An Ergonomics Analysis of Manual versus Chainsaw High Ladder Pruning of *Pinus radiata* in New Zealand

A thesis in partial fulfilment of the requirements for the degree of Master of Philosophy at Massey University.

Abstract:

Two methods of ladder pruning *Pinus radiata* from 4.5 - 6.0 metres were compared using a cost-benefit approach within a framework provided by ergonomics. Chainsaw pruning is practiced in areas of New Zealand where large branches occur.

The objectives of the research were to compare the costs and benefits of the two pruning techniques and provide recommendations as to whether or not the practice of chainsaw pruning should continue. These objectives were achieved by comparing the risk of injury, the physiological costs, the musculoskeletal costs, the productivity and the quality associated with the use of the two techniques.

The general methods used to assess the relative costs and benefits of the two techniques were:

1. Numeric descriptions of the 'risk' involved with each method of pruning
2. The use of a relative heart rate index to compare the physiological costs of the two techniques
3. Using questionnaires focusing on musculoskeletal pain and discomfort to assess any relative differences between the two techniques
4. Using continuous time study to quantify any difference in labour productivity between the two techniques
5. Sampling pruned trees to assess differences in the quality of work between manual and chainsaw pruning

The research concludes that although both methods of pruning are hazardous, chainsaw pruning is more hazardous than manual pruning. Chainsaw and manual pruning were found to have the same physiological costs. Findings of the research indicate that manual pruning is not associated with a higher prevalence of musculoskeletal discomfort than chainsaw pruning on a yearly basis, although it is associated with a greater relative increase in BPD on a day to day basis and that this may lead to the development of musculoskeletal disease. Chainsaw pruning was found to be significantly more productive than manual pruning, although this was at the cost of quality.

The research concludes by recommending that the use of chainsaw pruning should be limited to areas where the branches are demonstrably large. Further research is called for to compare the physiological and musculoskeletal costs of manual pruning in plantation areas of both large and small branch sizes. Further research is called for to compare the safety of two methods of chainsaw pruning with the use of the technique of wrapping one leg around the tree as opposed to not wrapping the leg around the tree. Research to investigate new ladder designs which are safer to use in the New Zealand forest environment is also called for.

Acknowledgments

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Chapter 1 Introduction to Ergonomics and Forestry

1.0 Introduction

This chapter introduces some of the fundamental ideas and concepts in ergonomics which will be used in the analysis of the work methods for manual and chainsaw pruning. It will then give a general overview of the forestry industry in New Zealand, to detail why pruning is performed in New Zealand forests and why the current research was undertaken.

1.1 An Ergonomics Framework

The current research will assess the relative costs and benefits of chainsaw versus manual ladder pruning of *Pinus radiata* within an ergonomics framework. In order to achieve this goal it is necessary to consider a relatively large number of variables. Each of the variables measured have some importance in the ergonomics and safety and health fields. By taking multiple bearings from varying aspects of the pruning task, the thesis will be able to build a clearer picture of the entire system and hence will provide more holistic conclusions to the research.

General Systems Approach

The systems approach to viewing 'things' or 'processes', first proposed by the biologist von Bertalanffy during the late 1930s and 1940s, was an attempt to break down the cross-disciplinary barriers constructed by scientific specialisation (Walker 1989). This period in time also saw a revolution in social science occur whereby there was a move away from the objectivist ontology of social science towards something more in tune with humans as 'humans' rather than humans as 'mechanistic (or machine like) beings' or purely 'responders' to an environment. Systems theory as proposed by von Bertalanffy has since been adapted by social scientists to suit approaches along the continuum between subjectivist and objectivist approaches. This research assumes the ontology and epistemology that humans are information processors, that our reality is set within the contextual field of our environment and that the best way to understand human nature as it relates to 'work' is to map contexts and to analyse 'wholes' in a Gestalten manner (Morgan and Smircich 1980). So the favoured position of this researcher is one of middle ground between the subjectivists and the objectivists. This philosophical position allows the best methodologies from both extremes of the continuum to be employed to gain an understanding of people in the workplace.

Prior to moving on to consider the systems focused on in the current research, an overview of general systems theory and the base assumptions of its use is called for. Sanders and McCormick (1992) suggest that systems exist for a purpose and are therefore 'purposeful entities'. Systems operate for a purpose to achieve some end. There are four main 'building blocks' of general systems theory (Slappendel 1992):

1. The structure of systems
2. Regulation and maintenance
3. Dynamics and change
4. Decline and breakdown

Each of these concepts will be briefly over-viewed.

Systems operate for a purpose. They take inputs from the environment and transform these inputs to outputs via various sub-system components working together in synergy. Thus the basic structure for any system involves an environment from which to receive inputs and supply with outputs and a process whereby the system, or components thereof, transform inputs to outputs. A purposeful system may be an industrial company taking in parts and raw materials, producing some product via human effort and technologies, then outputting the transformed inputs as finished products. Alternatively, a system may be a biological cell or organ fulfilling some function depending on the level of analysis one would care to use (Slappendel 1992).

Many systems (especially biological systems) require regulation and maintenance in order to continue to function within the limits of homeostasis or in accordance to their purpose (Slappendel 1992). System regulation introduces concepts of feedback and control essential to proper management in the social sense and maintenance in the biological sense. Regulatory mechanisms in both organisms and organisations operate to maintain control over internal processes when effects from the outside environment place stress on the system. Examples of this may be a market research section in a company or physical and chemical receptors of the body which provide feedback about our environment.

Nearly all systems are dynamic and hence change over time in response to a changing environment. For example a company may change its product range to compete with competitors or to cater to a changing consumer market. Similarly, the structure of a person's bone and muscle configuration may change over time as the stress placed on that part of the body leads to adaptation. An example of this type of adaptation is the building of muscles in the legs of a postal delivery person due to the physical demands of the task (Slappendel 1992).

Decline and breakdown are inevitable consequences of biological systems on which general systems theory is based. The decline and breakdown of a system due to continued strain is of special interest to the ergonomist as this is the cause of much personal injury and disease. Where the demands of a task (stressors) exceed an individual's capacity to adapt to these stressors, continued strain will be experienced. Continued strain will lead to 'breakdown' of the system under strain and other related (sub)systems (Slappendel 1992).

In general, systems exist for a purpose, they have regulatory and controlling mechanisms which help to keep them operating in line with their purpose, they are dynamic and have the ability to change in response to a changing environment, and generally they have a limited life cycle. The systems concept provides a solid basis from which to begin the interpretation of any entity whether this be a cell, an organ, an organism, a worker, team of workers or an entire company. Over time, general systems theory has been further refined and customised to the uses of various professions. The next section will outline the systems concepts which are commonly used by ergonomists.

What is Ergonomics ?

The term ergonomics comes from the Greek words 'nomos' meaning law and 'ergo' meaning work. Thus a loose transliteration would be the laws of work. According to Sanders and McCormick (1992) ergonomics is chiefly concerned with two objectives. Firstly to enhance the efficiency and effectiveness of the work people perform and secondly to enhance certain desirable human values such as improved safety, reduced fatigue and stress, increased comfort, greater user acceptance, increased job satisfaction, and improved quality of life. Ergonomics is concerned with optimising the 'fit' between people in the work place, the physical characteristics of that work place, and the complex interactions between people and their total working environment (Slappendel 1992).

Systems in Ergonomics

Within the ergonomics field the most frequently used system model is that of the 'Human-Machine System' (see Figure 1.01 overleaf). Within this general model Sanders and McCormick (1992) identify three types of human-machine systems:

1. Manual systems
2. Mechanical systems, and
3. Automated systems

Each of these systems have common characteristics. Sanders and McCormick (1992) identify human-machine systems as having the following characteristics:

1. Systems are purposeful
2. Systems can be hierarchical
3. Systems operate in an environment
4. Components serve function
5. Components interact
6. Systems, sub-systems and components have inputs and outputs.

Figure 1.01 The Human-Machine System

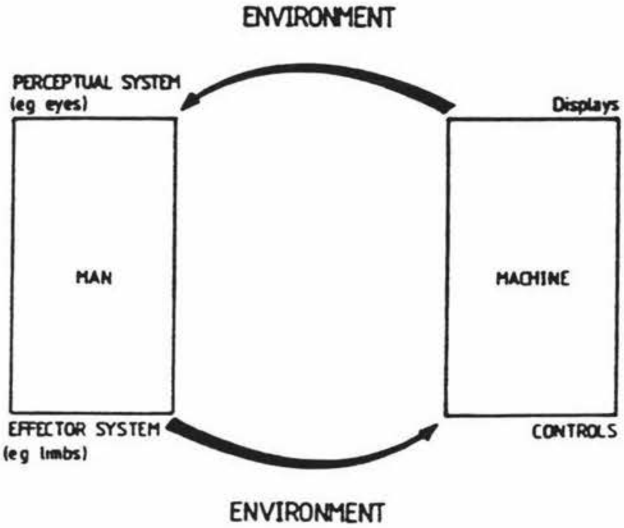


Figure 1.1 The 'man–machine' loop. The machine displays information to the human operator who operates his controls to affect the machine. The environment can interfere with the efficiency of this loop

Source: Oborne (1982)

Hence, while many systems are complex entities, they can be broken down into manageable components for analysis and understanding through the use of models without *reductio ad absurdum*. It must be noted that models are just models. They do not imply a 'cover-all' typology for analysis, but rather they provide a good starting point from which to customise and best fit the particular situation[1].

Systems analyses in ergonomics do not attempt to analyse every component or characteristic of the system. Rather, selected sub-systems or characteristics which are taken to be the most practical and pertinent from an ergonomics viewpoint are chosen for analysis. Sanders and McCormick (1992) cite Chapanis (1983) who stated that 'only a subset of factors are generally of highest importance in a specific application' and that 'the objectives are usually correlated'. So if a machine, product or task is ergonomically designed to be safer it will usually be less fatiguing, easier

[1] For more complete detail on system characteristics and systems types refer to Sanders and McCormick (1992).

to use, more productive and more satisfying to the user (Sanders and McCormick 1992). This is the rationale that will be taken in the current research.

Cost-Benefit Approach

The cost-benefit approach is one where the relative benefits of some 'thing' or 'process' are weighed up against the costs of that 'thing' or 'process'. In short, cost-benefit analysis will reveal whether a 'thing' or 'process' is justifiable on some grounds of judgment. Traditionally the grounds of judgement have been mostly financial. The grounds of judgement in the current research are those of safety, health, productivity and quality. If for example there were equal costs for two processes or operations but disparate benefits, a cost-benefit approach would dictate that the operation with the highest benefits would be preferred. Of course the reverse situation would also apply. The current research will use this approach as a means of weighing up the system characteristics of safety, physiological costs, musculoskeletal discomfort, productivity, and quality.

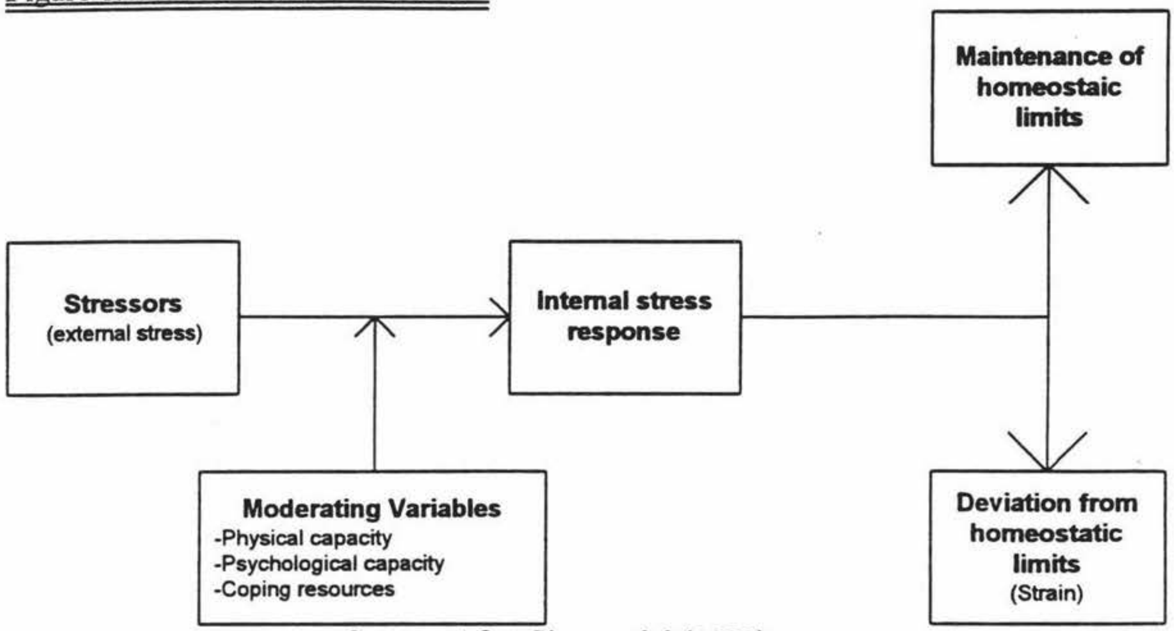
1.2 General Ergonomic Concepts

Stress-Strain

The stress-strain concept is one of the most important concepts in ergonomics and one of the most misquoted. In some literature physical or mental strain is commonly referred to while other literature refers to physical or mental stress. There should be a clear distinction between these two terms in the ergonomics and related professions. Stress and strain when used together properly refers to an important relationship in the way a person responds to the demands of a task. Used improperly, this simple and clear-cut relationship becomes obscure.

Stress on a person can be thought of as an external load on one of the body's systems. This load may be environmental, physical, emotional or cognitive. This 'stress' elicits a stress response by the body in an attempt to maintain homeostasis. Figure 1.02 (overleaf) represents the stress response relationship at a conceptual level.

Figure 1.02 Stress-Strain Mechanism



Source: After Slappendel (1992)

Stress on a person results in changes to bodily functions as the regulatory and control, or as Weiner (1982) explains 'stress response', mechanisms of the body attempt to maintain the steady state (homeostasis) of the body. When the stress on a person is such that the homeostatic limits are exceeded the body can be said to be experiencing 'strain'. This 'strain' is associated with injury or disease. A simple but effective example of this would be where a person's work requires considerable physical exertion. This exertion may increase the blood lactate and other haematological markers well above resting levels and is 'stress' on the body. Blood lactate levels will take some time to fall down to a resting level. If blood lactate levels do not come down to resting levels before commencement of the following day's work there will be a cumulative increase in the blood lactate level as each day passes. This situation will normally result in a 'strain' condition akin to athletic burnout. Trites *et al.* (1993) found consistent increases in the lactate dehydrogenase in their sample of Canadian tree planters throughout the tree planting season.

Homeostasis

Homeostasis is a concept which refers to the limits within which the body can continue to function without abnormal decline. This is an equilibrium situation which is dynamic in nature. Homeostatic limits are specific to the individual depending on that individual's capabilities and limitations. Furthermore, these limits are not a point but rather a range within which the body (system) can regulate and maintain itself without any tissue damage (decline). These limits are also dynamic in the sense that they can change over time. For example, a physically trained person could perform physical work longer and at a greater intensity than the same person in an untrained state and still be within their homeostatic limits (in other words, not in a strain situation). In essence therefore, homeostasis depends on a person's individual capabilities and limitations (Slappendel 1992).

Capability and Limitations

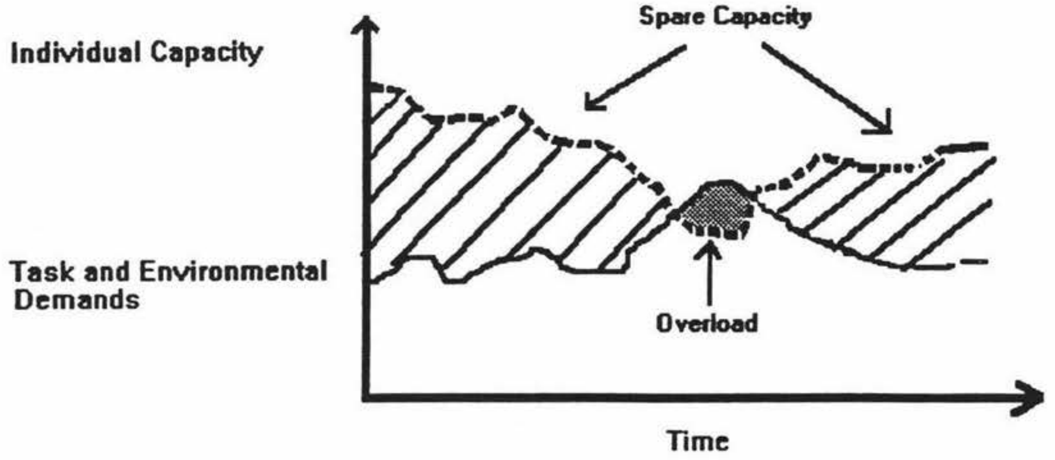
The capability of a person to withstand some stressor, perform some task or to process some information is a factor which is dependent upon that person's experience, training, intelligence and physical ability. Related to this concept is that of capacity. Capability is the ability to do 'something' while capacity refers to how much, how fast or how accurately 'some thing' can be done. Capacity and capability are concepts which by definition are related to the concept of limitation. The concept of limitation sets the human limits of 'what' or 'how much' can be done. These two broad concepts together give us a model of 'limited capacity' as shown in Figure 1.03 (overleaf). Spare capacity is represented in Figure 1.03 as the hatched are while the overload situation is shown as the dark shaded area.

When the demands of a task exceed the capacity of a person to perform that task the person is in a state of overload (or upset homeostasis). This can lead to impairments in performance (Slappendel 1992) or physical and emotional stress and/or strain. In short, this situation leads to a greater accident liability (Sanders and McCormick 1993, Radl *et al.* 1975).

