knowledge, one can determine an individual's energy consumption by simply multiplying their oxygen consumption by 4.8 or 20 in order to obtain their rate of energy expenditure.

Because of the complicated and time-consuming procedures involved in estimating oxygen consumption, attempts have been made to use heart rate which is very simple to measure, and can, at the same time be calibrated to give reliable information about physiological workload (Varghese et al., 1994). It has been well established that heart rate and energy expenditure bear a linear relationship, which can be used in the estimation of workload from heart rate (Ganguli and Datta, 1975; Lundgren, 1946; Malhotra et al., 1963; Payne et al., 1971; Saha, 1976).

The method used in the current study was based upon the subjects' heart rate recordings, as reliable workload/oxygen uptake relationships were obtained through cycle ergometry testing, with a mean correlation coefficient of 0.90 ± 0.07. Accordingly, estimated mean Vo_2 figures were multiplied by 4.8 and 20 in order to obtain the mean kcal min^{-1} and kJ. min^{-1} values. These min^{-1} values were then multiplied by the time spent at work in minutes to obtain an estimation of energy expenditure for the working period. Consequently, a mean ± standard deviation per minute estimated energy expenditure rate of 7.4 ± 0.8 kcal min^{-1} and 30.8 ± 3.3 kJ. min^{-1} was obtained. Total estimated work expenditure for the working day was 3699.3 ± 439 kcal and 15488.2 ± 1837 kJ, with the average working day consisting of 502 ± 12.6 minutes or alternatively, 8.4 hours.

The per minute rating of 7.4 ± 0.8 kcal min^{-1} places the current subjects' at the upper end of the heavy workload category as defined by Table 25. On an 8 hour working day, basis Grandjean (1988) would grade the current study's mean working expenditure (3699.3 ± 439 kcal) as being within the *severe* range of work expenditures (Table 24).

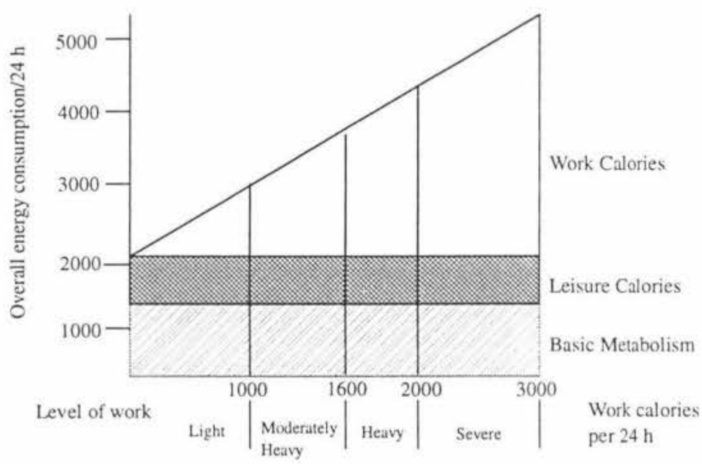
Table 25: Rating of Work Energy Expenditures

Work calories per 8-hour day (kcal)	Rating
< 1000	Light
1000 - 1600	Moderately heavy
1600 - 2000	Heavy
> 2000	Severe

Source: Grandjean (1988).

In terms of 24 hour energy expenditure rates, the current figures were again at the upper limits of extreme effort. When the work expenditure rate was added to the basal metabolic expenditure rate of 1700 kcal and the leisure energy expenditure rate of 600 kcal for a 24 hour period (Grandjean, 1988), a total estimated mean energy expenditure rate per 24 hours of 5999.3 kcal was achieved. Applying this figure to Hettingers (1960) diagram (Figure 36) gave a work expenditure rating of severe and a overall energy consumption/24 hour rating of "*extreme bodily effort*".

Figure 37: Summary of Overall Energy Consumption Compared With Working Consumption.



Source: Hettinger (1960)

An understanding of how physically demanding such work can be, is shown by Grandjean (1988) who states that "most work physiologists today consider an energy consumption of 4800 kcal per working day (averaged over a year) to be a reasonable maximum for heavy work". The current findings of 5999.3 kcal per 24 hours, shows that these subjects were working close to their upper limit in terms of energy expenditure. Fibiger and Henderson (1982), Hagen et al., (1993), Kukkonen-Harjula (1984), Matela and Sood (1984) and Van Loon (1971) confirm this finding as they were all classified felling and delimbing as very to extremely heavy physical work, where in the majority of cases the subject was working at the upper limit of internationally recognised levels for long term heavy physical work. Considering all of these factors, the current subjects workload, in terms of energy expenditure, would have to be rated as being within the "very heavy" to "severe" range.

6.2.1.8. Summary

A working heart rate of 107 ± 5.5 bt.min^{-1} , an estimated working oxygen consumption of 1.5 ± 0.2 l.min^{-1} and an estimated energy expenditure of 7.4 kcal.min^{-1} placed the current subjects' working activities in the moderate to heavy workload category (Table 25). Heart rate indices applied to the subjects' recorded heart rate data confirmed these findings, and rated the workload associated with the task of motor-manual tree felling and delimbing as moderate to heavy.

Table 26: Physiological Classification of Working Activities

	Oxygen Consumption (l.min^{-1})	Energy Expenditure (kcal.min^{-1})	Heart Rate (bt.min^{-1})
Light	< 0.5	< 2.5	< 90
Moderate	0.5 - 1.0	2.5 - 5.0	90 - 110
Heavy	1.0 - 1.5	5.0 - 7.5	110 - 130
Very Heavy	1.5 - 2.0	7.5 - 10.0	130 - 150
Extremely Heavy	> 2.0	> 10.0	150 - 170

Source: Åstrand and Rodahl (1986)

In general terms, heart rate indices are an effective means for determining physiological strain of subjects in applied field situations. The use of heart rate indices gives the ability to cross-reference results to obtain an overall assessment of the workload of a task. The ability to collect real time data from a working subject with minimal personal discomfort or disruption of their normal work routine, ensures the collection of accurate and relevant data. The ease and speed of data interpretation ensures that results can be quickly and effectively used to aid decision making in terms of task modification or implementation of interventions aimed at mitigating any adverse physiological effects identified.

6.3 Production

With the exception of subject four, no significant decrease in average daily production was recorded between the morning (am) and afternoon (pm) work periods. Subject four was the foreman of crew two and therefore tended to undertake additional organisational tasks after completing the mid day meal break. Consequently he spent less time in the afternoon actually concentrating on the task of tree felling. This was demonstrated by the fact that the cycle time per stem for subject four showed no statistical differences ($p > 0.05$) between the (am) and (pm) work periods.

Subject six showed a significant reduction in cycle time for the pm work period. Further investigation of specific elements within the cycle time category revealed that both productive time (ie. delay free) and delay time remained unchanged. However the time spent walking out of the block at the end of the day, a component of total cycle time, was significantly shorter in the pm than the am. It appears that this subjects working pattern was such that he finished felling at the end of the day close to the crew pick-up points. Therefore while actual average hourly production did not significantly change, total cycle times per stem decreased. None of the remaining subjects experienced any significant change ($p > 0.05$) in either cycle time per stem or average hourly production rate.

It appears that subjects one to four had difficulty returning to full production after the midday break during the period 12 pm to 1 pm, whereas subjects five and six returned to full production immediately. This has been attributed to the fact that subjects one to four only took 30 minutes for their midday break whereas subjects five and six took 60 minutes. This meant that subjects five and six had an additional 30 minutes in which to rest and recover from the morning run.

The impact of rest breaks on worker productivity has been previously investigated by other forestry based researchers investigating timber harvesting operations (Alluisi and Morgan, 1982; Fibiger and Henderson, 1982; Golsse and Rickards, 1990; Henderson, 1984; Johnson and Tabor, 1987; Krueger, 1991; McCormick and Tiffin, 1974; Paulo de

Souza et al., 1995). Rest pauses have been shown to provide periods in which workers were able to gain some respite from the physiological and psycho-physiological stressors effecting the worker (Brzezinska, 1968; Krueger, 1991; Rosa and Colligan, 1988).

Åstrand and Rodahl (1986) introduced the concept that the level of activity in many industrial tasks was self regulatory in that the rate of work and spacing of rest pauses were set by the individuals level of physical fitness. Fibiger and Henderson (1984) in their study of Australian hardwood tree fallers found very similar work-rest schedules being utilised as those found in the current study, with fallers frequently having what they termed "spontaneous rest pauses".

As stated by Alluisi and Morgan, (1982) and cited by Parker et al., (1993), short rest breaks in machine paced jobs do not reduce output even though less time is worked. Since a faller's work pace is largely influenced by the mechanical ability of the extraction machine to extract a drag, and then return for the next one, such findings are applicable. The reasons for maintaining productivity with shorter work time can be largely explained by the fact that, as stated by McCormick and Tiffin 1974, rest breaks serve to provide a relief from boredom, physiological stress, muscle fatigue and cardiac strain. The application of this rationale into the production forestry milieu has been suggested by researchers as a way to reduce physiological stress and muscle fatigue in fallers (Johnson and Tabor, 1987), and boredom in logmakers (Parker et al., 1993).

A further influence could be attributed to the fact that the wet bulb globe temperature (wbgt) index peaked for crew two at the 12:30 pm recording. Whilst the heat load may not have reached the critical 26°C WBGT level identified by Smith and Rummer (1988), it could possibly have impacted on the physical performance of subjects one to four due to the physiological and psychological responses of their bodies due to the increased heat load being experienced.

The physiological impact of heat on the body's performance has been well documented (Andersson, 1986; Armstrong et al., 1991; Benor and Shvartz, 1971; Chad and Brown, 1995; Faff and Tutak, 1989; Fuller and Smith, 1981; Kahkonen et al., 1992; Macworth, 1961; Ohnaka et al., 1993; Shvartz et al., 1976; Sirios and Smith, 1985; Smith and Sirois, 1982; Smith et al., 1986). The general finding from such research was that exposure to work and heat generated localised or general fatigue which will in turn normally had a negative effect on muscular based perceptual motor performance (Ramsey, 1995). Kroemer (1991) stated that short term maximal muscle strength exertion was not affected by heat or water loss. However, the ability to perform high-intensity endurance type physical work, as is commonly found in forestry work, was severely reduced during, and after, acclimatisation to heat. This assumption was backed up to a degree by the fact that subjects one to four recorded that they felt hotter in the afternoon than the morning. However, only subjects two and three recorded a significant increase ($p < 0.05$).

6.3.1 Summary

Production did not appear to be negatively affected by the progression of the working day. Principal factors contributing to this appear to be the effective use of rest breaks by the subjects, and the subjects' natural self pacing mechanism. These two factors, combined with favourable terrain, combined to ensure that the work rate chosen was one that could be sustained for prolonged hard continuous work.

6.4 Terrain

The terrain encountered by the subjects during the study proved to be very favourable in terms of both minimal ground slopes and low hindrance undergrowth. The expectation during the initial formation of the study, was that the selected crews involved in the study would be working in more adverse terrain conditions in order to ascertain the impact of these features on worker fatigue. However, both crews unexpectedly moved into forest compartments containing favourable terrain features immediately prior to the commencement of the study. Time constraints and operational practicalities prevented either delaying the study until alternative sites could be found, or moving the crews to alternative sites.

6.4.1. Summary

For this study, no inference could be drawn regarding the impact of terrain on worker fatigue apart from stating that any such effect was minimal.

6.5 Hazards

Forestry, and logging in particular, is a high risk occupation and consequently has a poor occupational accident and health record both internationally (Poschen, 1993) and domestically (Gaskin and Parker, 1993; Gibson, 1994). Forestry work has generally been characterised by a combination of natural and material risks to the health and safety of forest workers. The natural risks were associated with steep and broken terrain, dense crops and adverse working conditions, including extremes of climate - both hot and cold (Poschen, 1993). Tree felling and delimbing in particular, were areas of extreme risk for forest workers undertaking manual chainsaw operations. Poschen (1993) in his review of world forestry related accident data stated that of the three broad categories associated with industrial forestry, namely silviculture, harvesting and processing, harvesting accounts for up to 70% of total accidents. Of this 70%, felling and crosscutting were the jobs most prone to serious and fatal accidents.

The hazard ratios obtained in the current study showed little notable temporal variation with no significant ($p > 0.05$) increase between the morning (am) and afternoon (pm) work periods being identified. Whilst the hazard ratios were considerably lower than those reported by Parker and Kirk (1993b), they showed the same trend, that was, felling generated considerably fewer hazardous situations per 100 stems than trimming. Parker and Kirk (1993b) recorded a felling hazard ratio of 31.1 ± 3.9 hazards per 100 stems and a trimming hazard ratio of 85.7 ± 10.3 hazards per 100 stems. The current study recorded a felling hazard ratio of 4.9 ± 3.9 hazards per 100 stems and a trimming hazard ratio of 10.1 ± 5.2 hazards per 100 stems. The discrepancy between the two studies can be attributed to the fact that Parker and Kirk (1993b) combined very inexperienced fallers (less than one years experience) with experienced fallers (more than five years experience) to arrive at the felling and trimming ratios of 31.1 ± 3.9 and 85.7 ± 10.3

hazards per 100 stems respectively. The subjects in the current study were all very experienced fallers with on average 10.3 ± 6.0 years felling experience. Hence the lower hazard ratios. Since Parker and Kirk (1993b) did not differentiate felling and trimming hazard ratios for the experienced and inexperienced fallers, it was difficult to make direct comparisons with the current studies findings apart from stating that they are significantly lower. The percentage of hazards generated by felling (27.5 %) and trimming (72.5 %) in the current study also follows national trends in that analysis of lost time accidents within the New Zealand forest industry shows felling and trimming accidents to be the most common (Gaskin and Parker, 1993; Parker, 1995).

Several studies have been undertaken within the New Zealand forest industry relating to risk assessment and hazard occurrence for the tasks of felling and delimbing (Tapp et al., 1990; Parker 1991; Parker and Kirk, 1993b). Tapp et. al., (1990) found that loggers were well aware of which parts of the operation were dangerous, what types of injuries occurred and the parts of the body that were most vulnerable. This raised the question that if loggers were aware of the risks and dangers inherent in their occupation, why were those risks not avoided on more occasions? Parker (1991) tried to address this question by asking loggers to rank the severity of nine hazardous felling and trimming situations. The results showed that while loggers were accurate in correctly ranking hazardous felling situations, they tended to seriously under-rate the risk of injury due to certain less obvious hazardous trimming situations.

Identifying the actual nature of the hazards associated with felling and trimming operations was the objective of the work undertaken by Parker and Kirk (1993b). This study addressed the issue of a workers level of experience in relation to tree fallers hazard exposure. Results showed that inexperienced fallers were exposed to significantly more hazards than experienced loggers. It was also shown that many of these hazards were due to poor work technique.

However, this link between greater work experience and a reduced hazard exposure was not found in the work undertaken by Kirk and Sullman (1995) which investigated fatigue in cable hauler breakerouts. In fact a completely opposite correlation was found, in that the most experienced workers exposed themselves to significantly greater hazards than their less experienced co-workers. Kirk and Sullman (1995) attributed the negative safety behaviour of the experienced breakerouts to "optimistic bias" as outlined by Lark (1991) as being that when discussing personal risks, people claimed that they were less likely to be affected than their colleagues.

Such a phenomenon has been widely identified in other research (Lark, 1991; Ostberg, 1979; Parker, 1991; Zimolong, 1985). There are numerous explanations as to why people take risks, including boredom, sensationalism, genetics, poor risk perception and familiarity with the risk. Zimolong (1985) stated that a person's accepted risk level was established as a result of previous experiences and exposures to risk. In the breakerouts particular situation, the constant exposure to risk has led to familiarity with certain hazards and the development of poor risk perception. Such findings tie in with those of Parker (1991) who found that common everyday trimming hazards were not seen as being hazardous.

The role played by personal protective equipment (PPE) in the reduction of both frequency and severity of injury within the forestry sector is well documented (Bradford et al., 1992; Gaskin, 1989; Gaskin and Parker, 1993; Väyryen and Ojanen, 1983; Kirk, 1992; Kirk, 1993; Kirk and Parker, 1993b; Kirk and Parker 1994a; Klen and Väyryen, 1984; Sullman, 1994). However, while the use of such protective equipment is vital for the continued safe operation of many harvesting tasks, it is not the ideal solution to overcoming the problem of worker exposure to work related hazards.

An optimum solution to the hazards associated with the felling and trimming phases of the harvesting operation appears to be the mechanisation of these two procedures. There has been extensive research into the development of machines (Evanson and Riddle, 1994; Evanson et al., 1994; Gadd and Sowerby, 1995) and systems (Evanson, 1995; Hill and Everson, 1995) which are able to be effectively implemented into the felling and delimbing phases of the harvesting operation in New Zealand. Whilst possible to a degree, full mechanisation of New Zealand's harvesting operations is currently limited by unfavourable terrain, steep ground slope, large tree size and poor tree form as well as the cost effectiveness of such operations in smaller forest resource areas. Not surprisingly, a machinery survey undertaken by Lyon and Raymond (1993) found that motor-manual harvesting systems accounted for 95% of the total volume of timber harvested in New Zealand at that time. A further 3% was harvested by manual/mechanical combinations, and fully mechanised systems accounted for the remaining 2%.

In areas suitable for full or partial mechanisation, it was seen that the workers were taken away from the hazards associated with felling and trimming, and were placed in the relative comfort and safety of a machine cab. The results in terms of improved safety can be dramatic. Poschen (1993) stated that machine operators had less than 15% of the accidents suffered by chainsaw operators in harvesting the same amount of timber. The impact on physical workload can also be equally dramatic, as shown by Parker and Kirk (1994) in their review of physiological workloads associated with differing types of forest work.

Unfortunately, mechanisation is not the panacea it was first thought to be. More recently neck and shoulder strain injuries among machine operators have started to emerge. Such injuries are the result of long, repetitive and monotonous hours of manipulating machine controls. While difficult to diagnose objectively, occupational health specialists agree that such injuries may be as incapacitating as serious accidents and may force many operators to give up their jobs (Poschen, 1993).

6.5.1 Summary.

Results suggested that while hazards in the current study occurred less often than in previously documented research, the hazards encountered by the subjects followed national trends for felling and trimming. The fact that the subjects were, on average very experienced fallers, combined with favourable terrain and a low hindrance undergrowth, contributed to produce lower than expected hazard ratios. One pleasing aspect was that the phenomenon of "optimistic bias" noted by Kirk and Sullman (1995) was not evident in this study. Mechanisation of the felling and delimbing phases of the harvesting operation would significantly reduce the fallers exposure to hazards. Any such mechanisation must be implemented correctly in order to avoid the generation of alternative forms of debilitating injuries.

6.6 Psycho-physiological Measures

6.6.1 Rate of Perceived Exertion

The physical demands of a task affect psychological motivation, fatigue and satisfaction; conversely, the performer uses psychological cues to regulate physiological work pace (Capodaglio et al., 1995). As stated by Gamberale (1990), motivational factors and perception of effort play an important role in determining individual capacity for physical work. It is presumed that if an individual has an ability to accurately gauge the degree of physical effort required to undertake a task, then they will be better able to effectively regulate their work pace in order to avoid undue physical stress and strain.

The findings of this study showed a wide range in ability to accurately gauge the degree of physical effort required to undertake the task of felling and delimbing. Subjects one, three and five achieved good correlations (0.57 - 0.78), between heart rate (HR) and rated perceived exertion (RPE). Subject six began the day achieving good correlations (0.72), which gradually decreased to (0.33) as the day progressed. Subjects two and four achieved very poor correlations (-0.03 - 0.6), and appeared to have a limited ability to accurately gauge the degree of physical effort they experienced during the working day, no matter what the time of day.

An explanation for this wide variation in abilities is difficult to detect as there were no singular trends evident in either the physiological, production, hazard or subjective features recorded. For example subject six recorded a significant increase in subjective fatigue and a significant decrease in subjective comfort levels as the day progressed. This could be attributed as being the principal impetus for the lower correlations recorded for the afternoon period. However, subject three also recorded the same trend in subjective fatigue and comfort but did not experience any decrease in HR versus RPE correlations as the day progressed.

6.6.1.1 Summary.

The researcher could not find any clear distinctions between subjects with high HR versus RPE correlations and those with low correlations in terms of identifiable trends relating to either physiological, production, hazard, fatigue or subjective comfort measures.

6.6.2 Subjective Fatigue

Fatigue is a concept which defies precise definition. Cameron (1974), stated that fatigue was a generalised response to stress over a period of time, with effects which may be either acute or chronic, or both, confined to the subjective state of the individual or extending into measurable aspects of their performance.

A common assumption made by researchers has been that increased feelings of fatigue are inextricably tied to a decrease in physical performance. Cameron (1974) referred to earlier research undertaken in early 1900's by the Industrial Research Fatigue Board. The Board's studies dealt primarily with work environment, working hours and workplace design in the belief that workers' output was retarded by fatigue, and that alleviation of fatigue could maintain high productivity.

However, further review of the fatigue concept by Bartley and Chute in 1947 transposed the theory of fatigue away from its traditional operationist approach, to that of a more broader and humane approach. They emphasised the complex nature of fatigue and distinguished three distinct facets of the problem (Cameron, 1974). Bartley and Chute (1947) considered that the term *fatigue* should only be applied to the subjective feelings of lassitude and disinclination towards activity, features which typified an individual as suffering from fatigue. They offered the term *impairment* as being a way to identify the true reduction of physical capacity resulting from an accumulation of oxygen debt in muscle tissues. Deterioration in quality of performance for reasons other than sheer physical incapacity was termed *work decrement.* The key finding of this analysis was the conclusion that these three aspects of the fatigued state were complexly related. Therefore the presence of one aspect could not be reliably inferred from the presence of one or both of the others. Therefore workers could conceivably feel fatigued but show no deterioration in performance.

Such a scenario was attributed to the findings in the current study where although the subjects subjective fatigue ratings stated that they felt more weary (83%), tense (66%), weaker (100%) and more exhausted (83%) as the day progressed, a significant deterioration in performance was not recorded.

Bartley and Chute (1947) delineated the effects of fatigue into two distinct categories, acute and chronic. Chronic fatigue they defined as that which was not dispelled by normal processes of rest and recuperation. Acute fatigue was that in which *impairment* or *work decrement* responded to rest. The former was identified as being a common and serious problem whilst the latter was seen as being unlikely to present a serious practical problem.

6.6.2.1 Summary

The subjects in the current study appear to have been suffering from acute fatigue, which dispersed during the period of rest attained during the night. Whilst their level of *fatigue* may have steadily increased as the day progressed, no discernible deterioration in performance, either in the form of *impairment* or *work decrement* was noted.

6.6.3 Body Part Discomfort

All subjects experienced a degree of body part discomfort over a range of body parts. The lower back (segment 8), was the most frequently recorded body part experiencing discomfort (26 %), followed by the hips (segment 9), (14 %), mid back (segment 7) (9%) and the ankle (segments 26 and 27) (9 %). Severity ratings were predominantly slight (49%) to moderate (43%), with only eight percent being ranked as severe. Such a finding was not unexpected, as there has been an historic trend in back injuries amongst loggers worldwide. Poschen (1993) stated that back pain resulting from physically heavy work and unfavourable working postures, was very common among chainsaw operators. An extensive survey in Germany found that, after ten years of work, one third to one half of forest workers complained of back pain. Among older workers, up to two-thirds may be affected (Sabel, 1986).

There has also been extensive research undertaken in the area of lower back injuries within the logging sector of the New Zealand forest industry (Gaskin et al., 1988; Gaskin, 1990; O'Leary 1988; Sweetman, 1984). The work undertaken by Gaskin et al., (1988), O'Leary (1988) and Gaskin (1990) clearly documented the bio-mechanical loadings that were experienced by fallers who chose to delimb stems by standing on top, rather than beside, the stem. Since all of the subjects in the current study favoured the "on top" method of delimbing, the recording of such discomfort was not unexpected.

Overseas research has clearly identified the link between poor working posture of tree fallers and high rates of both energy expenditure and musculoskeletal damage (Hagen and Harms-Ringdahl, 1994; Harstela, 1990; Tatsukawa, 1994). Both Harstela (1990) and Tatsukawa (1994) have recorded fallers adopting harmful work postures for 50 to 62% of work time during felling and 46 to 50% for delimbing. Additionally, Tatsukawa (1994) identified the frequent occurrence of both localised muscle fatigue and musculoskeletal disorders (predominantly lower back pains), in motor-manual tree fallers.

The severity of the discomfort did not change during the progression of either the working day or week. It was thought that the discomfort might increase in severity as the day and week progressed. However this was not the case, as all subjects rated the same level of discomfort consistently throughout the working day and week with little variation. This was attributed to the nature of the discomfort, in that it was described by the subjects as a dull background form of pain, rather than a sharp localised pain. This being the case, the pain tended to stay with the subjects throughout the work period without any noticeable increase in severity.

Subjects three and four experienced hip pain, subject three as a result of aggravating an earlier injury where both hips had been severely damaged, and subject four due to hip joint wear and tear attributed to his age. Subject six experienced additional thigh, elbow and shoulder injuries as a result of his recreational activities which were then aggravated by the task of tree felling.