Human Error

Integral to the field of accident causation is the concept of human error. Meister (1971) defines human error succinctly as 'a deviation from required performance'. This is a good definition as it both leaves open all the possible consequences of

Figure 1.03 Model of Limited Capacity



Source: After Slappendel (1992)

human error and at the same time is non culpable (does not impose any 'blame'). Meister lists six error consequences within a human machine system. These are:

1. Delay in system operation
2. Human-initiated malfunctions
3. System breakdown
4. Failure to accomplish mission
5. Degradation in system performance
6. Possible danger and loss of life.

The high profile accidents at Three Mile Island, Bopahl, Chernobyl, and the Challenger disaster (Kirwan 1990) were all consequences of combinations of human error and management failing to exert control over the system. Human error is caused by a variety of relationships between the individual, their total working environment and their total social environment. The risk of human error can be reduced by good system design and system updates. Human error causation is inextricably linked into models of accident causation. A review of these is beyond the brief of this thesis[2].

[2] For comprehensive reviews of good models of accidents causation refer to Sanders and McCormick (1993) and Kirwan (1990); for individual models of accident causation see DeJoy (1990), Wagenaar, Hudson and Reason (1990) or Dwyer and Rafferty (1991).

1.3 Forestry (Background)

The New Zealand Forestry Resource

New Zealand has 1,308,000 hectares (ha) of exotic forestry of which 90% is planted in *Pinus radiata* (Forestry Facts and Figures 1994). As at April 1992, 14.8% of the *Pinus radiata* resource was aged less than 5 years old and 37.5% aged less than 10 years old (Forestry Facts and Figures 1994) with significant plantings continuing for the foreseeable future. Almost all these young trees will be pruned to maximise value recovery at clear-fell. This will require a massive amount of human resources to achieve.

The rate of new plantings per year between 1920 and 1990 peaked at near 57,000 ha per year up until the early 1980s when this rate decreased dramatically in line with both the standardisation of all land-based production incentives (Le Heron 1985) and an economic recession. Since the early 1990s the rate of new plantings has again increased dramatically from around 17,000 ha per year in 1990 to 60,000 ha per year in 1993 (Forestry Facts and Figures 1994). Due to the high rates of new plantings during the winter of 1994 there is expected to be a greater amount of pruning work and a consequent need for pruning workers over the next ten years and beyond.

Forest Operations

The tree growing cycle from planting through to harvesting can be broken into two broad operations. The planting and subsequent tending of trees is known as silviculture (or forestry[3]) while the harvesting of trees is known as logging. Both of these forest operations will now be outlined. The silvicultural regimes given are those currently in use (1994) by Carter Holt Harvey Forests Ltd (CHHF) Central Region in their management of *Pinus radiata*.

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[3] The terms silviculture and forestry are synonymous within industry. For the purposes of this thesis the reader is advised to look at the context of usage if there is any confusion between the forestry industry and the forestry (silvicultural) work-force.

Plantation Pine Silviculture

Plantation pine silviculture usually has three distinct phases: planting, thinning and pruning. Planting involves the restocking of previously logged areas or establishing new plantings on ex-farmland. Trees are planted at an initial stocking rate of around 833 - 1,000 stems per hectare (sph). Planting is normally done in the winter and early spring when there is an abundance of water. Many forestry workers will be employed in more than one operation during the course of a year.

Releasing is the operation where competing weeds, grasses and other vegetation surrounding the young pines are killed by chemical sprays in order that the young pines receive as much light as possible to enhance growth. By manipulating the silvicultural regime to produce the greatest possible quantity of high value[4] wood fibre products from a stand of trees, value recovery at harvest is optimised.

As the trees grow they require more space and light to maintain an optimal growth rate. This is achieved by reducing the number of sph or 'thinning' the crop. The trees that are chosen as first priority to be thinned are those which are malformed. Silvicultural thinning contractors are requested to leave behind non-malformed pruned final crop trees and sub-dominant unpruned trees as spacing trees. At 'first thinning' the stocking rate is reduced to between 750-800 sph. This first thinning is also known as 'thinning to waste' as the thinned trees are left where they fall as it is uneconomic to remove them to a mill. They consequently decompose and return nutrients to the soil and surrounding trees. The next thinning operation is known as 'final' or 'production thinning'. This operation further reduces the number of sph to the final crop target of 300 sph. The thinned trees are used for pulp and saw logs. The final crop trees remaining will be clear-felled when they are approximately 30 years old.

The rationale for pruning *Pinus radiata* is to optimise the value recovery from trees at clear-fell. Pruning results in timber which is free of defects caused by knots in the wood and has the aesthetic quality of continuous wood grain. A tree that has been

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[4] Based on current market trends and market projections.

pruned to 6.5 m above the ground produces a 'pruned butt log' used for veneers and in other high value added processes. Pruned butt logs are far more valuable than knotty 'saw' logs used for framing timber or exceptionally knotty 'industrial' logs used for pulp.

Pruning, like thinning, is carried out in stages. Initial pruning from the ground to 2.5 m is called 'first lift' or 'low' pruning. This is done at age 5 to 6 years when the trees would normally be expected to be 7 to 8 m high. For the low pruning the spacing of pruned trees is expected to be between 350 - 450 sph. This number is reduced in the subsequent 'lifts' to targets of 325 sph at 'medium' or 'second lift' pruning 2.5 to 4.5 m (tree age 7 years) and then 300 sph at 'high' or 'third lift' 4.5 m to 6.5m (tree age 8 to 9 years). Recently 'ultra high' or fourth lift pruning (from 6.5 m to 8.5 m) has been used in order to recover two 4 m pruned butts from the one tree. At the pruning stage production thinning has not taken place so the pruning task involves the pruner selecting the best trees to be pruned out of the crop.

The activity of pruning is usually done with hand held tools known as pruners[5]. Jacksaws may be used for larger branches (Figure 1.04). In the Hawkes Bay region and certain other areas of New Zealand small, lightweight chainsaws are used for pruning (Figure 1.05 (overleaf)).

Plantation Pine Harvesting

The final part of the production forestry cycle is that of logging (harvesting or clear-felling). When an area is ready for harvest all the trees in the area are cut down or 'clear felled'. Initial log processing takes place on a flat area known as a 'skid' or 'landing'. Then the logs are carried by truck to downstream industries comprising mainly of pulp and paper, whole log exports, sawn timber and veneers (Forestry Facts and Figures 1994). After clear-fell, harvested areas are replanted and the cycle begins again.

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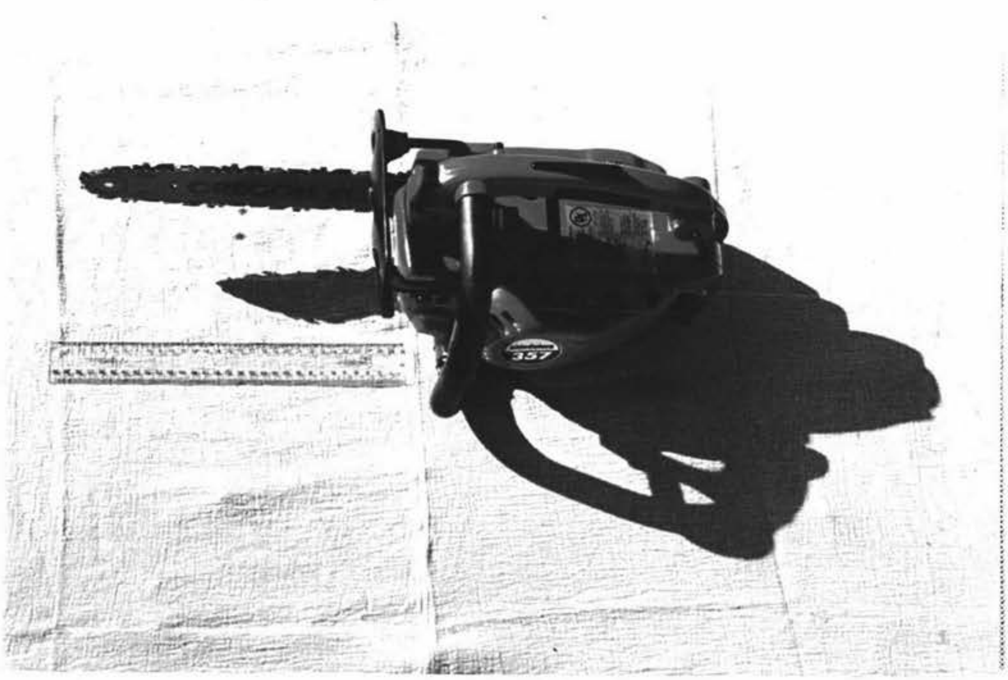
[5] Confusingly, the people who prune the trees are also known as pruners. The reader is advised to look at the context in which the word is used if there is confusion in any part of the research.

Figure 1.04 Pruning Tools

Figure 1.05 Pruning Chainsaw



Description of High Pruning

The pruning operation being considered in the current research is that of the third lift or high prune 4.5 m - 6.5 m. For this operation the pruner places a 4.2 m ladder against the tree and climbs the ladder until he or she is just below the first whorl of branches. These are then pruned using either a combination of pruners and jacksaws, or a chainsaw. Branches are pruned as close as possible to the stem of the tree without damaging the branch collar or the surrounding bark. Pruners generally wrap one leg around the stem of the tree and have the other leg on the ladder to allow greater movement and stability. When a branch is pruned, the pruners usually try not to prune it directly above their head. This is done by pruning branches to one side of the tree to avoid being hit by the falling branch. However, as the ladder is stationary there are always circumstances where the pruners will have to manoeuvre directly under branches that are about to fall. Alternatively the pruner may pre-empt this situation and lean out to one side of the tree to limit the chances of being hit by the falling branch. Once all the branches up to the prescribed height of 6.5 m have been removed the pruner descends the ladder and selects the next tree to be pruned. The tree selected should be the best tree in the immediate area keeping in mind that, of the available 750-800 sph, they are required to be prune the best 300 sph.

The New Zealand Forestry Workforce

Within the forest industry there are two main occupational groupings. The task of planting and tending of trees is performed by the silvicultural workforce while the harvesting of trees is the performed by the logging workforce. As at February 1993 there were almost twice as many people working in silviculture (4,552) than there were in logging (2,842) (Forestry Facts and Figures 1994). The silviculture figure represents pruners, tree planters, thinnings workers and nursery workers. The average age of the silviculture workforce is 25.8 years ± 7.7 (sd) with an average 4.2 years ± 4.5 (sd) of experience (Byers 1995 in press).

At the present time there is a drive by the New Zealand Forest Owners Association (NZFOA) to ensure that every person who works in New Zealand forests has, or is in training for, some Forest Industry Record of Skills (FIRS) modules by the first of January 1996 (Byers 1995 in press). This includes both the logging and silviculture sectors.

The silviculture workforce is made up of three major ethnic groups comprising of 52% Maori, 38% European and 9% Pacific Islander (Byers 1995 in press). Of the silvicultural workforce 58% have one or more FIRS modules with no differences in this percentage on the basis of ethnicity. The logging workforce has been exposed to more training; 76% have at least one FIRS module (Byers 1995 in press).

1.4 Study Background

Chainsaw pruning is a contentious issue at the present time. Although the use of chainsaw pruning is now widespread in some regions including the Hawkes Bay. Whether chainsaw pruning is a justified technique for pruning *Pinus radiata* forms the basis of the question...

"Is chainsaw pruning an acceptable work method ?"

To answer this question from an ergonomics perspective, the current research was commissioned by the Logging Industry Research Organisation (LIRO)[6] and CHHF (Central). The question was broken down by the researcher into hypotheses (see section 3.1) targeted at aspects of the pruning system.

The current research aims to compare components of high manual and chainsaw pruning systems of work using a cost-benefit approach within a framework provided by ergonomics. The criteria on which the research will focus are:

1. Safety
2. The comparative physiological cost of each system of work
3. The comparative prevalence of musculoskeletal complaints and discomfort between the two systems of work
4. Differences in productivity
5. Differences in the quality of pruning.

Chainsaw pruning is thought to be necessary because large diameter branches make manual pruning more difficult and strenuous. Soil and weather conditions, altitude,

[6] LIRO stands for the Logging Industry Research Organisation. LIRO is jointly funded by Government and industry and specialises in applied logging (and some forestry) research.

tree genetics and specific silvicultural regimes[7] in certain areas of the country promote the growth of branches with large diameters.

However, the use of chainsaws above the shoulder, up a ladder without a harness and at times with one hand is thought to be dangerous by many in the industry. At the time of this study, the Occupational Safety and Health Service (OSH) of the Department of Labour had not formally approved the general use of this technique of tree pruning and permitted chainsaw pruning only where there was a demonstrated need for the use of chainsaw pruning and the technique of the chainsaw pruner had been approved by an OSH inspector.

With the introduction of the Health and Safety in Employment Act 1992 (here after the HASE Act), there is a responsibility for forest companies as the principals of pruning contracts to ensure the safety of contractors and subcontractors (HASE Act 1992 s18{a}). Principals and contractors are expected to take all practicable steps to ensure that potential harm to employees and others in the workplace is minimised. "All practicable steps" is defined in section 2 of the HASE Act in terms of several considerations including the current state of knowledge:

2a. The nature and severity of the harm that may be suffered

2b. The current state of knowledge about the likelihood of the harm that may be suffered

2c. The current state of knowledge about the means to which this harm can be minimised and the likely efficacy of each of these means; and

2d. The availability and cost of each of these means. (HASE Act s2).

The current state of knowledge regarding the relative risks involved in chainsaw versus manual pruning is poor. This research will, through applied field research, evaluate the comparative ergonomic risks involved in manual and chainsaw pruning.

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[7] Variations in the silvicultural regime affect branch sizes. The silvicultural regime dictates the distance between trees which in turn affects the amount of light branches get which encourages or retards branch growth.

Furthermore, it will provide information relating to productivity and quality which are related to 'cost' as outlined above in section 2 (d) of the HASE Act.

1.5 Summary

This chapter has provided an overview of the research rationale. It was written in a manner to introduce the forester to ergonomics and the ergonomist to forestry. The next chapter reviews relevant literature and highlights those gaps in knowledge which the current research attempts to address.

Chapter 2 Literature Review

2.0 Introduction

This chapter will review the research that has been undertaken in the broad areas of safety, ergonomics, productivity and quality and specifically relate these areas to the forestry in general and silviculture in particular. Studies which form the basis of the knowledge used in the research will be reviewed with an emphasis on New Zealand research. Gaps in the literature will be identified and the contribution this research makes to the field will be outlined.

The chapter is divided into four parts. The chapter will begin with an overview of accidents and injury in forestry. Secondly, a model of injury causation will be presented and literature will be presented under four general headings within that model. Thirdly, the chapter will review literature on productivity and quality issues in the New Zealand forestry context and finally, the chapter will provide aims and objectives for the thesis.

2.1 Safety and Ergonomics

Internationally, the forestry industry is known to have a high rate of accidents, injuries and fatalities (Nordansjö 1988, Gaskin and Parker 1992, Meng 1991, Stone 1993, Marshall *et al.* 1994, Kawachi *et al.* 1994, Buchberger and Muhlethaler 1984, Slappendel *et al.* 1993). From these studies, forest workers have been identified as having a much higher rate of injury than baseline populations especially for musculoskeletal disorders (Buchberger and Muhlethaler 1984). Most of the work into the development of safe techniques and studies of other risk factors has been centred around the logging workforce with less attention being given to the silvicultural workforce (Slappendel *et al.* 1993). The high rate of fatalities in logging has provided impetus for research into safety that has not been witnessed in silviculture.

Most ergonomic research in New Zealand forestry has been conducted into logging (Vitalis 1986, Gaskin 1986, 1990, Gaskin and Parker 1992, Kirk 1992, Kirk and

Parker 1993b, Tapp *et al.* 1990, Parker 1991, 1992, 1993a, Parker *et al.* 1993, Parker and Kirk 1993). Historically ergonomics research into silvicultural aspects of the New Zealand forest industry has been somewhat lacking. Recently however, the pruning aspect of the silvicultural industry has been studied by Hartsough and Parker (1993a,b,c) and Kirk and Parker (1994:a,b,c). Both these studies focused on the physiological workload of low pruning Douglas-fir (from the ground up to 2.2m). However, the majority of the New Zealand forest resource is comprised of *Pinus radiata* and due to unequal branch size, and tree and branch characteristics the physiological workload of pruning Douglas-fir is not directly comparable with that of pruning *Pinus radiata*.

In a comprehensive review of the literature relating to work-related injury among forestry workers, Slappendel *et al.* (1993) identified a number of studies that have examined risk factors in forestry. The review took the approach of examining a four component socio-technical system within a model of injury causation. This basic outline can be used to cover those areas which have influence over the causation of injury and illness among silvicultural workers. The current research will follow the broad outline of this model as the prevention of injury and illness is the first aim of an ergonomics analysis. The model referred to the following socio-technical system components:

1. Personnel characteristics
2. Machinery, tools and equipment
3. Work organisation, and
4. The physical environment.

Before proceeding it must be emphasised that these are system components and as such they have important relationships between and among themselves.

2.1.1 **Personnel Characteristics**

Gaps in the literature have been identified for personnel characteristics of forestry workers in the link between the sensory capacities of workers and the recognition of signals relating to risks (Slappendel *et al.* 1993). Conflicting results were found in the literature for hazard perception by the people who face these hazards (Slappendel *et al.* 1993).

Risk and Hazard Perception

Research on hazard perception has been performed and summarised by a number of researchers (Zimlong 1985, Ostenberg 1980, Tapp *et al.* 1990, Helander 1991, Blignaut 1979a,b, Parker 1991, Parker and Kirk 1993, and Gibson 1994). Hazard perception is important because the detection of a hazard is a prerequisite to the avoidance of that hazard. Sanders and McCormick (1992) cite a study of 405 gold mining accidents by Lawrence (1974). It was reported that 36% of these accidents were due to a failure to perceive the hazard and 25% were due to under estimation of the hazard. Hence there is a real need for people in the work force to be made aware not only that a hazard exists, but also what relative risk that hazard represents. Accurate perception of hazards will enhance the capability of a person to reduce their own risk of injury. Under-estimation of a risk or hazard may lead to situations where a person will be injured as a result of the hazard.

Risk perception has been studied in the mining industry (Blignaut 1979a,b, Lawrence 1974), the construction industry (Helander 1991) and in the forestry industry (Pettersson and Ostenberg 1975, Tapp *et al.* 1990, and Ostenberg 1980, Parker 1991). Pettersson and Ostenberg (1975) and Ostenberg (1980) found that the hazards in the forestry industry were at times under-estimated and this was related to the influence of supervisors', the organisation of work and the need for better equipment. Hence the total relationship between personnel factors, the machines and tools they use, and the work organisation must be targeted to reduce the high accident rate in forestry. The current study will compare the accident rate between two methods of work (chainsaw and manual pruning) to investigate the relationship between organisation of work and the tools used with respect to the risk of accident and injury. Personnel factors *per se* will not be investigated in this research except for the perception of risk.

Education, Experience and Training

The experience, education and training of the silvicultural workforce has only recently been studied on a regional basis (Byers and Adams 1995). As already mentioned, the NZFOA has commissioned a report (Byers 1995) on the progress toward its goal to have every worker holding FIRS modules or be in training for one before the first of January 1996. At present 58% of the silvicultural workforce have completed some formal training in the FIRS program. Hence considerable effort will need to be put into the training and development of a professional forestry workforce in line with the NZFOA's goal.

Physiological Capacities and Demands

The physiological cost of work has, historically, been studied within the context of energy expenditure (Åstrand and Rodahl 1977). The classical approach to the study of the energy cost of a task was to measure oxygen consumption (V_{O_2}). This has been done in accordance with the established relationship that upon metabolic combustion, 1 litre of oxygen will yield 20 KJ of energy (Åstrand and Rodahl 1977, Grandjean 1988). Power output (watts) is measured on the cycle ergometer. From this power output, energy expenditure (joules) can be measured and hence oxygen consumption can be estimated.

The maximum volume of oxygen that a person's body can utilise dictates the duration and intensity of physical work that can be performed without reaching sustained anaerobic metabolism[8]. This volume can be measured by calculating what is called maximal oxygen uptake or $V_{O_2\ (max)}$. Once this has been performed it is possible to measure the percentage of a person's $V_{O_2\ (max)}$ that is being used to perform some task in order to assess the relative degree of stress being imposed on the persons cardio-vascular system.

[8] This does not refer to the initial oxygen demands of a task which results in a short period of anaerobic metabolism.

The physiological work capacity of forestry workers has been studied in the past in terms of measured oxygen consumption (V_{O_2}) (Kurumatani *et al.* 1992, Apud and Valdes 1993). The forestry workforce has been found to have a relatively high V_{O_2} $_{(max)}$ compared to other occupations which is due to the high physical demands of forestry work leading to the adaptation and self selection of workers (Kurumatani *et al.* 1992).

Due to the difficulties of measuring oxygen consumption directly (Åstrand and Rodahl 1977), it has become common place to estimate oxygen consumption indirectly from heart rate (Vitalis 1986). Similarly it is also common /estimate V_{O_2} $_{(max)}$ using heart rates during submaximal tests (Vitalis 1986). This method has been proven to be an effective estimator of maximal oxygen consumption with an accuracy of ± 15% (Rodahl 1989).

Grandjean (1988), Jeffrey (1984), Sato *et al.* (1986), Vitalis *et al.* (1986) and Vitalis (1986) all discuss the shortcomings of oxygen consumption as a measure of the total stress on the worker. Åstrand *et al.*' (1968) now classic study of nailing into a wall below, level with and above the level of the heart found pivotal evidence for the preference of heart rate over oxygen consumption. Oxygen consumption data were found to be insensitive to work performed above the heart (as is found in tree pruning) while heart rates, blood pressure and lactate concentrations did respond to this added stress.

Many researchers have used heart rate data and oxygen consumption data in their research in a way that takes into account the capacity of an individual's cardiovascular system (Åstrand and Rodahl 1977, Fibiger and Henderson 1984, Hartsough and Parker 1993a,b, Kirk and Parker 1994, Rodahl 1975:1989, Smith *et al.* 1985, Tomilson and Manenica 1977, Vik 1984, Vitalis 1988, Vitalis *et al.* 1994). Vitalis (1986) states the need for such relative measures. The relative V_{O_2} (max) score ($ml.kg^{-1}.min^{-1}$) is in effect a power to weight ratio and is much more relevant to the individual than a gross measure such as absolute V_{O_2} $_{(max)}$. This concept is parallelled in the approach taken when considering heart rate at work. Rather than simple heart rate response, a relative index of *%HRR* can be used. Absolute heart rate responses are meaningless in themselves. They tell us nothing of the stress relative to the capacity of the individual. Relative measures provide far superior indicators of the stress being placed on the individual.

The direct measurement of oxygen consumption in the field proves problematic due to the bulkiness of the equipment that must be used (Vitalis *et al.* 1986). The advent of portable measurement devices such as the PK Morgan Ltd oxylog[9] means that direct measures of oxygen consumption in the field are possible, although only in tasks where space is not restricted. It is far more practical and comfortable for research subjects to wear a portable heart rate monitor such as the PE 3000 sport tester (Polar Electro, Finland). In the case of chainsaw pruners, heart rate recording is made possible by 'hard-wiring' the heart rate monitors with shielded wire (Gaskin 1990). Hard-wired heart rate monitors are shielded from the electrical interference that is emitted from the ignition system of the chainsaw.

Ergonomic studies have measured the physiological stress response to forest work in Canada (Trites *et al.* 1993, Giguere *et al.* 1993, Robinson *et al.* 1993, Bannister *et al.* 1990). Trites *et al.* (1993) studied the cardiovascular and muscular strain of tree planters in British Colombia. Heart rate data were recorded which showed an average Percentage Heart Rate Ratio (%HRR) of 39.2%. Various blood chemistry markers were analysed to assess the degree of fatigue experienced by workers. Pre and post-work levels showed significant differences ($p < 0.01$) in elevated serum enzyme activities which increased, while blood haematology parameters decreased over the course of the planting season. These changes are presented as evidence of both the high physiological stress leading to limited strain of tree planters, and also as evidence of the physical adaptation of workers to their task.

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[9] The oxylog is an ambulatory unit which measures the concentration of oxygen in the expired air, and rates of ventilation.

Recent studies have used heart rate to estimate the physical stress of forest work on workers both in New Zealand (Parker and Kirk 1994, Parker 1992, Hartsough and Parker 1993a,b,c, Kirk and Parker 1994, Parker 1992, Trewin and Kirk 1992, and most recently Parker *et al.* 1995) and overseas (Vik 1984, Fibiger and Henderson 1984, Trites *et al.* 1993, Giguere *et al.* 1993, Robinson *et al.* 1993, Bannister *et al.* 1990, Apud *et al.* 1989). Heart rate has been identified as a better indicator of the total stress on the body than the simple energy expenditure-oxygen consumption relationship (Grandjean 1988, Jeffrey 1984, Sato *et al.* 1986, Vitalis 1986, and Vitalis *et al.* 1986). There is a continuing trend to present indicators of physical stress as measured by stress response (increases in heart rate) in terms of relative measures specific to the individual. Vitalis *et al.* (1994) presented their data on the heart rates of steel workers in the form of relative measures.

Recently Hartsough and Parker (1993a,b,c), and Kirk and Parker (1994) have studied the physiological cost of manual and chainsaw pruning of Douglas-fir. Their results point to pruning as having a tentative physiological workload classification as "moderate" to "heavy work" within the classification system offered by Rodahl (1989). Further investigation into the different methods of pruning work on different tree species will allow the relative physiological costs of manual versus chainsaw ladder pruning to be assessed.

Body Composition

To make comparative studies of the physiological workload on people at work it is important to account for the soma-type of the people being studied. Not only will this allow more valid comparisons but it will give an indication of the subject's likely state of health. The distribution of fat on the body is an important physiological variable because fat around the waist (central obesity) represents a greater risk of coronary heart disease than fat deposits around the thighs or buttocks (Hubert *et al.* 1983, Egger 1992, and Watson 1993). Fat around the flank, waist and abdomen is more metabolically active than fat stores around the peripheral areas of the body such as the thighs and buttocks according to a study by the National Institutes of Health Consensus Development Panel on the Health Implications of

Obesity (Anon 1985). Results from large epidemiological studies carried out in Sweden show that pear shaped people are less likely to develop coronary heart disease and diabetes, than apple shaped people (central obesity), who have an increased risk (Watson 1993). This emphasis in the recent research literature on where fat is stored on the body is warranted as it has been found to be a robust predictor of coronary heart disease (Anon 1985, Egger 1992, Hubert *et al.* 1983, and Watson 1993).

The body mass index (BMI) is a measure of body bulk (Watson 1993). Most of the time a high BMI is associated with excess fat. However, in the case of some physically active people and people with a 'heavy' soma-type this index can be misleading because they will have a greater proportion of muscle/bone mass which has a greater density than fat. Egger (1992) states that the predicability of waist-to-hip ratios (WHRs) can be enhanced by combining assessments with the BMI. This will be undertaken in the current research.

Perception of Physiological Demands

The perception of exertion and subsequent fatigue is important for industrial workers as fatigue is expressed in the attitude, orientation and adjustment of the worker (Yoshitake 1971). Furthermore, Giefing (1993) found that in tree pruning, the effect of social isolation increased the perception of fatigue and that this could not be accounted for in non isolated workers performing the same work. When pruning with a chainsaw the pruner is more socially isolated due to the noise of the chainsaw and the subsequent hearing protection that is worn.

The perception of exertion is influenced by two main physiological systems: the cardio-pulmonary system (central exertion) and the musculoskeletal system (local exertion) (Pandolf 1978). There is not only a close relationship between the physical load and the perception of effort and exertion but also between the perceived exertion and other symptoms that indicate medical illness (Borg 1985). Hence the perception of exertion gives vital feedback to a person about their pending state of health and allows them to adjust their work pace accordingly. The constant cybernetic feedback and control of exertion of the human system in light of Lundgren's natural effort limit (cited by Vik 1984) limits the objectively measured physiological cost of work to around 40% heart rate range or around 33% V_{O_2} $_{(max)}$ for most workers. The results of forestry research into the physiological cost of relatively self paced (piece rate) work in New Zealand (Hartsough and Parker 1993a,b,c, Kirk and Parker 1994a,b), and overseas (Apud 1989, Durnin and Passmore 1967, Vik 1984, and Fibiger and Henderson 1984) provides strong evidence to support this concept.

Rated perceived exertion has been studied in the Norwegian forest environment by Hagen *et al.* (1993). They found a moderate relationship ($r = 0.77$ $p < 0.001$) between RPE and heart rate in the laboratory situation but not so in the field ($r = 0.38$ $p > 0.05$). Suggestions that the laboratory situation involved a graded increase in effort are postulated to account for the difference in the two conditions. The far stronger correlations seen in the purely physical sciences are not seen between RPE and heart rate and should not be expected. Paradigms have been developed in some applications of science whereby correlations below $r = 0.8$ are considered to have limited worth. Indeed there could be a strong case not to compare RPE with heart rate at all. However a norm has been established in the literature and this will be followed in the research. To date there has not been any literature published which has assessed the RPE of forestry workers in New Zealand.

Musculoskeletal Discomfort

Putz-Anderson (1988) identifies musculoskeletal disorders as the prime disablers of working adults. Musculoskeletal disorders including strains and sprains have been reported to the LIRO silvicultural accident reporting scheme (ARS)[10] (Parker 1993:1994). While sprains and strains form 18% of all lost time injuries (LTIs) in the silvicultural workforce (Parker 1993), they are not the prime disablers of New Zealand forestry working adults in terms of the LTIs reported to the LIRO ARS. However, there may be some under reporting of strain type injuries to the ARS. It

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[10] The ARS is a voluntary scheme for the forestry industries in New Zealand. The ARS is supported by the New Zealand Forest Owners Association and is administered by LIRO.

may be concluded that musculoskeletal disorders (excluding bruising) are still a leading cause of LTI among forestry workers.

Pain and discomfort, like perceptions of exertion, provide essential warnings to 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, Wiker *et al.* 1990). Musculoskeletal pain and discomfort is therefore a good predictor of any over-exertion, the build up of fatigue, and impending tissue damage. Stressors on the musculoskeletal system which will overload the adaptive capacity of the individual will 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.

Corlett (1990) describes various measures for the assessment of musculoskeletal pain and discomfort and the prevalence of musculoskeletal disease. These include experimental studies to quantify the decay of the maximum voluntary contraction (MVC) of a muscle over time, electro-myographic monitoring of the electrical activity in a muscle, subjective methods of assessment of musculoskeletal discomfort, and retrospective musculoskeletal disorder surveys such as the Nordic musculoskeletal questionnaires. The Nordic musculoskeletal questionnaires (a more recent development of which is known as the HSE questionnaire) and body part discomfort (BPD) surveys are the cheapest and quickest way to assess the prevalence and prevalence of musculoskeletal disorders in the applied setting. The subjective assessments of subjects are found in the case of BPD surveys by showing a body part diagram with a Likert scale which rates discomfort. The HSE questionnaires are filled out by subjects individually or with help from researchers.

Biomechanical analysis of two delimbing techniques has been performed in New Zealand (Gaskin *et al.* 1988). However, this research did not assess the comparative discomfort of the chainsaw operators for each technique and was limited to a two dimensional static biomechanical model. A more sensitive measure of the load placed on the individual should ideally include a three dimensional dynamic biomechanical model and the BPD perceptions of the operators. However, as the technology required for a three dimensional biomechanical model is prohibitively expensive and a two dimensional model of the pruning task would be inappropriate a BPD survey would provide valuable insights into the biomechanical and musculoskeletal loadings experienced by research subjects. While there have been studies done to assess musculoskeletal loads and prevalence of disease via use of BPD and HSE questionnaires in other industries (Johansson 1994, Putz-Anderson 1988, Stuart-Buttle 1994) there have not been any attempts to do so with forest workers in New Zealand.

2.1.2 **Machinery, Tools and Equipment**

Studies on the correct usage of safety equipment (Sullman 1994) and personal protective equipment (Kirk and Parker 1992,1993) in the New Zealand forests have demonstrated the ongoing concern of the forestry industry with the impact of equipment design on safety. In Chile ongoing ergonomics research into forestry tools and work methods is being carried out. Recently Apud and Valdes (1993) studied two techniques of pruning *Pinus radiata*. Pruning with a pole saw (6m) was compared to pruning using a ladder and saw. From an ergonomics standpoint, ladder pruning was the best option. Benefits such as improved quality and quantity of production, more favourable working postures, less static loading and identical physiological costs are weighed against costs such as a higher risk of accidents.

There have been a number of studies done on optimising tool design for pruning operations in New Zealand (Everts 1984, Hall and Mason 1988, Hall 1986,88, Hall *et al.* 1986, Thompson 1970). This work focused on the efficiency of use and durability of manual hand held pruning tools. These studies constitute an indirect form of biomechanical assessment. Hall (1988) found significant differences in the force required to sever branches of varying diameters using blades of varying thickness. No direct biomechanical assessments were performed on people using these tools however. A complete biomechanical analysis of pruning work would provide valuable information for a comparative study of manual and chainsaw pruning in terms of both tool design and musculoskeletal loading. However, such an undertaking is outside the scope of this study due to the unavailability of suitable equipment and the need to limit the scope of the study.

Recently, Parker *et al.* (1995) studied the physiological workload of delimbing with three different size chainsaws. Many loggers in New Zealand use large and consequently heavy chainsaws for both felling and delimbing. The aim of this research is to provide information for the optimal weight of chainsaw as applied to specific tasks and encourage the use of the right tool for the job. There has not been any ergonomic evaluation of pruning chainsaws to date.

One of the most important tools to the pruner is the ladder. Within industry in general, of the accidents that occur on raised surfaces, approximately 70% occur with ladders (Juxptner 1976). A number of studies have been undertaken on ladder fall accidents (Cohen and Lin 1991, Bloswick and Chaffin 1987) and design features of ladders (Bloswick and Chaffin 1987, Chaffin and Stobbe 1979, Juxptner 1976, Redfern and Bloswick 1987). In New Zealand, Parker (1992) reported that 36% of all silvicultural accidents were due to falling off the ladder. Variables that have been identified as having the most impact on the safe use of ladders are rung separation, ladder slant, rung surface properties and ladder placement. Recently, new designs of silvicultural pruning ladders have been developed and field tested by a forestry company in New Zealand.

2.2.3 The Organisation of Work

Pruning work is contracted out to 'Contractors' who employ pruners on a piece rate basis. Pruners are paid on a per tree basis, and as such, are 'Subcontractors'. Experience from Swedish forestry has shown that the abolition of piece rates in forestry was accompanied by a greatly reduced injury rate (Nordansjö 1988). However, other factors were influential in this decline including the introduction of safer chainsaws with kickback guards and automatic chain breaks, purpose built chainsaws, legislation to ensure protective clothing was supplied and worn, and a move towards mechanisation (Nordansjö 1988). While these measures have been adopted in New Zealand forests, total mechanisation is unlikely to occur in New Zealand in the near future due to the steep terrain of many forest areas.

Personal protection measures have been adopted in New Zealand forests but the injury rate to silvicultural workers remains high compared to other industries (Marshall *et al.* 1994, Kawachi *et al.* 1994, Parker 1993). Pruners who use chainsaws are required within the scope of their contracts to wear protective leg wear, safety helmets, safety boots, and hearing protection in order to meet the requirements of the HASE Act. Under the same reasoning, manual pruners are at present only required to wear safety boots.