Unfortunately the subjects in this study did not modify their work method according to their body part discomfort. As stated, all six subjects recorded moderate to severe discomfort in the lower back region. However, they all continued to delimb by predominantly walking along the top of the stem. It appears that the alternative method of delimbing beside the stem (LIRA and Swedfor, 1980), with its associated lower spinal loading (Gaskin et al., 1988; O'Leary, 1988; Gaskin 1990), was too slow and required more physical effort to undertake than the more traditional "on top" delimbing method. Gaskin (1990) found the same level of resistance to the alternative method with the rationale commonly offered by loggers for not using this method being " it is easier to walk along the top of the log as it gives a relatively clear working platform".

For many of the subjects it was considered too late to change to the alternative method since they considered that the damage to their backs had already been done so they may as well continue to use the easier method in order to maintain production as easily as possible. In some cases, frequent visits to chiropractors and physiotherapists enabled the subjects to continue working as fallers. Another attitude which was prevalent during the study was that the fallers saw their current job of felling and delimbing as being a relative temporary situation. Most had ambitions of moving on to either the position of skidder or loader driver, or in fact leaving the industry altogether for some other occupation.

The perception that the alternative delimbing method was both more physically demanding and less productive, combined with a sense that the current situation was only one phase of their intended career path, meant that in most cases the physical warnings being generated in the form of body part discomfort, were largely ignored. As a consequence, severe musculo-skeletal damage was being incurred. In subject two's case, this damage resulted in back pain so severe that the subject subsequently left the forest industry.

6.6.3.1 Summary

The lower back (segment 8), was the most frequently recorded body part experiencing discomfort (26 %), followed by the hips (segment 9), (14 %), mid back (segment 7) (9%) and the ankle (segments 26 and 27) (9 %). Severity ratings were predominantly slight (49%) to moderate (43%), with only eight percent being ranked as severe. The severity of the discomfort did not change during the progression of either the working day or week. The primary cause of the discomfort was the use of poor work postures, particularly when delimbing.

6.6.4 Thermal Comfort, Sensation, Skin Wettedness and Regulation.

The subjects stated that they felt significantly ($p < 0.01$) more uncomfortable (50%), hotter (66%) and more sweaty (66%) in the afternoon (pm), than in the morning (am), time periods. The primary reason stated for these increased levels was an increase in ambient thermal temperature as the day progressed, which resulted in an increased sweat rate which in turn made working conditions more unpleasant. Bakkevig and Neilsen (1995), demonstrated that high heat and sweat production during work periods, leading to increased sweat accumulation, gave higher thermal discomfort ratings for rest periods as well as for work periods compared to intermittent work with lower work intensities. Combined with the temperature effect were the impacts of high levels of metabolic heat generation associated with high workload tasks such as felling and delimbing.

The wearing of personal protective equipment (PPE), in particular chainsaw operator protective legwear, safety helmet and ear protectors, further exacerbated the situation as PPE has been shown to prevent effective heat dissipation from the body (Laird et al., 1992; Martin and Goldman, 1972; Ohnaka et al., 1993; Staal Wästerlund and Kufakwandi, 1993). The impact of PPE on wearer comfort has received previous attention by researchers, both within the forest industry (Klen and Väyrynen, 1984; Väyrynen and Ojanen, 1983), as well as other industries (Laird et al., 1992; Martin and Goldman, 1972; Ohnaka et al., 1993; Staal Wästerlund and Kufakwandi, 1993).

Smith and Rummer (1988) noted that ambient thermal heat played an important factor in the wearing of PPE by forest workers. They noted that forest workers exposed to the most direct solar load tended to neglect their PPE under the hotter conditions perhaps in an effort to make their job more comfortable. Laird et al., (1992) found that the most common reason given by workers for the removal of PPE was that they felt that it was too hot to wear. Staal Wästerlund and Kufakwandi (1993), noted that the use of inappropriately designed PPE in hot climates can in fact worsen the situation by increasing the workers thermal load.

Whilst the subjects actual sweat rates were not determined, heavy sweat rates were recorded by the subjects themselves via the skin wettedness questionnaire. One notable feature absent from all subjects within the study, was the concept of fluid replacement during the working day. In general, the subjects only drank approximately 1 litre of fluid over a period of four hours. Consequently all subjects appeared to suffer from varying degrees of dehydration. The detrimental effect of dehydration on worker performance has been well documented (Below et al., 1995; El-Sayed et al., 1995; Kirk, 1995; Millard-Stafford et al., 1995; Thompson and Hellemans, 1994).

6.6.4.1 Summary

As the day progressed, significant decreases in thermal comfort and sensation ratings occurred, accompanied by an increase in the skin wettedness rating and hotter thermal regulation ratings for the majority of the fallers. The primary reason stated for these increased levels was an increase in both metabolic heat and ambient thermal temperature as the day progressed, resulting in increased sweating, thereby making working conditions more unpleasant.

6.7 Digit Symbol Substitution

Fibiger (1980) offers an "operational solution" to the measurement of mental workload in workplace situations. This "operational solution" entails the measurement of the workplace's physical factors (ie. climate, noise, vibration...), the subject's physiological parameters during a whole shift (ie. heart rate, blood pressure, catecholamine excretion...), the subject's working activities, a self estimation of mental and physical effort by the subject and finally, an evaluation of entropy of information (limited channel capacity). Such an "operational solution", whilst meeting the requirements of an ergonomic analysis in that it considers the worker as a part of the system, in respect of various factors which can influence their mental workload, mental stress and fatigue, would in many cases prove to be too complicated, time consuming and expensive to be applied in many field settings (Cameron, 1974; Fibiger, 1980; Okogbaa et al., 1994).

Hartley et al., (1994) again stated the need for an "operational" type solution for the measurement in the workplace of mental workload and fatigue. Hartley et al., (1994) required measures which were sensitive to fatigue or workload, portable and durable, able to collect data for an extended period of time, non-intrusive and acceptable to the subjects in order to encourage their use. Consequently the use of cardiac sinus arrhythmia was chosen since it met all of these criteria and had been previously proven to be highly correlated to mental workload.

The current study could not utilise the cardiac sinus arrhythmia measurement method since the heart rate monitors available could not provide the required level of sensitivity. Accordingly, an information processing measure based upon those used by Legg et al., (1991) was chosen. It was considered that such an information processing measure (DSS), when combined with measurement of the workplaces' physical factors (ie. climate, slope, hindrance), the subjects' physiological parameters during a whole shift (ie. heart rate, estimated work Vo_2), the subjects' working activities (production study), a self estimation of mental and physical effort (RPE and subjective fatigue questionnaire), provided a close approximation of Fibiger's (1980) "operational solution".

However, the use of the DSS information processing measure did not identify any significant decline in any of the six subjects over the period of the study. None of the subjects recorded any significant change in either the number of tests attempted, or the percentage of the tests they correctly completed. Subjects three through six all attempted between 60 and 70 digit symbol substitutions per test, achieving 98 to 100% accuracy. Subjects one and two achieved a slightly higher number of digit symbol substitutions, averaging between 85 to 90 per test, with an accuracy of 99 to 100%.

The task of tree felling requires constant mental agility in terms of simultaneously determining a plethora of factors relating to hazards, their solutions, the most appropriate manner in which to fell the tree, the best placement of the tree in order to expedite its subsequent extraction, location of fellow workers as well as possible obstacles which may damage the tree as it hits the ground. Consequently, one would expect that some degree of mental fatigue would manifest itself during the progression of either the day or week.

Initially it was considered that the lack of any change during the study could be attributed to one of two factors. Firstly, no actual temporal reduction in the subjects ability to undertake information processing tasks, (ie. mental fatigue), occurred. Secondly, the DSS information processing measure used was either too insensitive and/or inappropriate in this case.

However, one further explanation could be found in the notion of *recovery time* as described by Cameron (1974). Cameron delineates mental fatigue into two distinct types: acute and chronic. Acute mental fatigue was defined as being an aspect from which total recovery can occur under normal resting processes. Chronic mental fatigue represents the condition from which total recovery fails to transpire through normal resting (Okogbaa et al., 1994). This being the case then it was quite feasible that the fallers in the current study only experienced levels of acute mental fatigue from which they were able to quickly recover during periods of rest, both during the day and each night. Consequently no definable increase in mental fatigue could be identified during the study.

6.7.1 Summary

None of the six subjects recorded any significant change in either the number of tests attempted, or the percentage of the tests they correctly completed. Possible explanations for this finding could be; (1) no actual temporal reduction in the subjects ability to undertake information processing tasks, (ie. mental fatigue), occurred, (2) the DSS information processing measure used was either too insensitive and/or inappropriate in this case, or (3) that subjects only developed acute mental fatigue, and were able to totally recovery under normal resting processes. Consequently no definable increase in mental fatigue could be identified and/or measured during the study.

6.8 Ambient Thermal Environment

Work undertaken by Smith et al. (1986) investigating the effect of heat on forest worker performance, efficiency and safety identified a wbgt of 26.1°C as being the point at which temperatures impacted upon the worker. Temperatures above 26.1°C decreased productivity in manual workers by 5% and mechanised operators by 3%, and resulted in a slight but non-significant increase in unsafe behaviour. Kroemer (1991) found that mental performance in acclimatised people deteriorated once a wbgt of 30°C was reached. Ramsey (1995) also identified a wbgt temperature of 30°C as being the point where onset of performance decrements occurred.

Duchon and Hudock (1989) identified the wbgt range of 17.2°C to 22.7°C as being the temperature range within which safe work behaviour occurs. A significant increase in unsafe behaviour was recorded for temperatures above 22.7°C. Previous research has identified that the point at which temperature begins to significantly effect a workers mental and physical performance lies somewhere between 25°C to 30°C. The mean wbgt's for this study fall well below this level. In fact the highest points of the observed temperature ranges (24.1^{o}C), also fall short of the 25^{o}C to 30^{o}C level.

6.8.1 Summary.

Results from the current study tend to suggest that mean wbgts of 15.6 ± 1.5 ^{o}C (range 8.7 to 18.7 ^{o}C) and 18.2 ± 1.2^{o}C (range 14.8 to 24.1) had minimal effect on the subjects' performance levels.

6.9 Summary

This chapter has presented the discussion pertaining to each of the specific areas examined and their findings. The following chapter will present the conclusions of the research findings pertinent to each specific area examined, including suggested areas of future research identified during the course of this study.

CHAPTER 7: CONCLUSIONS

7.0 Introduction

This chapter presents the conclusions of the research in a brief and concise manner so as to present the crux of the research findings pertinent to each specific area of concern.

7.1 Physiological Indices

A mean working heart rate of 107 ± 5.5 $bt.min^{-1}$, an estimated mean working oxygen consumption of 1.5 ± 0.2 $l.min^{-1}$ and an estimated mean energy expenditure of 7.4 ± 0.8 $kcal.min^{-1}$ placed the current subjects working activities in the moderate to heavy workload category. Heart rate indices applied to the subjects recorded heart rate data, confirmed these findings, and subsequently rated rating the workload associated with the task of motor-manual tree felling and delimbing as moderate to heavy.

There was a significant ($p < 0.01$) increase in working heart rates when comparing morning (am) versus afternoon (pm) work periods. There was only a modest accompanying rise in ambient thermal environment in the afternoon, no significant change in productivity or cycle times and a significant increase in subjective fatigue ratings. The increased working heart rates have therefore been attributed to the subjects finding the work physically harder in the afternoon period as they strived to maintain their level of productivity in order to achieve their daily targets.

7.2 Production

Production did not appear to be negatively affected by the progression of the working day. This has been attributed to the effective use of structured and spontaneous rest breaks by the subjects, and the subjects natural self pacing mechanism. These two factors, combined with favourable terrain, combined to ensure that the work rate chosen was one that could be sustained for prolonged hard continuous work.

7.3 Terrain

The terrain encountered by the subjects during the study proved to be very favourable in terms of both minimal ground slopes and low hindrance undergrowth. Therefore it has been deduced that the impact of terrain on worker fatigue was minimal.

7.4 Hazard Analysis

Whilst the hazards in the current study occurred less often than in previously documented research, they followed national trends for felling and trimming. The fact that the subjects were on average very experienced fallers, combined with favourable terrain and a low hindrance undergrowth, contributed to produce lower than expected hazard ratios.

7.5 Rate of Perceived Exertion

No clear distinctions were found between subjects with high HR versus RPE correlations and those with low correlations in terms of identifiable trends related to either physiological, production, hazard, fatigue or subjective comfort measures.