Of all silvicultural LTIs reported to the LIRO ARS, pruning accounted for 71% in the 1990-1991, and 41% in the 1992 periods respectively (Parker 1992,1993). There is no data on the relative proportions of LTIs that can be attributed to either manual of chainsaw pruning. This thesis will attempt to examine the relative differences in the LTIs of chainsaw and manual pruners.

2.2.4 The Physical Environment

The physical environment introduces important variables into forest work. Issues of climate, terrain, flora, and lighting have been identified as variables which can affect the safety and productivity of people at work in the forest (Slappendel *et al.* 1993). The most important of these variables in the pruning environment are the thermal load on the person, the slope of the ground and the amount of slash and obstacles encountered while walking between trees. Lighting is not so important in the pruning situation as the trees are still young and canopy closure has not yet occurred and all pruning is done during daylight hours.

Vitalis (1986, 1987, 1988) found that thermo-regulation has a significant role in heart rate response whereas oxygen consumption proves to be insensitive. Thus it would seem that again heart rate responses are more sensitive to the total strain on the human system than changes in oxygen consumption and therefore provide a better estimate of the relative physiological cost to the individual than does oxygen consumption. Even though New Zealand is in a temperate climatic zone, there are still some situations where the thermal load on workers is considerable. Research into how the forestry thermal environment affects workers is currently being carried out by LIRO to assess the thermal load on breakerouts (P. Kirk pers. comm.).

The effect of ground slope in forestry work has been identified as a key physiological variable (Trewin and Kirk 1992, Vik 1984, Fibiger and Henderson 1984, Kirk and Parker 1992, Hartsough and Parker 1993a,b). Fibiger and Henderson (1984) noted that heart rate and percent V_{O_2} (max) correlated closely with slope, more so than with work output. Vik (1984) cites Lundgren's theory that as the "natural effort limit" is exceeded, work output will be reduced. At this limit the *stress* on the body will become *strain* and homeostasis will be upset. Evidence of this was found in Vik's study in Norway where each worker was his own control; steep terrain (slope > 30°) one day and normal terrain the next day. While no significant differences were found in % V_{O_2} (max) at work, average work output decreased from 3.6 cubic metres per hour ($m^3.hr^{-1}$) on normal terrain to 1.4 $m^3.hr^{-1}$ on steep terrain.

The effect of flora has been accounted for in many studies of physiological work load in the forests of New Zealand (Hartsough and Parker 1993:c, Kirk and Parker 1992, and Parker and Kirk 1994). Being constantly hindered will decrease the productivity of a forestry worker, as according to Lundgren's natural effort limit, this will cause a decrease in the work pace in order to maintain a relatively constant physiological workload.

2.2 Productivity and Quality

It has been found that where design improvements can be made which improve comfort and useability there are usually subsidiary benefits such as improved productivity and \ or quality (Sanders and McCormick 1992). Simpson and Mason (1990) discuss productivity as a legitimate objective in ergonomics.

Labour productivity has been studied in the forest environment in Norway (Vik 1984), Canada (Trites *et al.* 1993), Australia (Fibiger and Henderson 1984) and in New Zealand (Kirk and Parker 1992:1993, Gaskin *et al.* 1988, Hartsough and Parker 1993:c). Quality has also been studied in the New Zealand forests (Parker and Cossens 1993, Gaskin *et al.* 1988, Brown 1977, and Vaughan and Biddle 1987).

Hartsough and Parker (1993a,b,c) and Kirk and Parker (1994a,c) both studied the productivity of pruning Douglas-fir. However, these studies had small sample sizes (n = 2 and n = 1 respectively) so little inference could be made regarding other pruners. No data on quality of pruning was reported in either of these studies.

2.3 Cost-Benefit Analyses

Cost-benefit analyses were originally developed by economists due to the need to evaluate outcomes of economic policies in a wider context than direct financial returns (Corlett 1988). The cost-benefit approach is used widely within science and industry, including within the ergonomics field. In a review of cost-benefit analyses Corlett (1988) describes cost-benefit analyses that have taken place in advanced manufacturing organisational systems such as Volvo and Saab. Further cost-benefit techniques have been applied in the area of risk management and safety (Fine 1971, Farmer 1983, Kastenberg and Cave 1990). Most of these cost-benefit analyses have focused on attempts to estimate the financial costs and benefits to companies due to effects that ergonomic and safety interventions have on work attitudes, quality, safety, and other workforce performance indicators. In the main, this has been done in an attempt to persuade management to both adopt and fund ergonomic \ safety interventions in the workplace.

No literature has detailed cost-benefit proceedures to compare jobs, tasks or techniques. Similarly, the current literature does not provide methodological guidelines for researchers to follow when performing cost-benefit analyses above programs with a monetary base. Hence, this thesis will develop cost-benefit decision criteria specific to the hypotheses which will be tested (refer to section 3.1).

2.4 Summary

This chapter has reviewed much of the relevant literature and has not only identified gaps where further research is warranted but also those areas and methods of research that will be carried on with in the current research. Specifically, the current research proposes:

1. To provide comparative data on the rate of injury to silvicultural pruning workers,
2. To catalogue the hazard frequency and the risk of injury in chainsaw versus manual high pruning of *Pinus radiata*,
3. To detail the perceptions of hazard frequency that silvicultural pruners have, and to compare these perceptions to objectively observed hazard frequencies,
4. To compare the physiological cost of manual and chainsaw high pruning of *Pinus radiata* by using relative heart rate measures,
5. To establish the relationship of rated perceived exertion to heart rate between manual and chainsaw high pruners of *Pinus radiata,*
6. To compare the biomechanical and musculoskeletal loads imposed on pruners when using the two different methods of high pruning *Pinus radiata*, by using body part discomfort and musculoskeletal disorder questionnaires,
7. To compare the productivity between chainsaw and manual pruners when high pruning *Pinus radiata* while accounting for differences in branch sizes,
8. To compare the quality of pruning between each of the two techniques.

Chapter 3 Methodology

3.0 Introduction

This chapter details the research design, the procedure for subject selection, describe the specific methods used in the collection and analysis of data and analysis, and should provide sufficient detail so that another person apart from the researcher could pick up this section and be provided with adequate explanation to repeat the research.

3.1 Research Design

A quasi-experimental[11] design was undertaken in order to determine the cost-benefit of chainsaw versus manual high ladder pruning from an ergonomics perspective. The following general question is examined.

"Is chainsaw pruning an acceptable work method ?"

This question formed the basis for the development of hypotheses within a conceptual framework provided by ergonomics. This question was broken down into general hypotheses (level 1). The general hypotheses were expanded into operational hypotheses (level 2).

General Hypotheses (1st level)

1. Chainsaw pruning is more hazardous than manual pruning.
2. Chainsaw pruning has the same physiological cost as manual pruning.
3. Chainsaw pruning will be associated with a lower prevalence of musculoskeletal problems than manual pruning.
4. Chainsaw pruning is more productive than manual pruning.
5. Chainsaw pruning will produce more quality defects than manual pruning.

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[11] A quasi-experiment is an experiment in the field setting where many extraneous variables cannot be isolated or controlled as can be done in a laboratory type experiment.

Operational Hypotheses (2nd Level)

1a. Chainsaw pruners are exposed to more "significant hazards" than manual pruners.

1b. The accident frequency rate for chainsaw pruners will be higher than the accident frequency rate for manual pruners.

1c. The severity of chainsaw pruning accidents will be greater than that for manual pruning accidents.

2a. Chainsaw pruners and manual pruners will experience the same relative heart rate response.

2b. There will be no relative difference in the Rated Perceived Exertion (RPE) of manual and chainsaw pruners.

3a. Manual pruners will experience a higher prevalence of musculoskeletal disorders than chainsaw pruners.

3b. Manual pruners will experience more Body Part Discomfort (BPD), in more body areas and to a higher level, than chainsaw pruners.

4a. Chainsaw pruners will have a higher rate of productivity than manual pruners.

5a. Chainsaw pruners will have a higher rate of tree damage events per tree than manual pruners.

The first level hypotheses provide the broad outline and rationale for Sections 3.6 to 3.10. Within these sections the methods used to enable the testing of each of the operational (second level) hypotheses are examined. Where appropriate, statistical tests of significance are described.

3.2 A Quasi-Experiment: Sample Size and Subject Selection

Sample Size

The total sample size was eight subjects. The sample was evenly split between the chainsaw and manual pruners with four subjects in each group. The reasons for the sample size selected were that:

1. At the time of year when the study was being carried out (winter), most of the pruning labour force was involved in planting work. There were however a core of experienced pruning workers that were retained throughout the winter, and
2. The work performed by this sample was comprehensive enough to be representative of the work performed by pruners while still allowing the researcher to complete the research in the specified period.

Each subject was studied for three complete work days[12], Tuesday to Thursday inclusive, except one subject who was studied from Tuesday to Friday.

Subject Selection

Subject selection was non-randomised. It was not possible to have control over the subjects selected for the study. Subject selection was arranged by Carter Holt Harvey (CHH) Central Region's Safety and Training Officer. The researcher did, however, have control over subject rejection. If a subject was rejected for the study, none of that person's data would be included in any part of the analysis. Additionally, provision was made for partial rejection of subjects who did not meet the established protocol for a specific part of the research.

Ten subjects were selected of whom eight participated in the study. Two subjects were fully rejected. In the first case the subject was using a method of manual pruning which was significantly different from the rest of the pruners in the cohort. In the second case the pruner was working to a different prescription[13] than the others in his cohort. In the latter case the prescription the pruner was instructed to work to would have adversely affected the frequency of hazard occurrences in particular and possibly other aspects of the study such as physiological costs, body part discomfort, productivity, and quality.

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[12] There was no 'normal' work day for the pruners in this study. Some pruners started and finished later than other pruners (7:00 am - 3:00 pm). The workday would generally not start before 7:00 am nor finish after 5:00 pm. In addition, the work day would not 'normally' exceed 7 hours.

[13] A pruning prescription details the pruning height and the stocking rate (sph) that the pruner is to prune to.

Two of the eight subjects were only partially included in the analysis. Of these two subjects, one was a chainsaw pruner and one was a manual pruner. The reason for partial non-inclusion in the study for the chainsaw pruner was that in the first three days of the working week he was performing 'rework'. After careful consideration, the data for these days were omitted from the analysis because this operation was not fully representative of the pruning task. In the case of the manual pruner, the final days data were not included in the analysis due to the subject contracting a severe viral infection. The consequences could have introduced error into the physiological data, production data, and quite conceivably the musculo-skeletal, psycho-physiological and quality data.

Risk Score Questionnaire and Retrospective Accident Survey Sample

Data were also collected in the Hawkes Bay area on pruners' perceptions of hazard frequency, consequences and likelihood. Simultaneously, a retrospective accident history survey was carried out. The sample sizes for the questionnaire and survey were n = 24 manual pruners and n = 30 chainsaw pruners. The sample was drawn from pruners working for CHHF (Central Region) and was intended to encompass all of the organisation's pruning workforce. However, due to time limitations a complete census was not possible. Notwithstanding this, the sample resulted in an almost complete workforce coverage[14].

3.3 Statistical Design for Quasi-Experiment

In order to test the hypotheses two groups of subjects were needed. One group being chainsaw pruners and one group being manual pruners. Attempts were made to control for variables which may have affected the measures under investigation as set out in the second level hypotheses presented above. This allowed for optimal validity, given the constraints of applied research, when testing the hypotheses with data collected in the field. Hence a quasi-experimental design was established.

The intra-subject and inter-subject variability was accounted for in the study design by breaking the data down into half days (before and after the lunch break) and using

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[14] Approximately 90-95% of the CHHF (Central) pruning work-force completed the questionnaire.

a small sample t-test for inferential analysis. This gave an initial sample size of 3 days x 2 sampling periods per day x 4 pruners = 24 sampling periods for each of the two methods of pruning in the study. Pruners have no set time to take their lunch breaks, so are self paced in this respect. It could not be assumed that the data were normally distributed on an intra-subject basis from morning to afternoon, from day to day nor on any inter-subject basis. The use of the small sample t-test is explained below.

The research design which was used took the average of each sampling period (morning or afternoon) and calculated the average of these averages and the standard deviation of these averages. Under this method, normality can be assumed as the sampling distribution of averages is normal irrespective of the distribution of data in each data set. The sampling distribution of averages has a mean of $\mu_{\bar{x}} = \mu$ and a standard deviation of $\sigma_{\bar{x}} = s/\sqrt{n}$ = SE or the standard error of the mean. This is in accordance with the premises of the central limit theorem (Freund 1988). The small sample *t*-test statistic used was as follows..

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{s_1^2(n_1 - 1) + s_2^2(n_2 - 1)}{n_1 + n_2 - 2}\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

This small sample *t*-test was used in all tests except for the analysis of the BPD data where a large sample binomial test was used. The manner in which the data were divided into half days had the effect of increasing the sample size, and hence the number of degrees of freedom (n_1+n_2-2 *df*), for use in inferential analysis of the hazard, heart rate, RPE, production, tree characteristics, and quality data.

The results of hypothesis testing were interpreted from a cost-benefit perspective. That is to say, the overall merits of chainsaw pruning were weighed up against the overall costs, and recommendations were made on this basis. These recommendations were made with the pruner as a first priority and the overall production system as a second priority.

3.4 Ethical Approval

The research protocol received ethical approval, after minor alterations to the consent forms and information sheets, from the Massey University Human Ethics Committee. This committee is set up to administer a code of ethical conduct for research on human subjects.

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. There were no concerns about the submaximal exercise testing to establish the estimated V_{O_2} (max) of the subjects, as established protocol was adhered to,.

3.5 Subject Characteristics

This section of the research details the variables which were used to characterise the subject, and the method of collection for these measures. This section also details the method by which aggregate characteristics for each of the two groups of pruners were calculated.

Age

Data for the ages of the subjects were collected from self-reports during the administration of the HSE questionnaire (see Appendix 1).

Body Mass

The body mass[15] of subjects was measured using mechanical (Hanson Ireland) weigh scales on a hard surfaced floor.

Height

Subjects stood barefooted with their backs to a wall which had a temporary, incremental centimetre (cm) scale attached to the wall. Stature was found by using a

[15] The common usage for the term 'body mass' is 'body weight' or simply 'weight'.

hard ruler in the horizontal plane on the top of the pruners head. The point where the ruler touched the wall was taken as height.

Body Mass Index

Body mass indexes were found by using the following formula:

$$BMI = \frac{Body\ mass}{Height^2} \times 10{,}000$$

Where body mass is measured in kilograms (kg), and height in cm.

Waist to Hip Ratios

Waist to hip ratios (WHRs) were found by using the following formula.

$$HR = \frac{Waist\ girth}{Hip\ girth}$$

Where:

1. Waist girth was measured as the minimum horizontal circumference between the lower ribs and the iliac crest in cm, and
2. Hip girth was measured as the horizontal circumference around the maximum protrusion of the buttocks in cm (Watson 1993).

Waist measurements were performed over bare skin while hip measurements were performed with clothes on the subject. An arbitrary correction factor of 0.5 cm was taken off the hip girth to account for the effect of clothing. This was done as it was thought that hip girth measurements over the bare skin could be embarrassing for the subjects.

Estimated V_{O_2} (max)

VO_2 (max) was estimated by using cycle ergometry. An established protocol was used to assess subjects' V_{O_2} (max) scores in litres per minute ($l.min^{-1}$). The protocol adhered to can be seen in Appendix 2.

Age-corrected V_{O_2} (max)

Correction factors for the effect of age on V_{O_2} (max) were applied to all estimated V_{O_2} (max) scores. The correction factors as presented in Åstrand and Rodahl (1977) are shown below in Table 3.01.

Table 3.01 Age Correction Factors for V_{O_2} (max) Estimates

Age of Subject	Correction Factor
15	1.10
25	1.00
35	0.87
40	0.83
45	0.78
50	0.75
55	0.71
60	0.68

A graph was drawn which joined each *x,y* coordinate of age and correction factor respectively on standard grid lined paper using the correction factors of Apud (1989) shown in Table 3.01. The correction factors for the subjects whose ages fell between the values shown in Table 3.01 were interpolated from this graph. The graph joined *x,y* data points with straight lines.

Relative V_{O_2} (max)

Relative V_{O_2} (max) was found by dividing the absolute V_{O_2} (max) in $l.min^{-1}$ by the body weight in kilograms with a conversion of estimated V_{O_2} (max) into millilitres of oxygen per minute ($ml.min^{-1}$) as shown below:

$$\dot{V}_{O_2}\ ml.min^{-1}.kg^{-1} = \frac{\dot{V}O_2\ (max)\ (l.min^{-1})\ x\ 1000}{Body\ mass\ (kg)}$$

Body masses were found as described above.

Additional information

Additional information was also collected. This information included whether the subject smoked cigarettes and whether the subject drank tea or coffee at work.

Averages

The personal characteristics data described above were averaged in an attempt to obtain aggregate measures of the two groups of pruners under study.

3.6 Hazard Identification and Analysis

Significant hazards were identified[16] according to the FIRS module 2.4 'Silvicultural Pruning' and from the personal experience of Messrs O'Leary and Saunders. It was not thought practical to monitor all hazards involved in the pruning task, rather only those which were considered to be significant (ie those which pose the greatest risk) were evaluated. In terms of the HASE Act all the hazards monitored are "significant hazards". Significant hazards are defined in section 2 of the HASE Act as a hazard that is an actual or potential cause or source of :

(a) Serious harm: or

(b) Harm (being harm that is more than trivial) the severity of whose effects on any person depend on (entirely or among other things) on the extent or frequency of the person's exposure to the hazard: or

(c) Harm that does not usually occur, or usually is not easily detectable, until a significant time after exposure to the hazard.

Each of the hazards included in this study are sources of serious harm and are therefore "significant". Serious harm, as defined in the first schedule of the HASE Act includes, among other things "musculoskeletal disease,"...and..."bone fracture, laceration, crushing". These are all possible outcomes of the hazards that were monitored in the study.

The same hazards were monitored for chainsaw and manual pruners (see Tables 3.02-3.07 below). By monitoring the same hazards it was thought that direct comparisons could be made. This was in keeping with the original cost-benefit objectives of the research.

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[16] The suggestions for the identification significant hazards came from personal communication with Mr Brian Saunders and Mr Chris O'Leary. Brian Saunders is the safety and training officer for CHHF (Central) and Chris O'Leary is an ergonomist working for CHHF (Central).

3.6.1 **Definitions of Hazard Classes**

The six hazard classes recorded are shown below in Tables 3.02-3.07.

Table 3.02 Ladder Hazards

Hazard-1	**Ladder hazards**
Description	1. When the ladder was in an unstable position 2. When the ladder could not be placed firmly against the stem of the tree, or 3. When a pruner descended the ladder two or more rungs at a time.
Possible Consequences	Fall from the ladder. Catch legs in between rungs as the pruner is falling backwards.

Table 3.03 Cutting Large Branches Above the Head

Hazard-2	**Pruning large branches directly above the head**
Description	Pruning a large, heavy branch directly above the head and the shoulders.
Possible Consequences	Risk of being knocked off the ladder by the branch. Risk of being hit on the torso, head or in the face with the branch.

Table 3.04 Cutting across the Arms or Legs

Hazard-3	**Cutting across the arms or legs with the saw**
Description	When the chainsaw or jacksaw is in the immediate vicinity of either the legs or arms. This occurs when the pruner crosses the body to prune a branch rather than using the saw in the other hand.
Possible Consequences	Cuts to the lower arms and upper legs.

Table 3.05 Overreaching Hazards

Hazard-4	**Over reaching from the top of the ladder**
Description	When a pruner is stretched up onto the tip of the toes in order to prune a high branch.
Possible Consequences	Sprain injuries. A fall from the top of the ladder.

Table 3.06 Cutting Branch Too Close to the Stem Hazards

Hazard-5	**Pruning a branch under tension, too close to the stem**
Description	Some branches are in tension on the top side of the branch and in compression on the under side much more so than other branches. These are usually the heavier branches. Normal operating procedure is to prune these types of branches 30 cm out from the stem before the final cut next to the stem. When this precaution is not taken the potential hazard has not been eliminated.
Possible Consequences	Being hit by the branch in the face or other parts of the body and falling off the ladder.

Table 3.07 Holding on to the Branch Being Cut Hazards

Hazard-6	**Holding onto the branch being pruned**
Description	When the pruner is holding the branch which is being pruned. This is usually done to enhance balance. However, when the branch is actually pruned through it may take the pruner by surprise and cause a sudden loss of balance.
Possible Consequences	Falling from the ladder.

3.6.2 Method of Collection for Hazard Frequency Data

Basis of Monitoring Hazards Using Continuous Time Study

Hazard frequency has been studied by continuous time study in the past by New Zealand researchers (Kirk and Parker 1992:1993, Parker and Kirk 1993, Parker, Gaskin and Kirk 1994). Continuous time study allows for complete data capture and more meaningful analysis of any data collected. As such it provides superior results to activity sampling as the use of this method can lead to not observing hazards of short duration.

Observed Frequency of Hazard Occurrences

Hazard frequency data were collected using continuous time study (direct observation). All data were collected by the researcher. Records were made using the continuous time study program "Siwork3" (Rolev 1988) running on a Husky Hunter field computer. The data were summarised in the form of a rate based on the number of hazards per tree. For the purposes of the risk score, observed hazard frequency data were transformed according to the descriptors of Fine (1971).

Data collection was carried out for three consecutive work days for each subject (Tuesday to Thursday inclusive) where operational constraints allowed. Operational constraints such as bad weather, sickness, pruning to different prescriptions, and equipment failures meant that it was not always possible to gain three days of data for each research subject. The vantage point from where the direct observation was carried out was as close to the pruner as safety would allow. This was usually 3 - 8 metres away from the tree being pruned.

Means and standard deviations were calculated by including all valid data. Notes of errors were made in the field to identify which tree cycles were not to be included in the study due to the researcher inadvertently hitting wrong buttons on the field computer, or not being able to see the research subject clearly. The data that were considered valid were all the remaining hazard occurrences after these errors in data files were edited out. Non occurrences, that where frequency = 0, were included in the data sets as they are a valid frequency of occurrence. The average individual frequencies (morning and afternoon) of hazard occurrence were approximately normally distributed on an intra and inter daily and subject basis

Tests that were performed on the data were standard *t*-tests (see section 3.1). Data for the tests came from half day averages of hazard frequency. The sampling distribution of averages is normally distributed with the sample mean and population mean being equal. The variation between these averages that was used in the statistical testing was the standard error of the mean. Both of these fundamental assumptions are in accordance with the Central Limit Theorem (Freund 1988).

Perceived Frequency of Hazard Occurrences

Perceived hazard frequency was derived from questionnaire data. The questionnaire design was based around the concepts of Fine (1971) which were modified to cover the hazards listed above in section 3.6.1. Perceived hazard frequency came from self-reports of pruners. A questionnaire was administered to pruners by the researcher while they were at work and at pre-arranged meeting places on route to work.

An attempt was made to capture the whole pruning work force in the Hawkes Bay area. The specific area was delineated by CHHF's Hawkes Bay forests rather than any Regional boundaries. The area covered was from Mohaka forest in the North to Pohurakura forest in the North-West to Kaweka forest in the West and to Gwavas forest in the South-West. Due to time constraints and the distances that needed to be covered, a complete work force survey could not be achieved. Two crews in the Kaweka forest were missed with an estimated 10 pruners working in these crews. This made for an approximate work force coverage of 85%.

Each questionnaire took approximately ten to fifteen minutes for a pruner to complete. A total of 58 questionnaires were administered by the researcher; 55 were included in the study. Three questionnaires were not included as they did not indicate which method of pruning they were currently using. This question was vital for the purposes of comparing the two groups under study. A copy of the questionnaire is shown in Appendix 3.

3.6.3 Calculation of the Risk Score

Various methods of rating and prioritising risks have been developed (Steel 1990, Chundela 1982, Graham and Kinnery 1980, Petrovic 1980, and Eisner 1993). Other researchers have called for the evaluation of risk reduction measures using value for impact (cost-benefit) measures (Fine 1971, Kastenberg and Cave 1990). This approach provides a practical and viable rationale for the assessment of hazards and their abatement.

A method of both classifying and prioritising risks associated with a hazard as developed by Fine (1971) was employed in the analysis. A risk score is calculated by rating each of the three components of the risk score. Risk is then assigned as a function of hazard exposure, hazard consequences and hazard likelihood...

$$\text{Risk Score} = \text{Exposure} \, x \, \text{Consequences} \, x \, \text{Likelihood}$$

Each of the terms used in this formula are described below.

Frequency (Hazard Exposure)

For the purposes of the risk score observed hazard frequency data were used. Hazard exposure data were transformed from the observed frequency of hazards recorded during continuous time study (see section 3.6.2) to scalar ratings in accordance with the method of Fine (1971).

Consequences

Ratings of the most likely consequences for each hazard were determined by the reports of pruners in the Hawkes Bay area in the manner outlined above in section 3.6.2 Perceived Frequency of Hazard Occurrences.

Likelihood

The likelihood of actually being injured by the hazards included in the study was assessed using the same questionnaire as described above in section 3.6.2 Perceived Frequency of Hazard Occurrences.

3.6.4 Observed versus Perceived Hazard Frequency

The observed frequency of hazards were graphically compared to the perceived frequency of hazards from questionnaire responses in the first instance with data collected in the field and transformed according to the method of Fine (1971) in the second instance.

3.6.5 Retrospective Accident Surveys

Survey in Conjunction with the HSE Questionnaire

A one year accident history survey was carried out. The survey was appended to the back of the HSE questionnaire (Appendix 1) and was administered to the eight pruners in the study. The results were analysed using a small sample *t*-test for significant differences between means.

Hawkes Bay Pruning Work Force Survey

A one year retrospective accident history survey was carried out in October 1994 by the researcher. The workforce survey was performed at the same time as the risk score questionnaires were administered and the accident history surveys were appended to the back of the risk score questionnaires (Appendix 3). The survey resulted in 30 chainsaw pruners and 24 manual pruners being surveyed. The accident frequencies were analysed using a small sample *t*-test for significant differences between means.

3.7 Physiological Costs

This section deals with the parameters, methods and equipment used to determine the physiological costs of pruning work. The parameters used to determine physiological cost were:

1. Working heart rate - $HR_{(work)}$
2. Resting heart rate at work - $RHR_{(work)}$
3. Resting heart rate before work - $RHR_{(pre\text{-}work)}$
4. Resting heart rate after work - $RHR_{(post\text{-}work)}$
5. Percent heart rate range - %HRR
6. Rated perceived exertion - RPE

3.7.1 Method of Monitoring Heart Rates

Heart rate was monitored using calibrated PE 3000 Sport Testers (Polar Electro, Finland). The monitors were fitted to subjects at the earliest possible time before work started in the morning (7:00-8:00 am). Transmitters were held by clasps to an adjustable elastic strap fitted around the subject's chest. There were two electrodes on the strap which detected the peak electrical activity of the heart and transformed this to heart rate data. The transmitter then transmitted the signal to the receiver which was worn attached to a pouch on the pruner's tool belt or otherwise affixed to the pruner. The heart rate monitors were worn for the entire work day except when the heart rate monitors broke down or the Hunter field computer malfunctioned.

A one minute sampling interval was set. This sampling interval allowed the receiver's memory to log data throughout the day (up to 16 hours). Shorter sampling intervals yield greater accuracy but only allow the PE 3000 to record for 1 hour and 20 minutes (5 second intervals) and 4 hours (15 second intervals) respectively. Shorter sampling intervals would have necessitated down-loading the data stored by the heart rate monitors to a laptop computer in the field. Down-loading data in the field would have meant loss of data as the heart rate monitor would have had to be removed from the subjects, taken back to the vehicle (where the laptop computer was stored), down-loaded, and then taken back to the research subject. This could mean from 10 - 60 minutes of lost time study and heart rate data. Down-loading in the field increases the possibility of the transmitter, receiver, laptop computer and/or the down-load unit getting wet and hence becoming inoperable. This was another factor in the decision to use the 1 minute sampling interval.

3.7.2 **Methods for the Determination of Physiological Cost Parameters**

Protocols for the determination of physiological cost parameters as set out in section 3.7 were as follows.

Working Heart Rate

Working heart rate ($HR_{(work)}$) was determined on the following criteria. As soon as the subject began walking into the forest in the morning he was considered to be working (in the physiological sense). Working heart rate was assigned to all heart rate data from this point onwards until the main lunch break. Heart rate recordings of the lunch break did not include walking to or from any lunch areas. These activities were assigned to $HR_{(work)}$. At the end of the lunch break, heart rate records were again assigned as working heart rate until the subject had finished walking out of the forest at the end of the working day. Working heart rate included all micro pauses, short tea breaks and delays.

Times that were assigned as the beginning and end of the working heart rate record came from notes made in the field on the Husky Hunter field computer. The continuous time study program 'Siwork3' has a function which allows the researcher to write notes in a note file separate from the data file.

Resting Heart Rate at Work

Resting heart rate ($RHR_{(work)}$) was defined as all heart rate data between the time that the subject arrived at work, was fitted with the heart rate monitor and walked into the forest, after the subject finished walking out of the forest until he left the work site to return home, and all of the lunch break (excluding any time spent walking to and from lunch areas). During any of these three time periods the subject may have been involved in some degree of 'work' such as sharpening tools, refuelling chainsaws, and talking to the contractor and/or supervisor. This measure was mainly to delineate $HR_{(work)}$ rather than to define a resting heart rate for use in analysis. For these purposes the resting heart rate in the morning (RHR $_{(pre-work)}$) and the resting heart rate in the afternoon (RHR $_{(post-work)}$) were used.

Resting Heart Rate Before Work

Resting heart rates in the morning ($RHR_{(pre-work)}$) were recorded for analysis and comparison with resting heart rates in the afternoon. The protocol for $RHR_{(pre-work)}$, was that there were five or more data points (one minute apart) off the PE 3000 for that particular morning between the time the subject arrived at work, was fitted with the heart rate monitor, and the time he began walking into the forest. This measure was used as the basis for calculations of percentage heart rate range (%HRR) index.

The time spent at the vehicles in the morning was taken up by sitting down eating breakfast and talking with the other pruners. A note was made on the Hunter field computer if the subject went off into the bush to go to the toilet or if any other strenuous activity was undertaken and this heart rate data was omitted from the analysis of $RHR_{(pre-work)}$.

Resting Heart Rate After Work

After walking out of the forest at the end of the day subjects were asked to sit down for at least ten minutes. There were occasions where the subjects wanted to get into town before the shops and banks closed and were not willing to sit for ten to fifteen minutes. On these occasions the researcher offered a ride into town and left the heart rate monitors on the subject until we arrived in town. This allowed the $RHR_{(post-work)}$ to be calculated.

Resting heart rates after work ($RHR_{(post\text{-}work)}$) were analysed according to the following protocol. Two conditions had to be met for the heart rate data to be included in any analysis. Firstly, the five minutes directly after walking out of the forest were not to be included in the calculation of $RHR_{(post\text{-}work)}$ due to the effect of physical exercise (walking) which increases heart rates. Secondly, there must be at least five minutes of resting heart rate data remaining for analysis. There were instances where this protocol was not met and this data was not included in any analysis. This measure ($RHR_{(post\text{-}work)}$) and $RHR_{(pre\text{-}work)}$ were used for the determination of any significant differences in resting heart rates before work and resting heart rates after work.

Percent Heart Rate Range

Percent heart rate range *(% HRR)* was calculated by using the standard formula of ...

$$\% HRR = \frac{HR_{(work)} - HR_{(rest)}}{HR_{(max)} - HR_{(rest)}} x \ 100\%$$

Where $HR_{(work)}$ = average working heart rate for the time period under consideration as defined above.

$HR_{(rest)}$ = resting heart rate before work as defined above.

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

as described in Slappendel (1992).

Calibration of Heart Rate Monitors

Three experiments were performed to quantify whether the three PE 3000s intended to be used in the study were working within an acceptable margin of error. This margin of error was set at an 85% signal to noise ratio ($r^2 \geq 0.85$).

The first of the two calibration experiments were performed manually by the researcher recording the radial pulse of a subject working at varying resistances on a cycle ergometer. The second calibration experiment was performed as a check of the first experiment. There were concerns that the researcher was not qualified to take the radial pulse with the required degree of accuracy. Accordingly the services of a registered nurse were called on and the calibration experiment repeated.

Two out of the three correlations from the second calibration experiment were not acceptable. There were concerns that manually taking the radial pulse did not give the required degree of accuracy. On this basis a third calibration experiment was 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.

All tests were conducted at room temperature (18-20 °C). Tests 1 and 2 had a Toshiba (EL 775CB) 45 watt electric fan at half power directed frontally towards the person on the cycle ergometer. Test 3 was performed in a building with conditioned air. Equipment and protocols for each test can be seen in Appendix 2.

3.7.3 **Rated Perceived Exertion (RPE) Protocol**

Rated perceived exertion was assessed approximately hourly in the field. RPE was assessed as the subjects finished a tree and were at the bottom of their ladder when working, or at the vehicle before or after work, during lunch times and short refuelling or rest breaks, and when walking into or out of the forest. Subjects were asked 'Please rate your exertion', and at the same time shown the 'Borg Scale' (Appendix 4) on a laminated sheet. Using the note function on the continuous time study program Siwork3 (Rolev 1988), a record was made of the time the RPE was assessed. This allowed the time at which RPE was assessed to be matched with the corresponding heart rates.

Methods of Comparison with HR data

RPE scores and heart rates were matched according to the appropriate time of day in a spreadsheet. RPE was correlated with the average heart rate for the nearest minute when RPE was assessed.

The averages of the previous two, three, five, ten and fifteen minutes of heart rate data were also calculated. These averages were correlated with the appropriate RPE values and tabulated. This was done in order to assess what the optimum perceptual time frame is, when a person is asked to rate their central exertion. In other words, if a person is asked to assess their central exertion, will they respond as they feel at that exact moment in time or will they have built up a mental picture of their exertion over the previous 5 or 10 minutes or longer. Correlation analysis tested the face validity of this assertion for the stated time periods. Results of these correlations are shown in section 4.3.4.

3.7.4 **Environmental Temperature Monitoring**

Initially, the thermal environment was monitored during the work day with a calibrated Campbell Scientific CR-21 data logger weather station. The weather station logged three temperatures once every fifteen minutes. These were the wet and dry bulb temperatures and the black globe temperature. At the end of the day the temperature data were down-loaded into a computer through a data transfer software package called 'Procomm'. Once in this form, the data could be entered directly into a spreadsheet for transformation into the WBGT index and subsequent analysis.

The data logger weather station suffered repeated breakdowns and its use was discontinued. Attempts to compare forest WBGT index temperatures to those of the nearest weather station were made but were not successful.

3.8 Musculoskeletal Discomfort

The various measures used in this section of the research all have some bearing on the biomechanical and musculoskeletal stresses and/or strains experienced by the subjects. These measures assess the history of musculoskeletal discomfort over the past year (the HSE questionnaire) and the day to day discomfort experienced by the pruners (the body part discomfort survey). It is hypothesised that biomechanical stresses encountered by the research subjects will have manifest outcomes such as musculoskeletal pain or discomfort.

3.8.1 'Health and Safety Executive' Questionnaires

The HSE questionnaire was used to assess the prevalence of musculoskeletal disorders in the two study groups. A one year retrospective accident survey was appended to the back of each questionnaire to enable both the accident frequencies and the type of accidents which had been experienced by the pruners to be quantified. A copy of the questionnaire used and the retrospective accident survey is shown in Appendix 1.