7.6 Subjective Fatigue

Chronic fatigue appears to have been avoided, and acute fatigue mitigated to a large degree, by the use of the self-pacing mechanism combined with both structured and spontaneous rest breaks analogous with the work method adopted by motor-manual fallers. The subjects acute fatigue appeared to disperse during the period of rest attained during the night. Whilst their level of *fatigue* may have steadily increased as the day progressed, no discernible deterioration in performance, either in the form of *impairment* or *work decrement* was noted.

7.7 Body Part Discomfort

The lower back, hips and mid back were the most frequently recorded body parts experiencing discomfort. Severity ratings were predominantly slight (49%) to moderate (43%), with only eight percent being ranked as severe. The severity of the discomfort did not change during the progression of either the working day or week. The primary cause of the discomfort was the use of poor work postures, particularly when delimbing.

7.8 Thermal Comfort, Sensation, Skin Wettedness and Thermal Regulation.

Significant decreases in thermal comfort and sensation ratings occurred as the day progressed, accompanied by an increase in the skin wettedness rating and higher thermal regulation ratings for the majority of the fallers. The primary reason stated for these increased levels was an increase in both metabolic heat and ambient thermal temperature as the day progressed, which resulted in increased sweating, thereby making working conditions more unpleasant.

7.9 Digit Symbols Substitution

No significant change occurred in either the number of tests attempted, or the percentage of the tests correctly completed. Possible explanations for this finding could be; (1) no actual temporal reduction in the subjects ability to undertake information processing tasks, (ie. mental fatigue), occurred; (2) the DSS information processing measure used was either too insensitive and/or inappropriate in this case, or (3) that subjects only developed acute mental fatigue, and were able to totally recovery under normal resting processes. Consequently no definable increase in mental fatigue was identified during the study.

7.10 Ambient Thermal Environment

Results from the current study have suggested that mean wet bulb globe temperatures of 15.6 ± 1.5 ^{o}C (range 8.7 to 18.7 ^{o}C) and 18.2 ± 1.2^{o}C (range 14.8 to 24.1) had a minimal effect on the subjects' performance levels.

7.11 Summary

The research findings have been presented in their entirety. The following chapter outlines overall recommendations drawn from the research which apply to the New Zealand forest industry in its entirety.

CHAPTER 8: RECOMMENDATIONS

8.0 Introduction

This chapter outlines overall recommendations drawn from the research which apply to the New Zealand forest industry in its entirety. These recommendations are relevant to both the current, and future development of motor-manual felling and delimbing practices within the forest industry.

8.1 Heart Rate Indices

Heart rate indices should continue to be used as an effective means of determining the physiological strain of subjects in applied field situations. The use of heart rate indices gives the ability to cross-reference results to obtain an overall assessment of the workload of a task. The ability to collect real time data from a working subject with minimal personal discomfort or disruption of their normal work routine, ensures the collection of accurate and relevant data. The ease and speed of data interpretation ensures that results can be quickly and effectively used to aid decision making in terms of task modification or implementation of interventions aimed at mitigating any adverse physiological effects identified.

8.2 Rest Breaks

The use of both structured and spontaneous rest breaks should be encouraged and developed further by workers, contractors and forest companies. Rest breaks should not be seen by workers, contractors and forest companies as a hindrance to higher productivity due to increased down time. Rather, such breaks are recognised worldwide throughout many different industries, as a means of significantly reducing the physical and psychological impacts of undertaking hard physical work. The long term benefits resulting in the development of a sustainable workforce. This "worker sustainability", is vital if the future workforce is to evolve into highly skilled, safe and productive one.

8.3 Personal Protective Equipment

The continued development of effective forms of personal protective equipment (PPE) specifically tailored for the New Zealand forest industry is essential. Such development should specifically concentrate on the creation of PPE which offers both a high level of protection and user comfort, particularly in terms of heat dissipation. Only by doing so will user acceptance levels be increased and the true gains, in terms of reduced accident frequency and severity, be achieved within the forest industry.

8.4 Mechanisation

Mechanisation of the felling and delimbing phases of the harvesting operation should be the prime directive of the New Zealand forest industry. The attainment of such a goal would significantly reduce the forest worker exposure to hazards currently occurring in harvesting operations. Any such mechanisation must be implemented correctly, in order to avoid the creation of alternative forms of debilitating injuries.

8.5 Summary

This chapter has emphasised recommendations relevant to both the current, and future development motor-manual felling and delimbing practices within the forest industry. The following chapter will now discuss areas requiring future research.

CHAPTER 9: FUTURE RESEARCH

9.0 Introduction.

This chapter reviews principal research areas within the forest industry which, as a result of this current study, have been found somewhat lacking and therefore warrant further research.

9.1 Musculo-skeletal Disorders

Current commonly used motor-manual felling and delimbing methods are engendering severe rates of muscular-skeletal damage to the lower and mid back regions of forest workers. Poor work technique, muscle development, environmental factors and mental attitude all contribute to the creation of muscular-skeletal damage to the lower and mid back regions of forest workers. Future research should be directed towards objectively identifying these factors, and the role that each plays in the creation of muscular-skeletal damage to forest workers backs. Only by obtaining such objective and specific data, can effective interventions be developed which specifically target each component of this harmful scenario.

9.2 Fluids and Nutrition

Further research needs to undertaken to objectively determine the impact of correct fluid replacement and nutrition on forest worker fatigue, safety and productivity. These two factors have long been advocated as cheap and effective means of significantly reducing the physical and psychological impacts of undertaking hard physical work. Sadly however, their current use and comprehension within the New Zealand forest industry, is somewhat lacking to say the least.

9.3 Mental Workload.

Further research needs to be undertaken in order to develop an effective "operational solution" to the measurement of mental fatigue in applied field settings, such as those found within the forest industry. Currently available techniques appear to be heavily biased towards sedate occupations such as pilots, air traffic controllers and other white collar workers. Accordingly, measures currently perceived as being portable tend to be based around cardiac sinus arrhythmia or the mental undertaking of complex mathematical calculations.

Such measures are unsuitable for use within the forest industry due to two key factors. Firstly the harsh working environments encountered in many forest locations frequently damage the often delicate measuring instruments, resulting in either lost data, or the collection of atypical data since data can only be collected when conditions are optimal. Secondly, the educational composition of the New Zealand forest worker has historically been at the lower end of the scale. Consequently measures containing mathematical equations or complex forms of text are not well received. Therefore, if further advances are to be made in the determination of forest worker mental workload, considerable effort is required to develop a convenient and accessible "operational solution".

9.4 Summary

This chapter has identified key areas within the New Zealand forest industry which require further research. The area of concern has been detailed along with a focus for any such future research should it eventuate.

REFERENCES

Abeli, W.S. and Malisa, E.J. 1994. Productivity and workload when cutting with peg and raker toothed crosscut saws. In proceedings of the International IUFRO/NEFU/FAO Seminar on Forest Operations Under Mountainous Conditions with special attention to Ergonomics, Accessibility and Environmental Protection. Harbin, P.R. of China.

Alluisi, E.A. and Morgan, B.B. 1982. Temporal factors in human performance and productivity, Chapter 6. In E.A. Alluisi and E.A. Fleishman (Eds.), Human performance and productivity, Volume 3: Stress and Performance Effectiveness. Hillsdale, NJ: Lawrence Erlbaum.

Andersson, E. 1986. Introduction of a four-wheel wagon for manual transportation of logs in a timber depot in India: A work physiology study. Research Notes Nr 90/87, Swedish University of Agricultural Sciences, Faculty of Forestry, Department of Operational efficiency, Garpenberg, Sweden.

Anon, (1944) Relative humidity tables. Meteorological Office, Wellington. Met 331.

Apud, E., Elgstrand, K. and Teljstedt, H. 1972. An outline for the initiation of activities of ergonomics and occupational health within Chilean forestry. Department of Operational Efficiency Research Notes Nr 53, Royal College of Forestry, Stockholm, Sweden.

Apud, E., Bostrand, L., Mobbs, I.D. and Strehlke, B.(Eds.) 1989. Human Biological Methods for Ergonomics Research in Forestry. In Guide-lines on Ergonomic Study in Forestry. International Labour Organisation, Geneva.

Apud, E., Coffre, M., Vergara, N. and Burgos, R. 1990. Workload and output in different activities during final cut. in Proceedings P3.03 Ergonomics XIX World Congress IUFRO, Montreal, Canada.

Apud, E. and Valdes, S. 1993. Ergonomics in Chilean forestry. *Unasylva International journal of forestry and forest industries*. **44**, (172). Food and agriculture organisation, United Nations, Rome , Italy.

Apud, E. and Valdes, S. 1994. Physical Workload and Output for Planting on Grounds with Different Slopes. Proceedings of International IUFRO/NEFU/FAO Seminar on Forest Operations Under Mountainous Conditions with special attention to Ergonomics, Accessibility and Environmental Protection. Harbin, P.R. of China..

Armstrong. L.E., Szlyk, P., Sils, I.V., De Luca, J.P., O'Brien, C. and Hubbard, R.W. 1991. Prediction of the exercise-heat tolerance of soldiers wearing protective overgarments. *Aviation, Space and Environmental Medicine*, July, 673 - 677.

Åstrand, I. 1967. Degree of strain during building work as related to individual aerobic capacity. *Ergonomics*, **10**, p 293.

Åstrand, I.., Guharay, A. and Wahren, J. 1968. Circulatory responses to arm exercise with different arm positions. *Journal of Applied Physiology*, **25**, 528 - 538.

Åstrand, P.O. and Saltin, B. 1961. Maximal oxygen uptake and heart rate in various types of physical activity. Journal of Applied Physiology, **16**, 977 - 981.

Åstrand, P.O. and Rodahl, K.,1986. Textbook of work physiology. New York, McGraw Hill Book Company.

Aunola, S., Nykyri, R. and Rusko, H. 1979. Strain of employees in the manufacturing industry in Finland. *Ergonomics*, **22**, (1), 29 -36.

Bakkevig, M.K. and Nielsen, R. 1995. The impact of activity level on sweat accumulation and thermal comfort using different underwear. *Ergonomics*, **38**, (5), 926 - 939.

Bartley, S.H. and Chute, E.F. 1947. Fatigue and the impairment of man. New York. McGraw Hill Book Company.

Becker, W.G.E., Ellis, H., Goldsmith, R. and Kaye, A.M. 1983. Heart rates of surgeons in theatre. *Ergonomics*, **26**, (8), 803 - 807.

Below, P.R., Mora-Rodriguez, R., Gonzalez-Alonso, J. and Coyle, E.F. 1995. Fluid and carbohydrate ingestion independently improve performance during 1 h of intense exercise. *Medicine and Scienec in Sports and Exercise*, **27**, (2), 200 - 210.

Benor, D. and Shvartz, E. 1971. Effect of body cooling on vigilance in hot environments. *Aerospace Medicine*, **42**, 727 - 730.

Bombosch, F.E. 1994. The workload-stress-situation of forest workers during chainsaw operations. In XII World Congress on Agricultural Engineering: Volume 2. Milan, Italy.

Borg, G. 1970. Perceived exertion as an indicator of somatic stress. *Scandinavian Journal of Rehabilitation Medicine*, **2**, (92).

Borg, G. 1982. A category scale with ratio properties for intermodal and interindividual comparisons. In: H.G. Geissler and P. Petzold (Eds), Psychophysical judgement and the process of perception. VEB Deutcher Verlag der Wissenschaften, Berlin.

Borg, G. 1985. An introduction to Borg's RPE scale. McNaughton and Gunn Inc, Michigan.

Borg, G. 1986. Psychophysical studies of effort and exertion: some historical, theoretical and empirical aspects. *Wenner Gren Symposium International Series*, **46**, 3- 12.

Botsford, J.A. 1971. A wet globe thermometer for environmental heat measurement. *American Industrial Hygiene Association Journal*, January. 1 - 10.

Bradford, S., Isler, R., Kirk, P.M. and Parker, R.J. 1992. Conspicuous colours for loggers safety clothing. Logging Industry Research Organisation Report, **17**, (11).

Brzezinska, Z. 1968. The problem of general fatigue in jobs where active work is associated with a need for vigilance. *Prace Centralnego Instytut Ochrony Pracy*, **18**, (59), 341 - 351.

Byers, J. 1994. Career Aspirations and Industry Perceptions of Polytechnic Forestry Students - A Pilot Study. Logging Industry Research Organisation Report, **19**, (12).

Byers, J. S. 1995a. New Zealand Forest Owners' Association - Forestry Workforce Census 1994. Logging Industry Research Organisation Project Report 56

Byers, J. S. 1995b. LIRO Studies Forestry Students. *New Zealand Forestry*, May 1995.

Byers, J.S. 1996. Pers. comm.

Byers and Adams 1995. Otago Southland Forest Workforce - Five Years Later. Logging Industry Research Organisation Project Report No 58.