The Nordic musculoskeletal questionnaire has been translated into English for the British 'Health and Safety Executive' (HSE), and this is now known in the English speaking world as the HSE questionnaire. The reliability of the HSE questionnaire has been tested (Andersson *et al.* 1987, Dickinson *et al.*, 1992, and Kuorinka *et al.*, 1987) and been found to be good. Similarly the validity of the HSE questionnaire has been tested (Johansson 1994, and Andersson *et al.* 1987) and been found to be valid. To obtain useful data out of this type of questionnaire it is important to have reasonably large sample sizes as the tests which are used are non-parametric and have little statistical power when small samples are used. Generally, the Mantel-Haenszel and McNemar tests, which require sample sizes of at least five, are used in the analysis of HSE questionnaires as referred to in Andersson *et al.* (1987).

It is important for ergonomics practitioners to standardise the administration of the questionnaires (Kuorinka *et al.*, 1987, and Andersson *et al.* 1987). The HSE questionnaires were completed by the subjects after they had performed the submaximal V_{O_2} tests. The conditions under which they completed the questionnaire were relaxed and the subjects were instructed to ask for help if they needed it. All of the subjects who filled out the questionnaire were literate. Some subjects had a few problems with the way the questionnaire was designed and felt that the questions on page three of the questionnaire (see Appendix 1) were a little confusing. Other comments were that the descriptors at the top of the column describing the prevalence of musculoskeletal discomfort could have been emphasised more (perhaps larger font) and that the columns were too close together. The columns could be separated in the future to allow easier discrimination of one question from the next. In general, the administration of the questionnaires went smoothly within the environment in which they were filled out.

Administration of Questionnaire

The questionnaire was administered at the time of the submaximal fitness test. Where this was impractical for the subjects due to them wanting to get to work, the questionnaire was filled out at lunch time in the field. All subjects were verbally requested to ask the researcher if there was anything about the questionnaire they did not understand or if they were having difficulty filling out any part of the questionnaire. When assistance was required it was given in relative privacy and complete confidentiality.

Analysis of Questionnaire Answers

The HSE questionnaire was analysed manually by calculating descriptive statistics. Frequencies are presented in a body part pictogram form (see section 4.4.1 results) and implications are discussed (see section 5.4 discussion).

3.8.2 Body Part Discomfort (BPD) Surveys

BPD surveys were conducted before work and after work according to the method of Corlett and Bishop (1976). The surveys were used to both anticipate musculoskeletal disorders and to assess the relative changes in magnitude before and after work, as well as within and between the groups of chainsaw and manual pruners in the study.

Administration of Survey

The BPD surveys were administered to the subjects while they were at their vehicles both before walking in and after walking out of the forest block. The pruners walked into the forest block at the start of the day from their vehicles which were parked as close as possible to where they would be working. At the end of the day, they of course walked back to their vehicles to go home. Simultaneously, a laminated sheet was shown to the subjects with the body segmented into numbered body parts (see Appendix 5). A 3-point Likert scale beneath the body part diagram was used to determine the magnitude of any pain or discomfort. The procedure and rationale was explained to the subjects on the first morning of the research. The subjects did not mind participating in the BPD questionnaires as their administration took very little time (less than 30 seconds).

BPD was assessed by giving a series of verbal questions to the subjects. The first question that was asked was 'Do you feel any discomfort at the moment?'. When the answer was "no", the survey was discontinued and "nil" discomfort was recorded. If the answer was yes, the next question asked was 'Please show me where you feel any discomfort'. This was then followed by 'Please rate your discomfort'. Results from the BPD surveys were recorded by using the note function in the manner described above (section 3.4.5).

Analysis of BPD Survey

Survey results were collated and analysed in a spreadsheet. The occurrences of discomfort were counted. Counts were made on the basis of presence or absence of discomfort irrespective of the rated magnitude of the discomfort. On this basis, ratings of 1 (Just noticeable pain / discomfort) and 2 (Moderate pain / discomfort) were treated the same. The counts for presence of pain / discomfort were then divided by the total responses of presence and absence of pain / discomfort. This was done for the before and after work periods for both chainsaw and manual pruners. Thus a proportion showing the presence of pain / discomfort was calculated.

For the statistical analysis of the BPD data a binomial model was used. Data were analysed for the before and after work periods on an intra-group and inter-group level. The number of successes or x (affirmative responses) in n trials (number of possible affirmative responses) formed the proportions used for testing hypotheses.

At the null hypothesis level there was assumed to be no difference between the two groups, following on from operational hypothesis 2b, hence a pooled standard error was used. This allowed for comparisons of before work prevalence of pain discomfort between the two research groups. Further tests were performed to compare before and after work prevalence on an intra-group level and after work prevalence on an inter-group level. The test statistic used for the determination of any significant differences was:

$$Z = \frac{\frac{x_1}{n_1} - \frac{x_2}{n_2}}{\sqrt{\hat{p}\,(1-\hat{p})\,(\frac{1}{n_1} + \frac{1}{n_2})}}$$

where $\hat{p}$ is given by

$$\hat{p} = \frac{x_1 + x_2}{n_1 + n_2}$$

and x_n = the number of affirmative responses, and

n_n = the number of possible affirmative responses.

$\hat{p}$ = the pooled proportion of affirmative responses divided by possible outcomes.

The results of the BPD surveys were also graphed using the chart function available in Microsoft Excel. Column charts showing the comparisons can be seen in section 4.3.2.

3.9 Productivity

The objective of this section of the research is to test the hypothesis that chainsaw pruning is more productive than manual pruning. The aims of this section are to detail the method of data collection for the determination of the following productivity parameters:

1. Walk distance
2. Walk time
3. The hill slope encountered while walking
4. Hindrance to walking

5. Pruning time
6. Total time to complete walk and prune cycle
7. Delays
8. Tree characteristics which influence pruning time

Productivity data were collected by using the continuous time study on Siwork3 (Rolev 1988). Data which describe tree characteristics were collected separately.

Walk Distance

The distance walked between trees was estimated by the researcher. The researcher calibrated his ability to estimate distance by comparing estimated distance and actual (measured) distance approximately every 1 to 2 hours. The checks were performed using a 'hip chain' attached to the belt and worn around the waist. A cotton string was tied to a fixed starting point. The string is pulled off a spool within the hip chain which spins a counter as the wearer walks away from the starting point.

Walk Time

Walk time was recorded from the time the pruner's foot touched the ground until the top of his ladder touched the stem of the next tree to be pruned.

Hill Slope

Hill slope was estimated using a Sunnto clinometer. A reference point was painted on the pruner's ladder while it was leaning against a tree either before starting work or while the first tree was being pruned. The reference point was painted with fluorescent paint at the researcher's eye level. By lining up the clinometer (at the researchers eye level) with the mark on the ladder (also at the researchers eye level) an accurate estimation of hill-slope was found (see Appendix 6).

Hindrance Ratings

Hindrance was subjectively assessed by the researcher. Hindrance along the path the pruner walked between each tree was rated according to a one to four scale according to Hartsough and Parker (1993). The following protocol was used in the assessment of the hindrance rating:

1. Not hindered
2. Hindered
3. Continuously hindered
4. Constantly struggling

Prune Time

The time spent pruning was measured from when the top of the ladder touched the tree to be pruned until the pruner's foot touched the ground. Delay times were not included in prune times.

Total Cycle Times

Total cycle times were generated by the continuous time study program Siwork3. Total cycle times included all time elements in the production cycle. Thus total cycle times included all micro pauses, walk times, prune times, lunch breaks and all delays.

Delays

Delays were divided into three categories; personal, operational and mechanical:

1. Personal delays included micro pauses and toilet stops.
2. Mechanical delays were noted when any repair and maintenance was being done to the tools and equipment that the pruners use in their work. Mechanical delays included sharpening tools, replacing blades and refuelling chainsaws. When these operations were performed before starting work in the morning they were not noted.
3. Operational delays included such things as talking to the contractor, foreman or forest manager, and on-the-job training.

Tree Characteristics

A random sample of 5% of trees pruned was used to estimate various tree and stand characteristics. The 5% sample was decided upon after discussion with operations staff from CHHF (Central Region). The total number of trees pruned in that day was multiplied by 0.05 to obtain the number of trees to sample. During the direct observation period each tree was numbered with fluorescent paint.

Trees were selected by using a 5% random number table. Random numbers were selected from a random number table until the desired sample size was obtained. Once the sample size had been determined the researcher went back into the forest and measured the trees whose numbers had been selected by the random number method. On occasion the same list of random numbers was used.

Random sampling of trees was done to control for any differences in branch size, numbers of branches, number of whorls and the number of branches per whorl between the two study groups. These tree characteristics may have had an effect on productivity and physiological cost variables. A standard sheet was used in the sampling of trees (see Appendix 7). Dimensions measured for each tree were:

1. Each horizontal pruned branch diameter
2. Each vertical pruned branch diameter
3. The number of pruned whorls on each tree
4. The number of pruned branches in each pruned whorl
5. The DBH of each tree in the sample

These data allowed information to be obtained on the following tree characteristics for each of the two groups of pruners:

1. The average number of branches per tree
2. The average number of whorls per tree
3. The average number of branches per whorl
4. Average branch radius

5. Average branch cross-sectional area
6. Total cross-sectional branch area per tree
7. The diameter at breast height (DBH) of each tree

The way in which data were analysed for each of the preceding tree characteristics is now detailed.

Average Number of Branches per Tree

The average number of branches per tree was calculated by counting the number of branches for each tree in the sample. The sum of all these 'number of branches per tree' was then divided by the total number of trees sampled in the respective study groups (chainsaw or manual). This gave the figure for the average number of branches per tree.

Average Number of Whorls per Tree

The average number of whorls per tree was calculated in the same way as is described above for 'average number of branches per tree.

Average Number of Branches per Whorl

The number of branches per whorl for each tree in the sample was calculated by dividing the total number of branches by the total number of whorls in that tree. This calculation gave the average number of branches per whorl per tree (branches.$whorl^{-1}$.$tree^{-1}$) for each individual tree sampled. Next, the sum of the average number of branches. $whorl^{-1}$.$tree^{-1}$ were divided by the sample size to get an overall average branches. $whorl^{-1}$. $tree^{-1}$ in the respective sample group.

Average Branch Diameter (cm)

Average branch diameter was calculated by:

1. Averaging the horizontal and vertical branch diameters for each pruned branch recorded in the field

2. Individual branch diameters for each tree were summed and divided by the number of pruned branches in that tree to get an average branch diameter for each tree
3. This average branch diameter was then summed for every tree in the sample group and divided by the total number of trees in the sample group

This operation gave the average branch diameter and was performed for both the manual and chainsaw pruning groups.

Total Cross-sectional Branch Area per Tree (cm^2)

The cross-sectional area of each branch was calculated using individual branch diameters described in the preceding paragraph. Individual branch area was calculated using the following formula...

$$\text{Cross Sectional Area} = \pi D^2$$

Where D = Average (individual) branch diameter

These individual branch areas were then summed to get the total cross-sectional area of pruned branches in each tree. These total cross-sectional areas per tree were then themselves summed and divided by the total number of trees in the respective sample to obtain an average total cross-sectional area of branches per tree.

Diameter at Breast Height[17] (DBH) (cm)

The DBH for each tree in the sample was taken with a standard diameter tape. These data were averaged to provide information on the average DBH for the trees pruned by two groups of pruners.

Determination of Significant Differences

Tests of significance were used as a basis on which to make inferences from sample data. The tests that was used was the standard Z-test (Freund 1988). This test is based on test statistic..

[17] Diameter at breast height is the horizontal diameter around a tree at a height of 1.4 metres above the ground.

$$Z = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

Where $\bar{x}_n$ = Sample average

s_n = Sample standard deviation

n = Sample size

3.10 Quality

Quality data (number of tree damage events) were collected by direct observation. While measuring a 5% sample of pruned branch sizes (see section 3.9) the researcher was also able to sight and record damage events which the trees had incurred as a result of being pruned. The researcher sighted damage events from a vantage point up the trees.

Damage

The occurrences of four types of damage events were counted. The occurrences of damage were recorded on a standard form (see Appendix 7). The data were then entered into a spreadsheet for coding and analysis. Damage events were coded according to the following list of damage types:

1. Damage to the branch collar
2. Damage to bark on the stem around the branch
3. Leaving some of the branch protruding from the collar (coat hangers)
4. A combination of collar and bark damage

Data for chainsaw pruners and manual pruners were kept separate. The total number of damage events were counted for each group and divided by the total number of trees pruned for each group to get comparative rates of 'damage per tree'.

3.11 Summary

The chapter has expressed the overall research aims and objectives in the form of operational hypotheses. Each of sections 3.6 to 3.10 were designed to allow for the testing of the hypotheses specific to the general question "Is chainsaw pruning an acceptable work method ?".

The different variables, and hence methods of approach, in each of the sections are illustrative of the multi-disciplinary approach employed in ergonomics analysis which typically covers many system characteristics. The considerable length of this section is due to the relatively large number of variables under investigation. This was not an attempt to cover the field, rather to accommodate the operational hypotheses and allow valid comparisons to be made.

This chapter has covered the use and calibration of the equipment used in data collection. The methods of data collection and the protocols used in the analysis of data were detailed. The sample size and statistical design were demonstrated giving a guide to the interpretation of the results presented in the following chapter. Each of the variables used for the determination of the various parameters of the research was explained.

Chapter 4 Results

4.0 Introduction

This chapter presents the results of data collection and analysis. Each section examines the hypotheses set out in section 3.1 and supporting data where appropriate. The interpretation of the results will be presented in the discussion (Chapter 5).

4.1 Subject Characteristics

The subject characteristics of the pruners are presented here as gross characterisations of each of the two groups of pruners. The results for each group of pruners (chainsaw and manual) are kept in separate tables.

General

General characteristics of the subjects are presented in Tables 4.01 and 4.02 (overleaf).

Table 4.01 Subject Characteristics of Chainsaw Pruners.

Subject	8	4	3	1	Averages (SE)
Age	29	26	24	31	27.5 (1.6) X
Height (cm)	181	187	177	168	178.4 (4.0)
Mass (kg)	74	85	70	59	72 (5.4)
Waist (cm)	79	83	79	75	79.2 (1.6)
Hip (cm)	95	107	99	89	97.6 (3.6)
Smoker ?	yes	no	yes	no	50 %
Coffee / tea ?	yes	yes	yes	yes	100 %
WHR	0.835	0.779	0.794	0.842	0.813 (0.02)
BMI	22.48	24.31	22.34	20.90	22.51 (0.70)

Age and Experience

The chainsaw pruners in the sample were on average older (average 28.34 ± SE 1.6 yrs vs 21.75 ± 2.8 yrs) and more experienced (79 ± SE 22.2 months vs 43 ± 28.6 months) than the manual pruners.

Table 4.02 Subject Characteristics of Manual Pruners.

Subject	7	6	5	2	Average (SE)
Age	16	23	29	19	21.75 (2.81)
Height (cm)	185	183	185	173	182 (2.9)
Mass (kg)	65	86	80	73	76 (4.5)
Waist (cm)	74	86	86	74	80 (3.5)
Hip (cm)	93	101	97	89	94.9 (2.5)
Smoker ?	no	yes	yes	no	50 %
Coffee / tea ?	yes	yes	yes	yes	100 %
WHR	0.797	0.859	0.808	0.831	0.824 (0.01)
BMI	19.08	25.68	23.29	24.39	23.11 (1.43)

The length of time in the forestry industry was determined from the HSE questionnaire completed by the pruners in the study (see Appendix 1). The reports of pruners for the length of time involved in pruning work yielded both numeric and categorical data. The categorical data were added to the numeric data by taking the midpoint of the category (see Appendix 1: question 9.1) for the time spent pruning and this was added to the numeric answers given (see Appendix 1: question 8). On this basis, the reports for length of time involved in pruning work are guidelines rather than definitive statements.

V_{O_2} (max) Determinations

Tests for the estimation of V_{O_2} (max) on the basis of cycle ergometry yielded the results in Table 4.03 and 4.04 (overleaf).

4.2 Hazard Analysis

The hazard analysis section of this chapter deals with the calculation of the 'Risk Score' and the presentation and analysis of results from a one year retrospective accident history survey carried out in the Hawkes Bay area during October 1994.

4.2.1 Risk Score

The following overall frequencies of hazard occurrences were found from continuous time study (see Table 4.05). Tests for significant differences (small sample *t*-test) were performed. All tests in Table 4.05 were judged against critical values with $n_1 + n_2 - 2 = 36$ df.

Table 4.03 Estimated V_{O_2} (max) of Chainsaw Pruners.

Subject	8	4	3	1	Average (SE)
Work rate (watts)	203	154	148	150	163.8 (13.1)
Heart Rate (b.min^{-1})	145	140	151	147	145.8 (2.3)
Estimated V_{O_2} (max) l.min^{-1}	4.5	3.7	3.1	3.2	3.6 (0.3)
Age	29	26	24	31	27.3 (1.6)
Age Corrected estimated V_{O_2} (max) l.min^{-1}	4.2	3.6	3.2	3.0	3.5 (0.3)
Mass (kg)	74	85	70	59	72 (5.4)
Estimated V_{O_2} (max) ml.min^{-1}.kg-1	56.9	42.3	45.8	49.9	48.7 (3.1)

Table 4.04 Estimated V_{O_2} (max) of Manual Pruners.