Cameron, C. 1974. A theory of fatigue. In, Man under Stress, Proceedings of the 9th annual conference of the Ergonomics Society of Australia and New Zealand, Taylor and Francis.

Capodaglio, P., Capodaglio, E.M. and Bazini, G. 1995. Tolerability to prolonged lifting tasks assessed by subjective perception and physiological responses. *Ergonomics*, **38**, (10), 2118 - 2128.

Chad, K.E. and Brown, J.M.M. 1995. Climatic stress in the workplace; Its effect on thermoregulatory responses and muscle fatigue in female workers. *Applied Ergonomics*, **26**, (1), 29 - 34.

Chaffin, D.B. and Andersson, G.B.J. 1984. Occupational Biomechanics. New York, Wiley.

Chiles, W.D., Iampietro, P.F. and Higgins, E.A. 1972. Combined effects of altitude and high temperature on complex performance. *Human Factors*, **14**, 161 - 172.

Corlett, E.N. and Bishop, R.P. 1976. A technique for assessing postural discomfort. *Ergonomics*, **19**, (2), 175 - 182.

Costa, G., Berti, F. and Betta, A. 1989. Physiological cost of apple-farming activities. *Applied Ergonomics*, **20**, (4), 281 - 286.

Christofolini, A., Pollini, C., Maggi, B., Costa, G., Colombini, D., Occhipinti, E., Bovenzi, M. and Peretti, S. 1990. Organisational and ergonomic analysis of forest work in the Italian alps. *International Journal of Industrial Ergonomics*, **5**, (3), 197 - 209.

Cumming, G.R., and Glenn, J., 1977. Evaluation of the Canadian home fitness test in middle-aged men. *Canadian Medical Association Journal,* **177**, 346 - 349.

Diament, M.L., Goldsmith, R., Hale, T. and Kelman, G.R. 1968. An assessment of habitual physical activity. *Journal of Physiology*, **200**, 44 - 45.

Duchon, J.C. and Hudock, S.D. 1989. Effects of environmental stressors on vigilance performance. Bureau of Mines information Circular 9224.

Durnin, J.V.G.A. and Passmore, R. 1967. Energy, Work and Leisure. London, Heinemann.

El-Sayed, M., Rattu, A.J.M. and Roberts, I. 1995. Effects of carbohydrate feeding before and during prolonged exercise on subsequent maximal exercise performance capacity. *International Journal of Sport Nutrition*, **5**, (3), 215 - 224.

Evans, W.j., Winsmann, F.R., Pandolf, K.B., and Goldman, R.F., 1980. Self-paced hard work comparing men and women. *Ergonomics*, **23**, 613 - 621.

Evanson, T. 1995. An Evaluation of Two Hahn Harvesters Working in Clearfell Cable Operations. Logging Industry Research Organisation Report, **20**, (9).

Evanson, T, and Riddle, A. 1994. Evaluation of a Waratah Hydraulic Tree Harvester Model HTH 234. Logging Industry Research Organisation Report **19**, (3).

Evanson, T., Riddle, A. and Fraser, D. 1994. An Evaluation of a Waratah Model HTH 234 Harvester in a Cable Hauler Operation. Logging Industry Research Organisation Report, **19**, (5).

Faff, J. and Tutak, T. 1989. Physiological responses to working with fire fighting equipment in the heat in relation to subjective fatigue. *Ergonomics*, **32**, (6), 629 - 638.

Fine, B.J. and Kobrick, J.L. 1978. Effects of altitude and heat on complex cognitive tasks. *Human Factors*, **20**, 115 - 122.

Fibiger, W. 1980. Some methodological problems of mental workload evaluation. In Proceedings of the International Union of Forestry Research organisations Seminar, Design of work systems in forestry- with special regard to psychological aspects. Garpenburg, Sweden, September 21 - 26.

Fibiger, W,. and Henderson, M, E,. 1982. Physiological inputs to motor-manual techniques of thinning radiata pine. *New Zealand Journal of Forestry Science*, **12**, (2), 162 - 170.

Fibiger, W,. and Henderson, M, E,. 1984. Physical workload in thinning pine plantations. *Australian Forest Research.* **14** pp135-146.

Fleishman, E. A. and Hogan, J.C. 1978. Taxonomic methods for assessing the physical requirements of jobs: the physical abilities analysis approach. Technical report 301/R7-8-6, Advanced Research Resources Organisation, Bethesda, MD.

Food and Agricultural Organisation of the United Nations. 1974. Logging and Log Transport in Man Made Forests in Developing Countries. FAO/SWE/TF 116, Rome.

Food and Agriculture Organisation 1992. Introduction to Ergonomics in Forestry in Developing Countries. FOA Forestry Paper 100.

Ford, D. 1995. An ergonomic analysis of manual versus chainsaw high ladder pruning of *Pinus radiata* in New Zealand. A thesis submitted in partial fulfilment of the requirements for the degree of Master of Philosophy at Massey University.

Fordham, M., Appenteng, K. and Goldsmith, R. 1978. The cost of work in medical nursing. *Ergonomics*, **21**, (5), 331 - 342.

Forestry Facts and Figures 1994. A publication of the New Zealand Forest Owners Association. Wellington.

Forestry Facts and Figures 1995. A publication of the New Zealand Forest Owners Association. Wellington.

Frings-Dresen, M.H.W., Kemper, H.C.G., Stassen, A.R.A. Crolla, I.F.A.M. and Markslag, A.M.T. 1995. The daily work load of refuse collectors working with three different collecting methods: a field study. *Ergonomics*, **38**, (10), 2045 - 2055.

Fuller, F.H. and Smith, P.E. 1981. Evaluation of heat stress in a hot workshop by physiological measurements. *American Industrial Hygiene Association Journal*, **42**, 32 - 36.

Gadd, J. and Sowerby, T. 1995. The Waratah 240 HTH-Debarking and Logmaking Tree-Length Eucalyptus Regnans. Logging Industry Research Organisation Report, **20**, (1).

Gamberale, F. 1972. Perceived exertion, heart rate, oxygen uptake and blood lactate in different work operations. Ergonomics, **15**, 545 - 554.

Gamberale, F. 1990. Perception of effort in manual materials handling. *Scandinavian Journal of Work Environment and Health*, **16**, (1), 59 - 66.

Ganguli, S. and Datta, S.R. 1975. Prediction of energy cost from peak heart rate in lower extremity amputees. *Biomechanical Engineering*, **10**, 52 - 55.

Garg, A., and Saxena, U. 1979. Effects of lifting frequency and technique on physical fatigue with special reference to psychophysical methodology and metabolic rate. *American Industrial Hygiene Association*, **40**, 494 - 503.

Gaskin, J.E., 1986. Ergonomics - A science to improve the safety and productivity of logging workers. Logging Industry Research Association Report No.30.

Gaskin, J.E., 1989. The development of protective legwear for chainsaw operators. In Proceedings of Clothing and Textiles Symposium, Policy and research for the 1990s. University of Otago, Dunedin.

Gaskin, J.E. 1990. Evaluation of two motor-manual delimbing techniques. *International Journal of Industrial Ergonomics*. **5**, 211 - 218.

Gaskin, J.E., O'Leary, C and Slappendel, C. 1988. Evaluation of two motor-manual delimbing techniques. Logging Industry Research Association Report **13**, (10).

Gaskin, J.E and Guild, B. 1989. The workload of motor manual delimbing. Logging Industry Research Organisation Report **14**, (15).

Gaskin, J.E.; Parker, R.J. 1993. Accidents in Forestry and Logging Operations in New Zealand, Unasylva 172, **44**, 19 - 24.

Gellerstedt, S. 1991. Forest workers without back problems. Swedish University of Agricultural Sciences, Small Scale Forestry, Newsletter Vol 2.

Genaidy, A.M., Houshyar, A. and Asfour, S.S. 1990. Physiological and psychological responses to static, dynamic and combined arm tasks. *Applied Ergonomics*, **21**, (1), 63 - 67.

Gibson, R. 1994. Attitudes towards safety in the New Zealand forest industry. Logging Industry Research Organisation Report 53.

Goldsmith, R., O'Brien, C.O., Tan, G.L.E., Smith, W.S. and Dixon, M 1978. The cost of work on a vehicle assembly line. *Ergonomics*, **21**, (5), 315 - 323.

Golsse, J.M. and Rickards, J. 1990. Woodlands equipment maintenance: an analysis of mechanical labour energy expenditure. *International Journal of Industrial Ergonomics*, **5**, (3), 243 - 253.

Grandjean, E. 1988. Fitting the Task to the Man. Taylor and Francis, London.

Grandjean, E. 1979. Fatigue in industry. *British Journal of Industrial Medicine*, **36**, (3), 175 - 186.

Grether, W.F., Harris, C.S., Mohr, G., Nixon, C., Ohlbaum, M., Sommer, H., Thaler, V. and Veghte, J. 1971. Effects of combined heat, noise and vibration stresses on human performance and physiological functions. *Aerospace Medicine*, **42**, 1092.

Grether, W.F. 1973. Human performance at elevated environmental temperatures. Aerospace Medicine, 44, 747 - 755.

Gun, R.T and Budd, G.M. 1995. Effects of thermal, personal and behavioural factors on the physiological strain, thermal discomfort and productivity of Australian shears in hot weather. *Ergonomics*, **38**, (7), 1368 - 1384.

Hagen, K.B., Vik, T., Myhr, N.E., Opsahl, P.A. and Harms-Ringdahl, K. 1993. Physical workload, perceived exertion, and output of cut wood as related to age in motor-manual cutting. *Ergonomics*, **36**, (5), 479 - 488.

Hagen, K.B. and Harms-Ringdahl, K. 1994. Ratings of perceived thigh and back exertion in forest workers during repetitive lifting using squat and stoop techniques. *Spine*, **19**, (22), 2511 - 2517.

Harnett, D.L. 1982. Statistical methods, 3rd edition. Massachusetts: Addison-Wesley.

Harstela, P. 1990. Work postures and strain of workers in Nordic forest work: A selective review. *International Journal of Industrial Ergonomics*. **5**, (3), 219 - 226.

Hartsough, B. and Parker, R.J. 1993. Pruning Douglas Fir. Logging Industry Research Organisation Technical Note 10.

Henderson, M. 1984. Physiological workload in Australian hardwood fallers: Implications for human error. In proceedings "Human Resources in Logging" New Zealand Logging Industry Research Association, New Zealand.

Hettinger, T. 1960. Angewandte Ergonomie. Bartmann-Verglag, Frechen, BRD.

Hill, S. and Everson, T. 1995. The Trinder Static Delimber in a Ground Based Clearfell Operation. Logging Industry Research Organisation Report, **20**, (10).

Hughes, A.L. and Goldman, R.F. 1970. Energy cost of hard work. *Journal of Applied Physiology*, **29**, 570 - 572.

Imbeau, D., Desjardins, L., Dessureault, P.C., Reil, P. and Fraser, R. 1995. Oxygen consumption during scaffold assembling and disassembling work: Comparison between field measurements and estimation from heart rate. *International Journal of Industrial Ergonomics*, **15**, 247 - 259.

Jianghong, Z. and Long, T. 1994. An evaluation of comfort of a bus seat. Applied *Ergonomics*, **25**, (6), 386 - 392.

Johansson, J.Å. 1994. Work-related and non-work-related musculoskeletal symptoms. Applied Ergonomics, **25**, (4), 248 - 251.

Johansson, S.E. and Ljunggren, G. 1989. Perceived exertion during a self-imposed pace of work for a group of cleaners. *Applied Ergonomics*, **20**, (4), 307 - 312.

Johansson, S.E. and Borg, G. 1993. Perception of heavy work operations by tank truck drivers. *Applied Ergonomics*, **24**, (6), 421 - 426.

Johnson, D. and Tabor, F.C. 1987. Body of Work. Northern Logger and Timber Processor, May, 8 - 18.

Hartley, L.R., Arnold, P.K., Smythe, G and Hansen, J. 1994. Indicators of fatigue in truck drivers. *Applied Ergonomics*, **25**, (3), 143 - 156.

Kahkonen, E., Swai, D., Dyauli, E. and Monyo, R. 1992. Estimation of heat stress in Tanzania by using ISO heat stress indices. *Applied Ergonomics*, **23**, (2) 95 - 100.

Karhu, O., Kansi, P. and Kuorinka, I. 1977. Correcting work postures in industry: a practical method for analysis. *Applied Ergonomics*, **8**, (4), 199 - 201.

Karrasch K. and Muller, E.A. 1951. Das verhalten der pulsfrequenz in der erholungsperiode nach korperlicher arbeit. *Arbeits-physiologie*, 14, 369 - 382.

Karvonen, J., Cwalbinska - Moneta, J. and Saynajakangas,S. 1984. Comparison of hearts measured by ECG and microcomputer. *The physician and sportsmedicine*, **12**, 65 - 69.

Keawplang, C., Ngamachi, M., Intaranont, K. and Buripand, N.B. 1993. Physical workload of handling tasks in a foundry shop in Thailand. The Ergonomics of Manual Work. The proceedings of the International Ergonomics Association World Conference on Ergonomics of Material Handling and Information Processing at Work. Warsaw, Poland. Taylor and Francis, London.

Kihlberg, S., Lindbeck, L. and Kjellberg, A. 1994. Pneumatic tool torque reactions. *Applied Ergonomics*, **25**, (4), 242 - 247.

Kirk, P.M. 1992. Safety-Link Multi-Monitor Emergency Alarms Systems. Logging Industry Research Organisation Technical Note TN-8, August.

Kirk, P.M. 1993. Earmuff effectiveness against chainsaw noise over a 12 month period. *Applied Ergonomic,* **24**, (4), 279 - 284.

Kirk, P.M. 1995. Dehydration - The dry horror's. Logging Industry Research Organisation Technical Note, TN-16.

Kirk, P.M. and Parker, R.J. 1993a. Tough Tasks. *NZ Forest Industries*, June.

Kirk, P.M. and Parker, R.J. 1993b. The impact of spiked boots on the safety, workload and productivity of breaking-out. Logging Industry Research Organisation Report, **18,** (3).

Kirk, P.M. and Parker, R.J. 1994a. The Effect of Spiked Boots on Logger Safety, Productivity and Workload. *Applied Ergonomics*, **25**, (2), 106 - 111

Kirk, P.M. and Parker, R.J. 1994b. Physical Demands of Steep Terrain Forestry Work in New Zealand. In proceedings of the International IUFRO/NEFU/FAO Seminar on Forest Operations Under Mountainous Conditions with special attention to Ergonomics, Accessibility and Environmental Protection. Harbin, P.R. of China.

Kirk, P.M. and Sullman, M.J.M. 1995. An ergonomic investigation of hauler breaker-outs. Logging Industry Research Organisation Report 55.

Kirk, P.M. and Parker, R.J. 1996. An ergonomic evaluation of Douglas Fir manual pruning in New Zealand. *Journal of Forest Engineering*, **7**, (2), 51 - 58.

Klen, T. and Väyrynen, S. 1984. The role of personal protection in the prevention of accidental injuries in logging work. *Journal of Occupational Accidents*, **6**, 263 - 275.

Kukkonen-Harjula, K. 1984. Oxygen consumption of lumberjacks in logging with a power saw. *Ergonomics*, **27**, (1), 59 -65.

Kroemer, K.H.E. 1991. Working strenuously in heat, cold, polluted air and at altitude. *Applied Ergonomics*, **22**, (6), 385 - 389.

Krueger, G.P. 1991. Sustained Military Performance in Continuos Operations: Combatant Fatigue, Rest and Sleep Needs. United States Army Aeromedical Research Laboratory Report No 91 - 19.

Laird, I., Pack, R. and Carr, D. 1992. A survey on the use and non-use of respiratory protective equipment. In Proceedings of New Zealand Ergonomics Society Annual Conference, 26 -27 March.

Lammert, O. 1972. Maximal aerobic power and energy expenditure of Eskimo hunters in Greenland. *Journal of Applied Physiology*, **33**, 184 - 188.

Lark, J. 1991. Risk Taking: Perspective's and Intervention. *Professional Safety*, November, 36 - 39.

Le Blank, J.A. 1957. Use of heart rate as an index of work output. *Journal of Applied Physiology*, **10**, 275 - 280.

Le Heron, R, B. 1985. Changing private-state relations of exotic afforestation, 1960-1985. in Proceedings of the 13th Geography Conference. New Zealand Geographical Society, Christchurch, New Zealand

Leger, L. and Thivierge, M. 1988. Heart rate monitors: validity, stability and functionality. *The Physician and Sportsmedicine*, **16**, 142 - 151.

Legg, S.J., Eder, G.S. and Colrain, I.M. 1991. Slip crew fatigue in long distance flights. In Proceedings of the 9th Commonwealth Defence Science Organisation Conference General Symposium, New Zealand, 25 - 28 February.

Legg, S. J., Perko, L. and Campbell, P. 1995. Subjective perceptual methods for comparing backpacks. In Ergonomics Tomorrow: Adapting the Future. Proceedings of the sixth Conference of the New Zealand Ergonomics Society. Lincoln, Christchurch, New Zealand.

Levine, L., Evans, W., Winsmann, F.R. and Pandolf, K.B. 1982. Prolonged self-paced hard physical exercise comparing trained and untrained men. *Ergonomics*, **5**, (5), 393 - 400.

Lewis, M.I., Meese, G.B. and Kok, R. 1983. The effects of moderate cold and heat stress on the potential work performance of industrial workers. Part IV: Performance in physiological responses of trained workers in relation to eight environmental conditions. (National Building Research Institute Council for Scientific and Industrial research, Pretoria), CSIR research report 589.

LIRA and Swedfor Consultancy 1980. Development of safe felling and delimbing with chainsaws. Logging Industry Research Association Report 14.

Ljungberg, A.S., Gamberale, F. and Kilbom, Å. 1982. Horizontal lifting - physiological and psychological responses. *Ergonomics*, **25**, 741 - 757.

Lockhart, J. 1966. Effects of body and hand cooling on complex manual performance. *Journal of Applied Psychology*, **50**, 57 - 59.

Lundgren, N.P. 1946. Physiological effects of time schedule work on lumber worker. *Acta Physiolcaogi Scandinavica*, **13**, (41), 1 - 137.

Lyon, C and K Raymond 1993. A Survey of the Logging Industry - 1991. Logging Industry Research Organisation Report, **18**, (1).

Maas, S., Kok, M.L.J., Westra, H.G. and Kemper, H.C.G. 1989. The validity of the use of heart rate in estimating oxygen consumption in static and in combined static/dynamic exercise. *Ergonomics*, **32**, (2), 141 - 148.

Mackie, R.R., and O'Hanlon, J.F. 1976. A study of the combined effects of extended driving and heat stress on driver arousal and performance. *Vigilance: Theory, Operational Performance and Physiological Correlates.* edited by R.R. Mackie. (Plenum Press, New York), 537 - 558.

Macworth, N.H. 1961. Researches on the measurement of human performance, Selected Papers on Human Factors in the Design and Use of Control Systems. (Dover - New York), 174 - 331.

Maleta, B.P. and Sood, K.G. 1984. Physical workload and productivity in timber harvesting: A case study in the mountain forests of West Bengal. *The Indian Forester*, **110**, (3), 274 - 292.

Malhotra, M.S., Gupta, J.S. and Rao, R.M. 1963. Pulse count as a measure of energy expenditure. *Journal of Applied Physiology*, **18**, 999 - 1006.

Mascord, D.J. and Heath, R.A. 1992. Behavioural and physiological indices of fatigue in a visual tracking task. *Journal of Safety Research*, **23**, (1), 19 - 25.

McCormick, E.J. and Tiffin, J. 1974. Industrial Psychology. Englewood Cliffs, NJ: Prentice Hall.

Meese, G.B., Kok, R., Lewis, M.I. and Wyon, D.P. 1981. The effects of moderate cold and heat stress on the potential work performance of industrial workers. Part II: Performance of tasks in relation to air temperature under eight environmental conditions. (National Building Research Institute Council for Scientific and Industrial research, Pretoria), CSIR research report 318.

Michael, E.D., Hutton, K.E., and Horvath, S.M. 1960. Cardiorespiratory responses during prolonged exercise. *Journal of Applied Physiology*, **16**, p 997.

Millard-Stafford, M., Sparling, P.B., Rosskopf, L.B., Snow, T.K., Dicarlo, L.J. and Hinson, B. 1995. Fluid intake in male and female runners during a 40-km field run in the heat. *Journal of Sports Science's*, **13**, (3), 257 - 263.

Minard, D., Goldsmith, R., Farrier JR, B. H. 1971. Physiological evaluation of industrial heat stress, *American Industrial Hygiene Association Journal,* **32**, 17-28.

Mital, A., Bishu, R.R. and Manjunath, S.G. 1991. Review and evaluation of techniques for determining fatigue allowances. *International Journal of Industrial Ergonomics*, **8**, (2), 165 - 178.

Montoliu, M.A., Gonzalez, V. and Palenciano, L. 1995. Cardiac frequency throughout a working shift in coal miners. *Ergonomics*, **38**, (6), 1250 - 1263.

Mortagy, A.K. and Ramsey, J.D. 1973. Monitoring performance as a function of work/rest schedule and thermal stress. *American Industrial Hygiene Association Journal*, **34**, 474 - 480.

Myles, W.S., Eclache, J.P. and Beaury, J. 1979. Self pacing during sustained, repetitive exercise. *Aviation, Space and Environmental Medicine*, **50**, 921 -924.

Nielsen, R. and Meyer, J. 1987. Evaluation of metabolism from heart rate in industrial work. *Ergonomics*, **30**, 563 - 572.

NIOSH, 1981. Work practices guide for manual lifting, *NIOSH Technical Report*, U.S. Government Printing Office, Washington D.C.

Nwuba, E.I.U. and Kaul, R.N. 1987. Energy requirements of hand tools for wood cutting. *Journal of Agricultural Engineering Research*, **36**, (3), 207 - 215.

Nunneley, S.A., Dowd, P.J., Myhre, L.G. and Stribley, R.F. 1978. Physiology and psychological effects of heat stress simulating cockpit conditions. *Aviation, Space and Environmental Medicine*, **49**, 763 - 767.

Öberg, T., Sandsjö, L. and Kadefors, R. 1994. Subjective and objective evaluation of shoulder muscle fatigue. *Ergonomics*, **37**, (8), 1323 - 1333.

Ohnaka, T., Tochihara, Y. and Muramatsu, T. 1993. Physiological strains in hot-humid conditions while wearing disposable protective clothing commonly used by the asbestos removal industry. *Ergonomics*, **36**, (10), 1241 - 1250.

Okogbaa, G.O., Shell, R.L. and Filipusic, D. 1994. On the investigation of the neurophysiological correlates of knowledge worker mental fatigue using the EEG signal. *Applied Ergonomics*, **25**, (6), 355 - 365.

O'Leary, C.M., 1988. A biomechanical analysis of two delimbing techniques. A dissertation in partial fulfilment of the requirements for the degree of Bachelor of Forestry Science at the School of Forestry Science, University of Canterbury, New Zealand.

O'Leary, C.M., 1992. Pers. Comm.

Östberg, O. 1979. Risk Perception and Work Behaviour in Forestry: Implications for Accident Prevention Policy. Accident Analysis and Prevention, Vol 12, 189 - 200.

Pandolf, K.B. 1978. Influence of local and central factors in dominating rated perceived exertion during physical work. *Perceptual and Motor Skills*, **46**, 683 - 698.

Parker, R.J. 1991. Loggers' ranking of felling and trimming hazards. Logging Industry Research Association Report, **16**, (4).

Parker, R.J., 1992. Ergonomics Research in the New Zealand Logging Industry. New Zealands Ergonomics. **7** (3).

Parker, R.J. 1994. Analysis of lost time accidents - 1993 Logging. Logging Industry Research Organisation Report.**19**,(9).

Parker, R.J. 1995. Analysis of Lost Time Logging Accidents - 1994. Logging Industry Research Organisation Report **20** (11).

Parker, R.J; Cossens, P, and Strang, M, 1993. Human Factors in Log Making. Logging Industry Research Organisation Report **18**, (17).

Parker, R.J. and Kirk P.M. 1993a. Physiological Workload of the New Zealand Forest Worker. New Zealand Institute of Forestry Conference Proceedings, Napier, May 1993.

Parker, R.J.; Kirk, P.M. 1993b. Felling and delimbing hazards. Logging Industry Research Organisation Report. **18,** (22).

Parker, R.J. and Kirk, P.M. 1994. Physiological workload of forest work. New Zealand Logging Industry Research Organisation Report. **19**, (4).

Parsons, K.C. 1993. Human Thermal Environments. Taylor and Francis. London.

Passmore, R. and Durnin, J.V.G.A. 1955. Human Energy Expenditure. *Physiological reviews.* **35**, 801 - 840.

Paulo de Souza, A., Minette, L.J. and Fiedler, N.C. 1995. Analysis of ergonomic factors in timber cutting operations using chainsaw. Caring for the Forest: Research in a Changing World. Proceedings of IUFRO XX World Congress, Tampere, Finland.

Payne, P.R., Wheeler, E.F. and Salvosa, C.B. 1971. Prediction of daily energy expenditure from average pulse rate. *American Journal of Clinical Nutrition*, **24**, 1164 - 70.