Subject	7	6	5	2	Average (SE)
Work rate (watts)	161	208	242	131	185.6 (24.6)
Heart Rate (b.min^{-1})	157	147	149	139	148 (3.8)
Estimated V_{O_2} (max) l.min^{-1}	3.15	4.60	5.20	3.25	4.1 (0.5)
Age	16	23	29	19	21.8 (2.8)
Age Corrected estimated V_{O_2} (max) l.min^{-1}	3.43	4.67	4.91	3.45	4.1 (0.4)
Mass (kg)	65	86	80	73	76 (4.5)
Estimated V_{O_2} (max) ml.min^{-1}.kg-1	52.8	54.3	61.4	47.2	53.9 (2.9)

Table 4.05 (overleaf) shows chainsaw pruners had a significantly higher hazard frequency for four out of the six hazard classes that were studied. Tables 4.06 and 4.07 (overleaf) present hazard frequencies for morning and afternoon periods for chainsaw pruners and manual pruners respectively.

Table 4.05 Frequency of Hazard Occurrence.

Hazard	Chainsaw Average Hazards/Tree (SE) n = 19	Manual Average Hazards/Tree (SE) n = 19	Sig
Ladder Hazards	0.327 (0.012)	0.302 (0.091)	ns
Cutting large branches above head	0.073 (0.017)	0.079 (0.008)	ns
Cutting across arm / leg	0.057 (0.021)	0.013 (0.004)	*
Over reaching from ladder	0.062 (0.012)	0.025 (0.013)	*
Cutting branch too close to the stem	0.085 (0.017)	0.004 (0.002)	* * *
Holding onto branch being cut	0.037 (0.012)	0.009 (0.003)	*

* = p < 0.05, * * = p < 0.01, * * * = P < 0.001, ns = not significant. All tests are one sided with 36 *df* and have the alternative hypothesis that chainsaw pruning has a higher rate of hazards per tree

Table 4.06 Chainsaw Pruners' Hazard Frequency. Morning vs Afternoon.

Hazard	Average (SE) Hazards / Tree (morning) n = 10	Average (SE) Hazards / Tree (afternoon) n = 9	Sig
Ladder Hazards	0.36 (0.15)	0.29 (0.14)	ns
Cutting Large Branches above Head	0.08 (0.03)	0.07 (0.03)	ns
Cutting across arm / leg	0.07 (0.03)	0.05 (0.03)	ns
Over reaching from ladder	0.08 (0.02)	0.04 (0.02)	ns
Cutting branch too close to stem	0.07 (0.02)	0.10 (0.03)	ns
Holding onto branch being cut	0.04 (0.01)	0.04 (0.02)	ns

* = p < 0.05, * * = p < 0.01, * * * = P < 0.001, ns = not significant. All tests are two sided with 17 *df*

Table 4.07 Manual Pruners' Hazard Frequency. Morning vs Afternoon.

Hazard	Average (SE) Hazards / Tree (morning). n = 10	Average (SE) Hazards / Tree (afternoon). n = 9	Sig
Ladder Hazards	0.27 (0.12)	0.34 (0.14)	ns
Cutting Large Branches above Head	0.07 (0.01)	0.08 (0.01)	ns
Cutting across arm / leg	0.01 (0.00)	0.02 (0.01)	ns
Over reaching from ladder	0.03 (0.02)	0.02 (0.02)	ns
Cutting branch too close to stem	0.01 (0.00)	0.00 (0.00)	ns
Holding onto branch being cut	0.00 (0.00)	0.02 (0.01)	*

* = p < 0.05, * * = p < 0.01, * * * = P < 0.001, ns = not significant. All tests are two sided with 17 *df*

Tables 4.06 and 4.07 show that there was no variation between the averages for morning and afternoon hazard frequencies for the manual pruners with the exception of holding onto the branch being cut.

Observed vs Perceived Hazard Frequency

The perceived hazard frequency of each group of pruners was found from questionnaire data (appendix 3). These data were then compared to data derived from observed hazard frequencies observed by the researcher during continuous time study. Figures 4.01 and 4.02 show the results of these comparisons.

Figure 4.01 Observed vs Perceived Hazard Frequency for Chainsaw Pruners

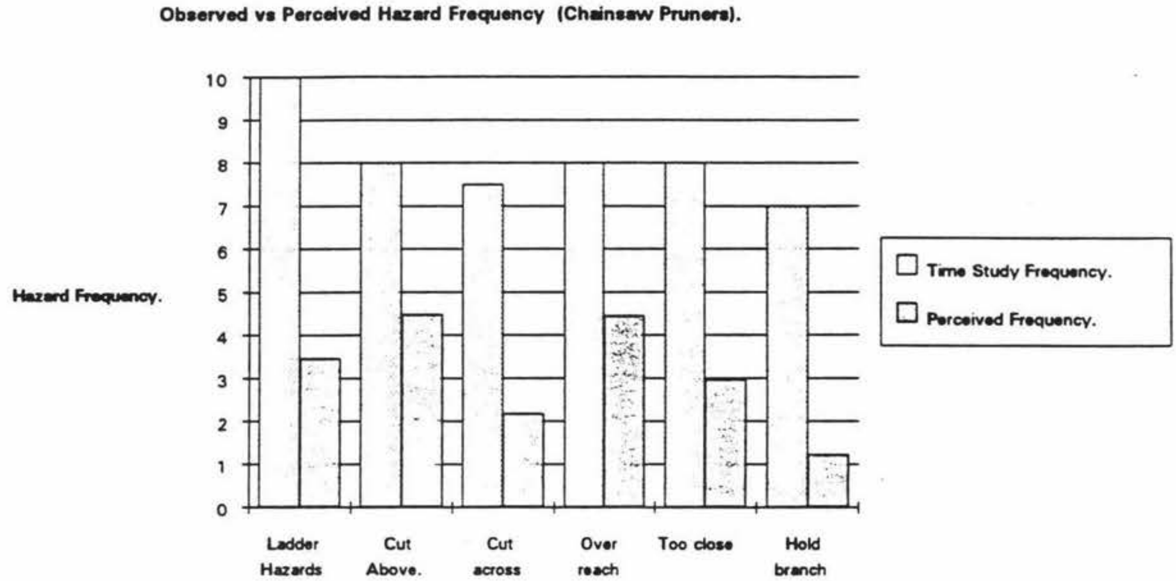
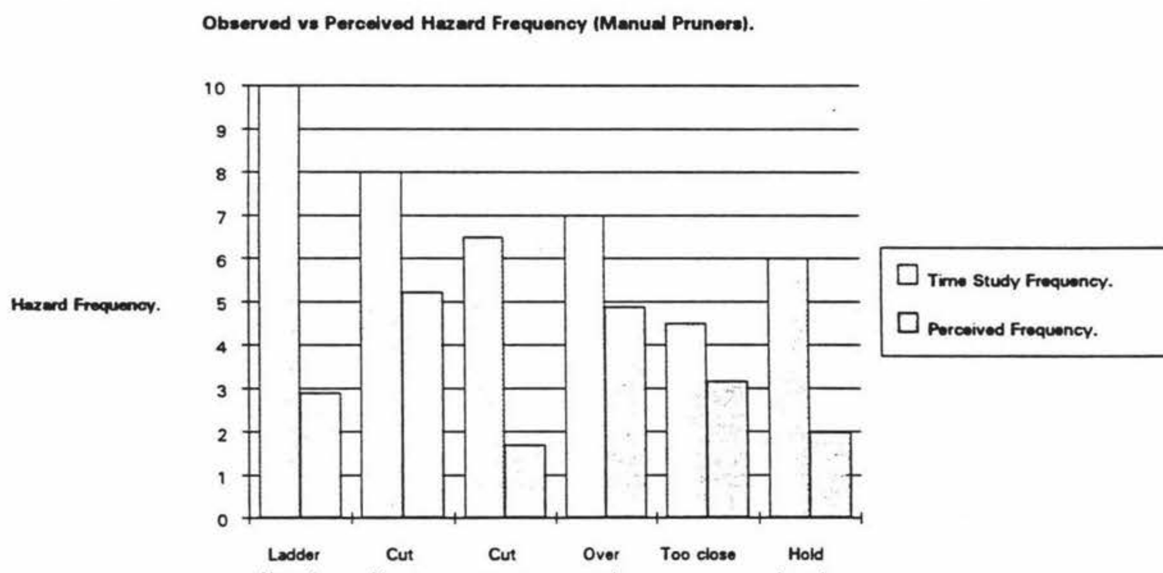


Figure 4.02 Observed vs Perceived Hazard Frequencies for Manual Pruners



Number of Trees Pruned Per Day

There were no statistical differences (small sample *t*-test *16 df* one sided) in the number of trees pruned per complete work day between chainsaw and manual pruners (see Table 4.08). As there were no significant differences in the average number of trees pruned per day, these figures were used in the calculation of the average number of hazards per day for both the manual and chainsaw pruners.

Table 4.08 Average Number of Trees Pruned per Day

	Average number of trees per day	Number of complete days in study period	SE
Chainsaw pruners	136.3	11	7.5
Manual pruners	137.0	7	11.0

For the calculation of the risk score, hazards per tree were multiplied by the average number of trees per day to get the average number of hazards per day. The rate of hazards per day was then compared to the exposure component in Fines (1971) Risk Score in order to get a rating for 'exposure'. Ratings for 'consequences' and 'likelihood' were found from the responses of pruners to the risk score questionnaire (see Appendix 3).

Tables 4.09 and 4.10 (overleaf) show the calculated 'Risk Scores' for manual and chainsaw pruning respectively.

Table 4.09 Risk Scores For Manual Pruners.

	Exposure	Likelihood	Consequences	Risk score
Ladder	10	3.1	3.7	116.4
Cut Above	7	5.0	4.8	165.3
Cut Across	6	4.4	6.7	175.2
Over Reaching	6.5	4.2	6.3	170.2
Too Close	3	3.5	5.4	56.7
Holding	6	3.8	6.8	154.5
			Total Risk Score	838.2

Appendix 8 lists priorities for action according to calculated Risk Scores.

4.2.2 Retrospective Accident Survey in Conjunction with the HSE Questionnaire

A small, one year, retrospective accident survey was carried out in conjunction with

Table 4.10 Risk Scores For Chainsaw Pruners.

	Exposure	Likelihood	Consequences	Risk score
Ladder	10	3.4	4.7	157.1
Cut Above	7	4.6	7.5	241.4
Cut Across	7	4.3	12.0	362.6
Over Reaching	7	3.9	7.4	204.9
Too Close	7	3.9	7.8	214.0
Holding	6.5	3.6	10.2	241.4
			Total Risk Score	1421.5

the administration of the HSE questionnaire. The sample included only those pruners who were participants in the continuous time study. In addition, the pruners' main occupation over the previous year was asked of them to confirm that they had not recently (within the retrospective one year) changed from manual to chainsaw pruning. The results are presented in Table 4.11 below.

Table 4.11 Retrospective Accident Survey of Pruners in the Study

	Chainsaw Pruners N = 4	Manual Pruners N = 4	Significant ?
No. of injuries Av (SE)	0 (0)	4 (0.71)	ns
No. of days lost Av (SE)	0 (0)	6 (0.87)	*

* = $p < 0.05$, * * = $p < 0.01$, * * * = $P < 0.001$, ns = not significant. Test is one sided with 6 *df*

This test was one sided. The alternative hypothesis was weighted in the direction of the operational hypothesis 1b (section 3.1), that chainsaw pruners will have a higher accident frequency rate than manual pruners. No statistical differences were found in the number of lost time injuries between the manual and chainsaw pruners. There were, however, significantly more days lost due to injury by the manual pruners in the study group. The study groups were not statistically large.

4.2.3 Retrospective Accident Survey in Conjunction with the Risk Score Questionnaire

The results of the second retrospective accident survey, which covered accident frequencies[18] over a one year period (October 1993 - October 1994), are show in

[18] 'Frequencies' as used in this thesis are discussed in Section 5.2.2.

Table 4.12.

Table 4.12 Accident Frequencies October 93 - October 94

	Accident Frequency	Sample size	SE
Chainsaw pruners	0.100	30	0.056
Manual pruners	0.125	24	0.092

A small sample *t*-test showed that there were no significant differences (52 *df*, one sided) between the retrospective accident frequencies of manual and chainsaw pruners. This was a one sided test against the alternative hypothesis that chainsaw pruners would have higher accident frequencies than manual pruners. The alternative hypothesis was in line with operational hypothesis 1b that the accident rate for chainsaw pruners will be higher than for manual pruners. On the basis of sample data, the researcher must either accept the null hypothesis that there was no difference in the accident rates of the manual and chainsaw pruners or reserve judgement.

4.3 Physiological Costs

This section of the chapter presents the results and analysis of parameters which were used to determine the physiological costs of each method of pruning. Specifically, the section covers the calibration of the heart rate monitors used in the study, the submaximal V_{O_2} (max) tests, the Percentage Heart Rate Range at work index, the resting heart rate before and after work, Rated Perceived Exertion, the calibration the weather stations, and the presentation of descriptive data on the thermal environment during the study period.

4.3.1 Percentage Heart Rate Range (%HRR) at Work

Tables 4.13 and 4.14 show heart rate and *%HRR* data for each group. Average *%HRR* for each group is shown in the bottom right hand corner of each table.

There were no statistical differences between the average %HRRs of the chainsaw or manual pruners using a small sample *t*-test (two sided).

Table 4.13 *%HRR* of Chainsaw Pruners

Subject	HR$_{(work)}$	RHR$_{(work)}$	RHR$_{(pre\text{-}work)}$	%HRR
8	121.4	85.8	81.8	36.3
4	113.6	73.8	68.5	35.9
3	124.3	83.6	88.8	34.7
1	128.9	78.1	71.6	48.4
			Average	38.8

Table 4.14 *%HRR* of Manual Pruners

Subject	HR$_{(work)}$	RHR$_{(work)}$	RHR$_{(pre\text{-}work)}$	%HRR
7	131.6	87.6	77.8	42.6
6	115.0	78.1	77.0	31.6
5	129.1	90.2	88.9	39.4
2	137.8	89.2	90.0	43.5
			Average	39.3

4.3.2 **Resting Heart Rates at Work (RHR)**

Table 4.15 presents averages of average RHRs (*pre* and *post-work*), the standard errors for each average, the sample sizes, and findings on significant differences between the morning and afternoon RHRs.

Table 4.15 Test of Significant Differences between RHR *pre-work* and RHR *post-work*.

	RHR (*pre-work*) Av (SE)	n (morning)	RHR (*post-work*) Av (SE)	n (afternoon)	Sig
Chainsaw	77.8 (3.1)	10	86.2 (2.1)	8	ns
Manual	82.9 (1.9)	11	86.1 (3.5)	9	*

* = $p < 0.05$, * * = $p < 0.01$, * * * = $P < 0.001$, ns = not significant. All tests are two sided with n_1+n_2 -2 *df*
m = morning, a = afternoon

4.3.3 **Calibration of Heart Rate Monitors**

Calibration of the three PE 3000 heart rate monitors under three different test conditions yielded the following results (Table 4.15). Correlations (r) are given in Table 4.16 (overleaf).

Table 4.16 Heart Rate Calibration Tests.

	Test # 1	Test # 2	Test # 3
HR mon # 1	0.99	0.86	nd
HR mon # 2	0.99	0.92	0.93
HR mon # 3	0.94	0.93	0.97

nd = no data

4.3.4 **Rated Perceived Exertion (RPE)**

RPE was compared to heart rate readings from the PE 3000 heart rate monitors. The heart rate readings which were used for comparisons were the instantaneous readings at the time when the question "please rate your exertion" was asked. Additionally the average heart rates for the preceding 2, 3, 5, 10 and 15 minutes were also included in the correlation analysis.

Correlation Coefficients

Correlations were performed between the RPE of pruners and their corresponding heart rate readings off the PE 3000 sports testers. Correlations were performed for individual subjects on the basis of the following list of criteria:

1. Individual days
2. The sum of all the days in the study period
3. All mornings in the study period
4. All afternoons in the study period

Appendix 9 shows the set of correlations for each individual in the study group against the instantaneous reading off the PE 3000, and the averages of the previous 2, 3, 5, 10, and 15 minutes of heart rate records. There was considerable variation in the correlations of heart rate and the RPE of the individual pruners. There was however a trend evident that without exception the correlations for all afternoons were lower than for all mornings.

Table 4.17 (overleaf) shows aggregate correlation coefficients for all mornings and all afternoons for chainsaw and manual pruners. The last two columns show the correlations for all manual and all chainsaw pruners (both morning and afternoon). Chainsaw pruners' RPE scores had weak negative correlations for the aggregate afternoon period while manual pruners had moderate positive correlations. This effect affected the overall correlations for both morning and afternoon which were highest for manual pruners. Correlations of the greatest magnitude are shown in bold type in Tables 4.17 and 4.18 (overleaf).

Table 4.17 RPE Correlations for Chainsaw vs Manual

	Csaw all mornings n = 34	Mn all mornings n = 23	Csaw all afternoons n = 19	Mn all afternoons n = 36	Csaw mornings + afternoons n = 49	Mn mornings + afternoons n = 59
RPE	1	1	1	1	1	1
HR instnt	0.50	0.67	-0.02	0.41	0.46	0.48
HR 2min	0.58	0.76	0.03	0.39	0.53	0.50
HR 3min	0.57	**0.79**	-0.01	0.42	0.55	0.53
HR 5min	**0.66**	0.78	-0.01	0.47	**0.59**	0.56
HR 10min	0.63	0.72	0.08	0.55	0.57	0.59
HR 15min	0.54	0.72	**0.11**	**0.58**	0.51	**0.61**

Csaw = Chainsaw pruners, Mn = Manual pruners.

Table 4.18 shows the aggregate correlation coefficients of all morning RPEs, all afternoon RPEs, and the overall RPE values with corresponding heart rates.

Table 4.18 All RPE Correlations

	All mornings (Csaw + Mn) n = 54	All afternoons (Csaw + Mn) n = 58	All mornings and afternoons (Csaw + Mn) n = 120
RPE	1	1	1
HR instnt	0.54	0.25	0.44
HR 2min	0.64	0.24	0.49
HR 3min	0.66	0.26	0.52
HR 5min	**0.67**	0.34	0.54
HR 10min	0.60	0.45	**0.55**
HR 15min	0.52	**0.49**	0.52

Csaw = Chainsaw pruners, Mn = Manual pruners.