Poschen. P. 1993. Forestry, a safe and healthy profession ?.Unasylva 172, **44**, 3 - 12.

Poulton, E.C. and Kerslake, D.M. 1965. Initial stimulating effect of warmth upon perceptual efficiency. *Aerospace Medicine*, **36**, 29 - 32.

Poulton, E.C. and Edwards, R.S. 1974. Interactions and range effects in experiments on pairs of stressors: Mild heat and low-frequency noise. *Journal of Experimental Psychology*, **102**, 621 - 628.

Poulton, E.C., Edwards, R.S. and Colquhoun, W.P. 1974. Interaction of the loss of a night's sleep with mild heat: task variables. *Ergonomics*, **17**, 59 - 73.

Prebble, R.L., 1981. Criteria for protective clothing for chainsaw operators. Logging Industry Research Association Report **6**, (3).

Prebble, R.L., 1984. A review of logging accident statistics in New Zealand. In Human Resources in Logging. Proceedings of a seminar held in Rotorua, June 1984. 65 - 71.

Quinn, K.J.D., 1974. Eton four-figure mathematical and statistical tables. Eton Press Ltd. Christchurch, New Zealand.

Radjef, Y. 1972. Critical study of methods of assessing fatigue for occupational health purposes. Faculte de Medecine St. Antoine, Universite de Paris, Paris.

Ramsey, J.D., Dayal, D. and Ghahramani, B. 1975. Heat stress limits for the sedentary worker. *American Industrial Hygiene Association Journal*, **36**, 259 - 265.

Ramsey, J.D. and Pai, S.B. 1975. Sedentary work by females in hot environments, *Proceedings 19th Annual Meeting of the Human Factors Society*, 498 - 500.

Ramsey, J., and Kwon, Y. 1988. Simplified decision rules for predicting performance loss in heat. *Proceedings on heat stress indices*. Luxemborg: Commission of the European Communities.

Ramsey, J.D. 1995. Task performance in heat: a review. *Ergonomics*, **38**, (1), 154 - 165.

Razmjou, S. and Kjellberg, A. 1992. Sustained attention and serial responding in heat: Mental effort in the control of performance. Aviation, Space and Environmental Medicine, **62**, (7), 594 - 601.

Reilly, T. and Thomas, V. 1979. Estimated daily energy expenditures of professional association footballers. *Ergonomics*, **22**, (5), 541 - 548.

Robinson, D.G., Trites, D.G. and Banister, E.W. 1993. Physiological effects of work stress and pesticide exposure in tree planting by British Columbia silviculture workers. *Ergonomics*, **36**, (8), 951 - 961.

Rodahl, K. 1960. Nutritional Requirements under Artic Conditions, Norsk Polarinstitutt Skrifter No. 118, Oslo University Press, Oslo.

Rodahl, K,. 1989. The Physiology of Work. Taylor and Francis. London.

Rodahl, K. and Guthe, T, 1988. Physical Limitations of Human Performance in Hot Environments, with Particular Reference to Work in Heat-Exposed Industry. In "Environmental Ergonomics; Sustaining Human Performance in Harsh Environments". Mekjavic, I.B., Banister, E.W. and Morrison, J.B. (Eds). Taylor and Francis, Philadelphia.

Rodahl, K., Vokac, Z., Fugelli, P., Vaage, O., and Maehlum, S. 1974. Circulatory strain, estimated energy output and catecholmaine excretion in Norwegian coastal fishermen. *Ergonomics*, **17**, 585 - 602.

Rolev, A.M., 1990. Siwork 3 Version 1.2: Work Study and Field Data Collection System. Danish Institute of Forest Technology, Amalievej 20, DK-Frederiksberg C, Denmark.

Rosa, R.R. and Colligan, M.J. 1988. Long work days versus rest days: Assessing fatigue and alertness with a portable performance battery. *Human Factors*, **30**, (3), 305 - 317.

Roscoe, A.H. 1993. Heart rate as a psychological measure for in - flight workload assessment. *Ergonomics*, **36**, (9), 1055 - 1062.

Ryan, G.A. 1989. The prevalence of musculo-skeletal symptoms in supermarket workers. Ergonomics, **32**, 359 - 371.

Sabel, I. 1986. Occupational health services for workers in the state forest of Baden-Würtemberg. In proceedings of the seminar Occupational Health and Rehabilitation of Forest Workers, Kuopio, Finland, 3 - 7 June, Helsinki, Finnish Government Printing Press.

Saha, P.N. 1976. The practical use of some physiological research methods for assessment of work stress. *Journal of the Indian Association of Physiotherapist*, **4**, 9 - 13.

Sanchez, J., Monod, H. and Chaband, F. 1979. Effects of dynamic, static and combined work on heart rate and oxygen consumption. *Ergonomics*, **22**, 935 - 943.

Sanders, M.S. and McCormick, E.J., 1992. Human Factors in Engineering and Design. 7th Ed. McGraw-Hill, New York.

Sato, M, and Tanaka, S. 1973. Postural effects on the relationship between oxygen consumption and heart rate. *Journal of Human Ergology*, **2**, 21 - 30.

Seixas, F. and Ducatti, F.A. 1995. Evaluation of job rotation effects on chainsaw operators. *Journal of Forest Engineering*, **6**, (2), 59 - 63.

Shvartz, E., Meroz, A., Mechtinger, A. and Birnfeld, H. 1976. Simple reaction time during exercise, heat exposure and heat acclimation. *Aviation, Space, and Environmental Medicine*, **47**, 1168 - 1170.

Sirios, D.L. and Smith, L.A. 1985. Physiological demands of forest harvesting tasks: A case study of skidding operations. *Applied Ergonomics*, **16**, (3), 167 - 172.

Slappendel, C,. Laird, I,. Kawachi, I,. Marshall, S,. and Cryer, C. 1993. Factors affecting work related injury among forestry workers: A review of the literature. *Journal of Safety Research*. **24**, (3), pp 19-32.

Smith, L.A., and Sirois, D.L., 1982. Ergonomic research: Review and needs in southern forest harvesting. *Forest Products Journal*, **32**, (4), 44 - 49.

Smith, L.A., Wilson, G.D. and Sirois, D.L. 1985. Heart-rate response to forest harvesting work in the south-eastern United States during summer. *Ergonomics*, **28**, (4), 655 - 664.

Smith, L.A.; Seay, M.R. and Sirois, D.L. 1986. Heat stress effects on forest harvesting work behaviour. Proceedings of the Annual International Industrial Ergonomics and safety Conference, Louisville, KY, 449 - 456.

Smith, L.A. and Rummer, R.B. 1988. Development of a heat stress prevention activity guide for use by southern forest harvesting managers. Final Report No.19-87-065, New Orleans, USDA, Forest Service.

Smith, L.A. and Thomas, R.E.Jr 1993. Ergonomic research in the southern United States. *Unasylva International journal of forestry and forest industries.* **44**, (172). Food and agriculture organisation, United Nations, Rome , Italy.

Smolander, J., Louhevaara, V., Ahonen, E., Polari, J. and Klen, T. 1995. Energy expenditure and clearing snow: a comparison of shovel and snow pusher. *Ergonomics*, **38**, (4), 749 - 753.

Soule, R.G. and Levy, C.K. 1972. Voluntary march rate over natural terrain. *Federation proceedings*, **31**, 312.

Spiers, J.J.K., 1985. Loggers Language: A New Zealand Terminology. New Zealand Logging Industry research Association, P.O. Box 147, Rotorua, New Zealand.

Staal Wästerlund, D. and Kufakwandi, F. 1993. Improving working conditions in Zaffico, Zambia's parastatal forest industry. Unasylva 172, **44**, 13 - 19.

Stuart-Buttle, C. 1994. A discomfort survey in a poultry - processing plant. *Applied Ergonomics*, **25**, (1), 47 - 52.

Sullman, M.J.M. 1994. Increasing skidder operator seatbelt usage. Logging Industry Research Organisation Report, **19,** (8).

Sweetman, K. 1984. The logger's back - A physiotherapist's impression. In proceedings, New Zealand Logging Industry Research Association Seminar "Human Resources in Logging", June.

Tapp, L.; Gaskin, J.E.; Wallace, K., 1990. Loggers' assessments of risks in their work. Logging Industry Research Association Report, **15**, (1).

Tatsukawa, S. 1994. An Ergonomic Evaluation of the Cutting Work with a Light-Weight Chainsaw on Steep Terrain. In proceedings of the International IUFRO/NEFU/FAO Seminar on Forest Operations Under Mountainous Conditions with special attention to Ergonomics, Accessibility and Environmental Protection. Harbin, P.R. of China.

Thompson, C. and Hellemans, I. 1994. Sport Nutrition. In Science, Medicine and Sport; Enhancing Sport Performance. Edited by D.G. Russell and B.D. Wilson. University of Otago.

Trewin, A.R.D. and Kirk, P.M. 1992. Planting Bare-Rooted Seedlings of Radiata Pine on Difficult Terrain. Proceedings of the Logging Industry Research Organisation seminar on harvesting and re-establishment of difficult terrain, June 1992.

Trites, D.G., Robinson, D.G. and Banister, E.W. 1993. Cardiovascular and muscular strain during a tree planting season among British Columbian silvicultural workers. *Ergonomics*, **36**, (8), 935 - 949.

Ulmer, H.V., Janz, U. and Lollgen, H. 1977. Aspects of the validity of Borg's scale. Is it measuring stress or strain?. Wenner Gren Symposium International Series, **28**, 181 - 199.

Valdes, S. and Apud, E. 1994. Ergonomics and productivity in Chilean forestry. In proceedings of the International IUFRO/NEFU/FAO Seminar on Forest Operations Under Mountainous Conditions with special attention to Ergonomics, Accessibility and Environmental Protection. Harbin, P.R. of China.

Van Der Beek, A.J. and Frings-Dresen, M.H.W. 1995. Physical workload of lorry drivers: a comparison of four methods of transport. *Ergonomics*, **38**, (7), 1508 - 1520.

Van Loon, J.H. 1971. Physical workload in tree felling and the working capacity of older forest workers. In Volume II Part I Symposium on Ergonomics Applied to Forestry. FAO/ECE/LOG/243, Geneva.

Van Loon, J.H. 1976. Human Energy Expenditure in Mechanised Agricultural Work. in IAAMRH Journal, No. 1, p. 18.

Varghese, M.A., Saha, P.N. and Atreya, N. 1994. A rapid appraisal of occupational workload from a modified scale of perceived exertion. *Ergonomics*, **37**, (3), 485 - 491.

Väyrynen, S. and Ojanen, K. 1983. The protection of loggers' heads and eyes in forestry work. *Journal of Occupational Accidents*, **5**, 81 - 88.

Vik, T. 1984. Impact of terrain on human effort in forest operations. in Human resources in logging: The proceedings of a seminar held in Rotorua. June 1984.

Vitalis, *A*. 1981. An investigation of the relationship between pulse rate, environmental heat and work output of cane cutters in Fiji, unpublished Ph.D. Thesis, London University.

Vitalis, A., Gaskin, J.E. and Jeffery, G 1986. The physiological cost of work - An ergonomics approach. Logging Industry Research Association Report **11**, (9).

Vitalis, A. 1987. The use of heart rate as the main predictor of the cost of work. pp 168-181 in Proceedings of the inaugural conference of the NZ ergonomics society. Auckland Feb 1987.

Vitalis, A.; Pournaras, N.D.; Jeffrey, G.B.; Tsagarakis, G; Monastiriotis, G. and Kavvadiast, S., 1994. Heart rate strain in Greek steelworkers. *Ergonomics,* **21**, (5), 845 - 850.

Vogelaere, P., De Meyer, F., Duquet, W. and Vanjdefelde, P. 1986. Validation du Sport Tester PE3000 enfonction de l enregistrement Holter, *Science Sports*, **1**, 321 - 329.

Vogt, J.J., Libert, J.P., Candas, V., Daull, F. and Mairiaux, P.H. 1983. Heart rate and spontaneous work-rest cycles during exposure to heat. *Ergonomics*, **26**, 1173 - 1185.

Wenbin, L., Tomomichi, F., and Shoji, I. 1989. Effects of Both Slope Angle and Weight of Brush Cutters on Forest Workers' Heart Rate and Walking Speed. Memoirs of the College of Agriculture, **34**, (1), 43 - 51 Ehime University.

Wencl, J. 1971. Heart rate measurements during group work in logging. . In Symposium on Ergonomics Applied to Forestry, Volume 2. International Labour Office, United Nations, Geneva.

Wilson, N,. Russell, D,. and Wilson, B. 1993. Body Composition of New Zealanders. Life in New Zealand Activity and Health Research Unit. University of Otago. Dunedin.

Wyon, D.P., Andersen, I.B. and Lundqvist, G.R. 1979. The effects of moderate heat stress on mental performance. *Scandinavian Journal of Environment and Health*, **5**, 352 - 361.

Yu, C.Y., Keyserling, W.M. and Chaffin, D.B. 1988. Development of a work seat for industrial sewing operations: results of a laboratory study. *Ergonomics*, **31**, 1765 - 1786.

Zimolong, B. 1985. Hazard Perception and Risk Estimation in Accident Causation. Trends in Ergonomics/Human Factors II , 463 - 470.

Appendix A

Study Consent Form

I have read the information which explains the study and have had the details of the study explained to me. My questions about the study have been answered to my full satisfaction and I am aware that I can ask other questions at any time.

I understand that it is my right to withdraw from the study at any time, in full or in part, and do not have to give any reason for doing so to any person. I am under no pressure from any person to participate in this study against my will.

I agree to participate in the study on the following conditions;

1. **that if any data is to be published I will remain completely anonymous**
2. **that there will be no disclosure of any personal information to any person**
3. **only LIRO researchers will be able to access the information I provide**

I hereby give my free and informed consent to participate in the study

Signed____

Name ____

Date ____

Researcher

Appendix B

Information Sheet

Researchers: Patrick Kirk and Mark Sullman

Contact Information: C/- NZ Logging Industry Research Organisation
P.O. Box 147
ROTORUA.

Phone: [redacted]

[redacted] [redacted]

Study Details:
This study aims to investigated how tree faller fatigue levels change during the working day and how this impacts on worker safety, productivity and physical strain.

Participant Involvement:
The participants will have to wear a portable heart rate monitor, answer questions relating to questionnaires and have a researcher observing them from close quarters (0 - 3 metres). Participants will also undertake an estimated oxygen consumption test. This is a test which calculates how efficiently your body can convert oxygen into energy.

How much time will be involved ?.
Five days field data will be collected per participant.

What can the participants expect from the researchers ?

If you take part in this study, you have the right to:

- **refuse to answer any particular question, and to withdraw from the study at any time.**
- **ask any further questions about the study that occur to you during your participation.**
- **provide information on the understanding that it is completely confidential to the researchers. All information is collected anonymously, and it will not be possible to identify you in any reports that are prepared from the study.**
- **be given access to a summary of the findings from the study when it is concluded.**

Appendix C

Borg's RPE Scale

6 NO EXERTION AT ALL

7 EXTREMELY LIGHT

8

9 VERY LIGHT

10

11 LIGHT

12

13 SOMEWHAT HARD

14

15 HARD (HEAVY)

16

17 VERY HARD

18

19 EXTREMELY HARD

20 MAXIMAL EXERTION

Appendix D

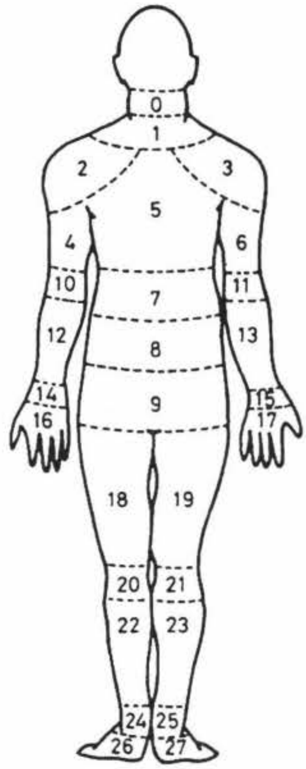
Self Assessment of Fatigue Questionnaire

How do you feel now?
(Please circle a number)

(Q1) Fresh	1	2	3	4	5	6	7	Weary
(Q2) Tense	1	2	3	4	5	6	7	Relaxed
(Q3) Strong	1	2	3	4	5	6	7	Weak
(Q4)Exhausted	1	2	3	4	5	6	7	Vigorous
(Q5)Wide Awake	1	2	3	4	5	6	7	Sleepy
(Q6) Bored	1	2	3	4	5	6	7	Interested

Appendix E

Body Part Discomfort Survey



0	**Neck**	**14**	**Left Wrist**
1	**Lower Neck**	**15**	**Right Wrist**
2	**Left Shoulder**	**16**	**Left Hand**
3	**Right Shoulder**	**17**	**Right Hand**
4	**Left Upper Arm**	**18**	**Left Thigh**
5	**Upper Back**	**19**	**Right Thigh**
6	**Upper right Arm**	**20**	**Left Knee**
7	**Mid Back**	**21**	**Right Knee**
8	**Lower Back**	**22**	**Left Lower Leg**
9	**Buttocks**	**23**	**Right Lower Leg**
10	**Left Elbow**	**24**	**Left Ankle**
11	**Right Elbow**	**25**	**Right Ankle**
12	**Lower Left Arm**	**26**	**Left Foot**
13	**Lower Right Arm**	**27**	**Right Foot**

1	**2**	**3**	**4**	**5**
None	Light	Moderate	Severe	Unbearable

Appendix F
Thermal Comfort, Sensation, Skin Wettedness and Regulation.

Thermal Comfort Rating Questionnaire

	Overall
(1)Very Uncomfortable	____
(2)Uncomfortable	____
(3)Slightly Uncomfortable	____
(4)Not Uncomfortable	____

Thermal Sensation Rating Questionnaire

	Overall
(1)Very Hot	____
(2)Hot	____
(3)Warm	____
(4)Slightly Warm	____
(5)Neutral	____
(6)Slightly Cool	____
(7)Cool	____
(8)Cold	____
(9)Very Cold	____

Skin Wettedness Questionnaire.

How does your skin feel ?.

More dry than normal	_____
Normal dryness	_____
Some parts of body moist	_____
Main part of body moist	_____
Some part of body wet	_____
Main part of body wet	_____
Sweat running off in some places	_____
Sweat running off in many places	_____

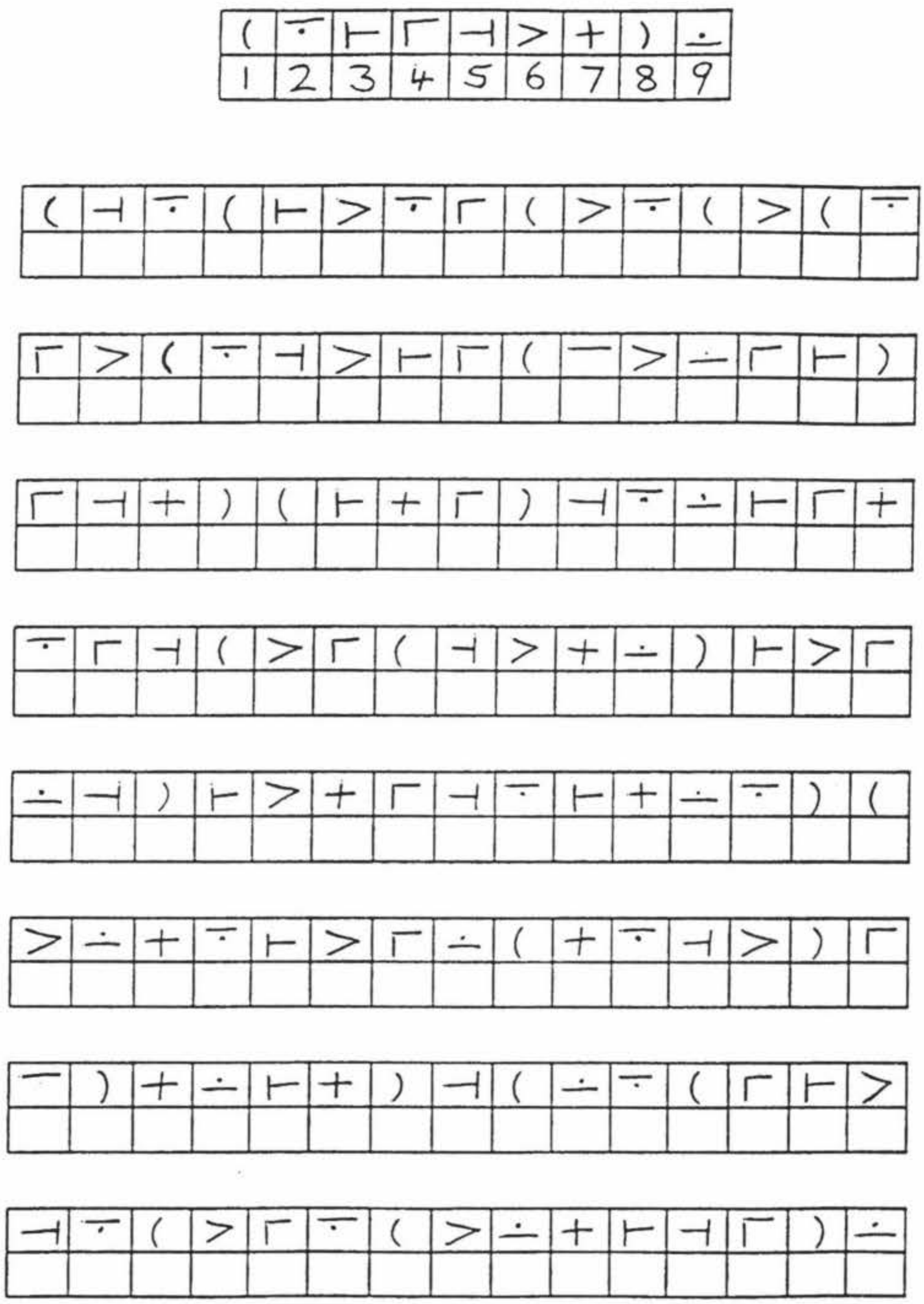
Thermal Regulation Questionnaire.

Are you ?...

Vigorously shivering	_____
Moderately shivering	_____
Slightly shivering	_____
Neutral	_____
Slightly sweating	_____
Moderately sweating	_____
Heavily sweating	_____

Appendix G

Digit Symbol Substitution Test



Appendix H

Glossary of Terms

(Spiers, J.J.K. 1985)

Backcut	The final saw cut in felling a tree, opposite the scarf and the intended direction of fall.
Breaker-out	Worker at the felling site responsible for connecting trees or logs to a hauler rope for transportation to a landing.
Breaking- out	Operation of a breaker-out
Butt	Base of a standing tree; Bottom (stump) end of a felled tree; The larger end of a log.
Clearfell	To fell and extract an entire stand or setting.
Clearfell Age	Age at which the stand is clearfelled.
Crew	A complete team of men needed to work one logging operation.
Cutover	Clearfelled area of forest.
Cycle Time	The time taken to complete a cycle.
Daily Target	Quota of trees that a faller must fell and delimb each working day.
Delimb	To remove limbs or branches from a tree or log
Delimbing	The action of removing limbs or branches from a tree or log.
Directional Felling	Felling trees according to a predetermined pattern to reduce breakage or to facilitate breaking out.
Drag	A log, or a number of logs, hauled from stump to landing.
Exotic Forestry	Forestry involving trees introduced from another country.
Extraction	General term for removing trees and logs from a felling area to a landing or road.
Faller	One who fells trees.
Felling	The act of cutting down a tree.
Felling Face	The edge of a stand of trees where felling is taking place.
Ground Based	Extracting trees using machinery that travels along the ground.
Harvesting	General term for removing products from a forest for utilisation.
Hauler	A machine equipped with winches which operates from a set position to haul drags from stump to landing.
Hinge Wood	A hinge cut so that more wood is left on one side of the hinge, and intended to pull the tree towards that side as it falls.
Landing	A selected or prepared area to which logs are extracted and where they may be sorted, processes, loaded or stockpiled.(Also called a skid).
Logging	Harvesting timber from a forest.

Mechanised Operations	Logging system relying entirely on machines, in which people are employed solely as operators.
Motor-Manual	Refers to work carried out by hand held power tools, (i.e. chainsaw).
Scarf	Notch cut in a tree stem above the stump to control its direction of fall.
Setting	Portion of a stand (or compartment) logged (or to be logged) to one landing.
Silviculture	Term used for growing and tending forest crops.
Skid	A selected or prepared area to which logs are extracted and where they may be sorted, processes, loaded or stockpiled. (Also called a landing).
Skid Worker	Person who works on landings unhooking drags and cutting logs.
Skidder	A self-propelled extraction machine with wheels or tracks specifically designed for the extraction of logs from the cutover.
Slash	Branches, bark, chunks, uprooted stumps and broken trees left on the ground after logging.
Stem	Main trunk of a tree from stump to tip
Stocking	Number of standing green (live) trees per hectare.
Trim	To remove limbs or branches from a tree or log
Woodlot	Area of privately owned plantation forestry located outside the large forest company forests.