4.3.5 **Thermal Environmental Monitoring**

Due to losses of data, equipment failure and a lack of valid thermal environment data nearest the work-sites no objective results can be submitted. Data collection for the research was carried out in the winter months. The researcher was at the work site at all times during data collection and in the researcher's opinion there was no significant load due to the thermal environment that would have affected the thermo-regulatory systems of the subjects while at work.

4.4 Musculoskeletal Discomfort

4.4.1 Health and Safety Executive Questionnaires

Results for the Health and Safety Executive questionnaires are shown graphically in Figure 4.03 (overleaf). No significant differences were found using significance tests for differences between proportions. The sample size is n = 4 for both chainsaw and manual pruners. The HSE questionnaire can be seen in Appendix 1.

4.4.2 Body Part Discomfort (BPD) Surveys

Gross Measures

Body part discomfort scores are shown in Figure 4.02. Overall, there was a significant ($p < 0.05$, one sided) rise in the BPD of the manual pruners as measured before and after work which was not evident for the manual pruners.

Site Specific Breakdown

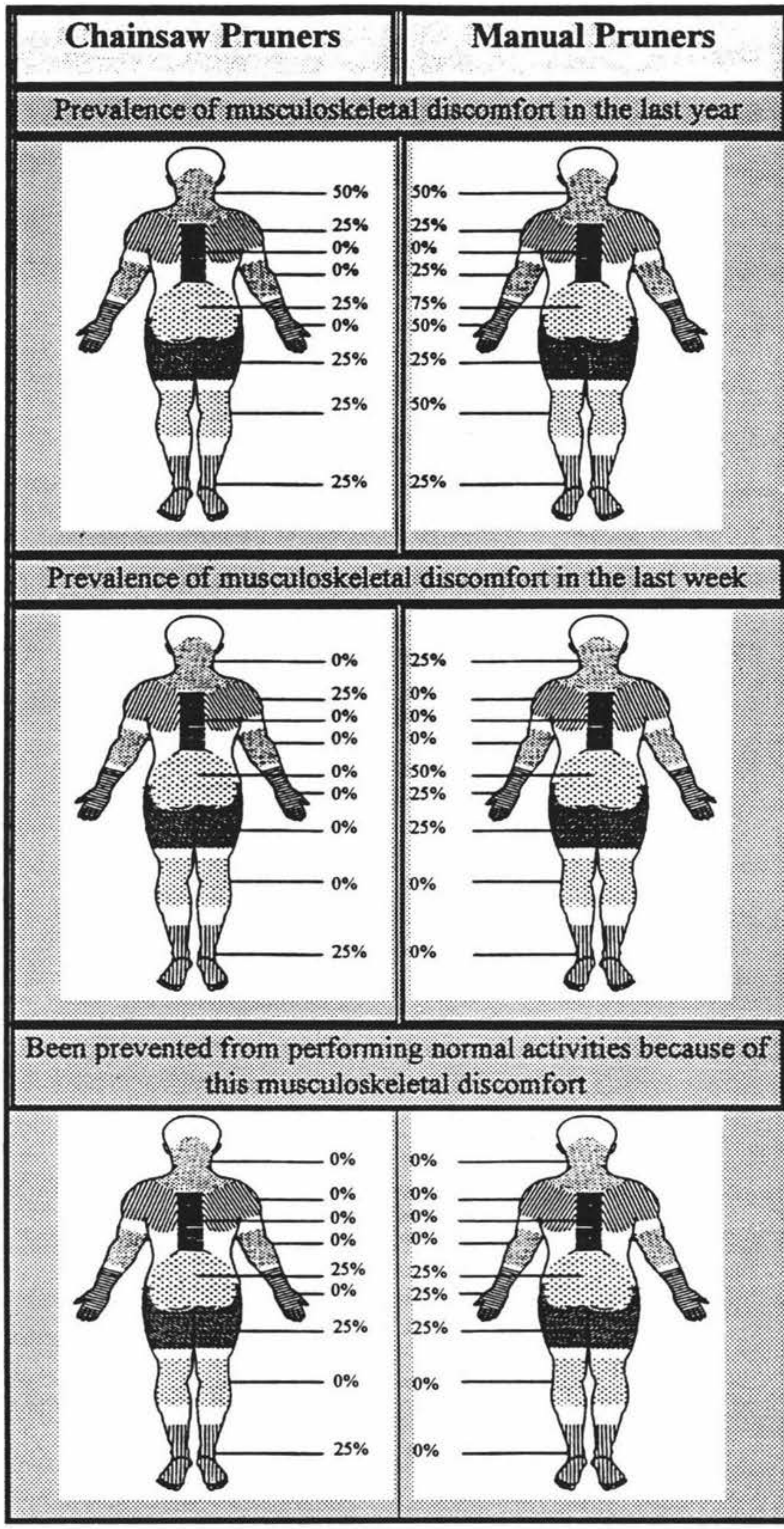
The above section provided gross measures for the prevalence of pain or discomfort before and after work. This section will deal specifically with those sites where discomfort occurred and how severe that discomfort was. This section will also describe whether there was a general trend for the eight subjects or whether a higher representation from one individual occurred. This was done in some attempt to account for inter-subject variability within the sample.

The discomfort ratings that were reported were nil, 1, and 2 from the Likert scale at the bottom of the BPD survey shown to the pruners (see Appendix 5). There were no reports of 'intolerable pain or discomfort' (ie ratings of '3') for any of the 38 times the survey was administered.

Chainsaw Pruners

The sites on the pictogram which chainsaw pruners to which responded as 'feeling discomfort' more than once in the 18 administrations of the BPD survey were in both thighs. Three reports each for sites 18 and 19 on the pictogram made up six

Figure 4.03 Comparison of Musculoskeletal Discomfort for Chainsaw and Manual Pruners



occurrences of BPD. Four out of the six occurrences for these sites were from the 'before work' period. There was one occurrence with a rating of '2' for the left thigh, which was for the after work period. The remaining ratings were all of '1' of which four were in the before work period. Four of these six reports were given by the same subject. This subject highlighted trouble in the hips/thighs/buttocks area in the HSE questionnaire.

Manual Pruners

There were four sites where manual pruners had a frequency of BPD which was greater than two in the 21 administrations of the BPD questionnaire. The first site was the mid abdominal, thoracic/lumbar spine area (site 8, see body pictogram Appendix 5). There were two BPD ratings given for this site. One was in the before work period while the other was in the after work period. Both of these BPD ratings for this site had a severity of '1' and they were both from the same subject. This subject noted trouble in the lower back over both the last year and the last seven days in the HSE questionnaire.

The second site was the left forearm (site 12). There were three reports of BPD at this site. Two of these three reports were from the after work period. Two BPD ratings of '1' for this site which were given by the same subject (after work and the consecutive before work period), who was right handed. The remaining BPD rating was a '2' for the after work period. This subject was left handed.

The third site was the left hand (site 16). For the left hand, there were two ratings of '1' given by the same subject in the after work period. This subject highlighted trouble in the wrists/hands area in the HSE questionnaire for the last 12 months, last 7 days and noted that he had been prevented from carrying out normal activities during the last 12 months due to this trouble.

The fourth and final site was the right hand (site 17). There were six ratings of '1' given of which two were from the before work period. These two BPD ratings were given by the same subject. In addition, three of the remaining four (after work) BPD ratings were given by the aforementioned subject. This was the same subject who highlighted the wrists/hands area in the HSE questionnaire as was described in the previous paragraph.

4.5 Productivity

Table 4.19 shows the aggregate results for work components of the production cycle. Significance tests are one sided with $n_1 - n_2 - 2$ *df*. The alternative hypothesis is that chainsaw pruners will have a higher rate of productivity than manual pruners in line with operational hypothesis 4a.

Table 4.19 Cycle Elements for Manual and Chainsaw Pruners

	Csaw Av (SE)	Csaw n	Mn Av (SE)	Mn n	Csaw or Mn greater ?	Sig
Distance (m)	5.9 (0.6)	19	8.1 (0.5)	19	Manual	* *
Slope (deg)	8.3 (1.2)	19	13.1 (0.7)	19	Manual	* * *
Hindrance	1.6 (0.1)	19	2.1 (0.1)	19	Manual	* * *
Walk time †	52.8 (4.0)	19	87.1 (7.0)	19	Manual	* * *
Prune time †	145.5 (6.9)	19	176.3 (7.9)	19	Manual	* *
Total cycle time †	253.4 (13.2)	19	352.7 (48.3)	19	Manual	*

* = $p < 0.05$, * * = $p < 0.01$, * * * = $P < 0.001$, ns = not significant.
Tests are one sided with 36 *df* with the alternative hypothesis being that chainsaw pruners will have lower time values for elements in the production cycle.
† times are in centiminutes. 100 centiminutes = 1 minute.

Cycle Time

Delay-free cycle time was found by adding the prune time to the walk time. Actual production rates varied considerably with the theoretical 'delay-free' production rates. Table 4.20 (overleaf) shows the production rates for chainsaw and manual pruners.

Significant differences were found between the actual production rates of the chainsaw and manual pruners ($p < 0.01$, one sided) and also between the theoretical (delay free) production rates ($p < 0.001$, one sided). The one sided alternative hypotheses were that chainsaw pruning would be more productive than manual pruning.

Table 4.20 Actual vs Theoretical Production Rates

	Chainsaw pruners Average rate (SE)	Csaw n	Manual pruners. Average rate (SE)	Mn n	Sig
Actual production rate (trees per hour)	24.8 (1.2)	19	19.7 (1.3)	19	* *
Delay free production rate (trees per hour)	31.7 (1.6)	19	23.5 (1.0)	19	* * *

* = $p < 0.05$, * * = $p < 0.01$, * * * = $P < 0.001$, ns = not significant. Tests are one sided with $n_1 + n_2 - 2$ *df*
Csaw = Chainsaw pruners, Mn = Manual pruners.

4.5.1 **Delays**

There were five types of delays recorded during the continuous time study in the field. The length of these delays are presented in Table 4.21. Data came from the half day averages for morning and afternoons. Testing was performed in the manner described in section 3.1.

Table 4.21 Comparison of Delay Times Between Chainsaw and Manual Pruners

Element †	Csaw Av (SE)	Csaw n (days)	Mn Av (SE)	Mn n (days)	Sig
Researcher delays	0.4 (0.1)	19	8.1 (6.9)	19	ns
Operational delays	5.6 (2.7)	19	6.5 (4.0)	19	ns
Personal delays	4.2 (1.1)	19	21.0 (14.1)	19	ns
Mechanical delays	15.4 (4.7)	19	6.1 (6.0)	18	ns
Short work breaks	50.1 (11.0)	19	202.3 (158.9)	19	ns

* = $p < 0.05$, * * = $p < 0.01$, * * * = $P < 0.001$, ns = not significant. Tests are two sided with $n_1 + n_2 - 2$ *df*
† Times are in centiminutes.
Csaw = Chainsaw pruners, Mn = Manual pruners.

Although there were no significant differences in the length of delays, there was a higher variation in the length of delays for the manual pruners.

4.5.2 **Tree Characteristics**

Tree characteristics were measured to assess any differences in the form of trees pruned by manual and chainsaw pruners. Table 4.22 (overleaf) presents results for various tree characteristics.

No significant differences were found in tree characteristics except for the total cross-sectional area of branching which was greater for the chainsaw pruners, and the DBH of trees which was greater for the manual pruners.

Table 4.22 Comparison of Tree Characteristics for Chainsaw and Manual Pruners

Characteristic	Chainsaw. Av (SE)	Csaw trees	Manual. Av (SE)	Mn trees	Sig
Number of Branches per Tree	17.0 (1.1)	48	15.5 (1.9)	34	ns
Number of Whorls per Tree	3.0 (0.2)	48	2.8 (0.3)	34	ns
Number of Branches per Whorl	5.7 (0.1)	48	5.6 (0.2)	34	ns
Average Branch Diameter (cm)	3.4 (0.1)	48	3.2 (0.2)	34	ns
Average Branch Size (cm^2)	11.5 (0.8)	48	10.0 (1.0)	34	ns
Total Cross-sectional Branch area (cm^2)	155.8 (11.3)	48	120.5 (14.4)	34	*
DBH (cm)	24.9 (0.7)	27	27.7 (0.7)	34	* *

* = $p < 0.05$, * * = $p < 0.01$, * * * = $P < 0.001$, ns = not significant. All tests are two sided with n_1+n_2-2 *df*
DBH = Diameter of tree at breast height (1.4m)

4.6 Quality

The rate of damage per tree was calculated from sample data. As there were no significant differences in the number of branches per tree between the trees pruned by the manual and chainsaw pruners, damage is shown as a rate per tree. Figure 4.04 (overleaf) and Table 4.23 (overleaf) show the rate of damage for each of the manual and chainsaw study groups. Standard errors are shown in Table 4.23 (overleaf).

Rates of damage per tree were tested using small sample t-tests against alternative hypotheses that chainsaw pruning would produce a higher rate of damage per tree. These rates can be seen in Table 4.23 (overleaf).

There was no statistical differences ($p > 0.05$) in the number of collar damage events per tree between the chainsaw and manual pruners. There were statistically significant differences in the number of bark damage events per tree ($p < 0.001$, one sided), the number of coat-hangers per tree ($p < 0.01$, one sided), and the number of combined collar and bark damage events per tree ($p < 0.001$, one sided).

Figure 4.04 Comparison of Damage Events per Tree

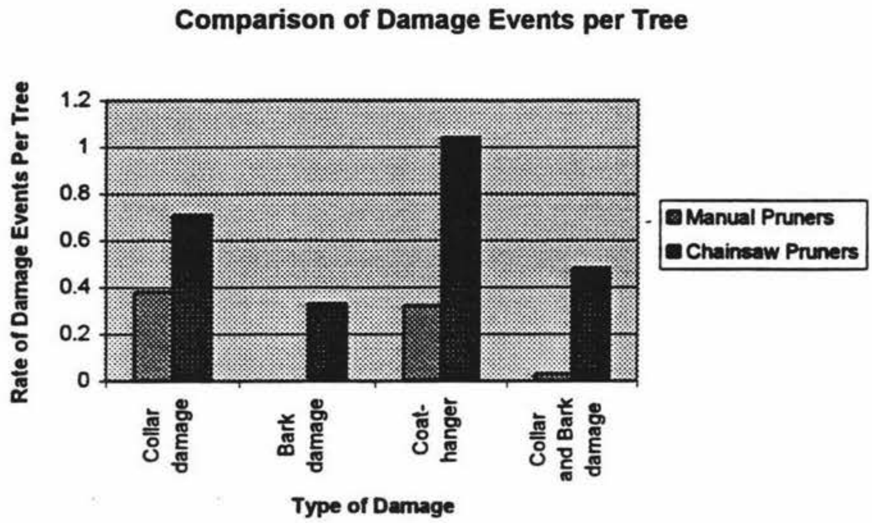


Table 4.23 Damage Events per Tree. Chainsaw vs Manual Pruning

	Manual Pruning. Av (SE)	Chainsaw Pruning. Av (SE)	Sig
Collar Damage.	0.38 (0.08)	0.71 (0.13)	ns
Bark Damage.	0 (0)	0.33 (0.11)	* * *
Coat-hanger.	0.32 (0.13)	1.04 (0.21)	* *
Collar and Bark Damage.	0.03 (0.02)	0.48 (0.13)	* * *

* = $p < 0.05$, * * = $p < 0.01$, * * * = $P < 0.001$, ns = not significant.

All tests are one sided with n_1+n_2-2 *df* with the alternative hypothesis that chainsaw pruning will result in a greater rate of damage per tree.

4.7 Summary

The physical characteristics of the subjects, the analysis of hazards and risk, the physiological cost, productivity, and quality issues associated with the two methods of pruning have been presented. The chapter focused on the results that were specific to the operational hypotheses set out in section 3.1 (research design). Additional data and results relevant to some results are presented in the following chapter or in appendices. The results are interpreted in the following chapter.

Chapter 5 Discussion

5.0 Introduction

This chapter will discuss the results of the research within an ergonomics framework. The chapter is divided into seven sections. Firstly, the physical characteristics of the subjects will be summarised and commented on. Secondly, the hazard analysis will be interpreted and discussed in detail to clarify and explore the validity of the results. Thirdly, the implications of the data relating to the physiological costs of the two methods of pruning will be explored and compared to other similar research. Fourthly the musculoskeletal data and their implications are discussed. Fifthly and sixthly the data relating to productivity and quality respectively are discussed. Finally the chapter will amalgamate all of the results and a cost-benefit analysis will be undertaken. The cost-benefit is discussed.

Discussion within each of these sections will include the interpretation of results with respect to the operational hypotheses (section 3.1) and discussion of any limitations of the research. Results from this study will be compared with research findings from other similar studies. Finally, relevance to other sections of the research will be explored. Conclusions will be presented in Chapter 6.

5.1 Subject Characteristics

The personal characteristics of each subject are shown in Tables 4.01 and 4.02. Each of these characteristics will now be discussed.

Height and Body Mass

The manual pruners were taller (182 ± 2.9 cm vs 178 ± 4.0 cm) and heavier (76 ± 4.5 kg vs 72 ± 5.4 kg) than the chainsaw pruners. The average BMIs and WHRs of the two groups were similar.

One of the manual pruners had a BMI just over 25 which is above the recommended upper limit (Watson 1993). However, when this is checked against the WHR of the subject (WHR = 0.859) it would appear that the subject is not suffering from central obesity, rather he has a higher proportion of muscle and/or bones of greater density which give rise to the higher BMI.

Watson (1993) cites a study by the US Metropolitan Life Insurance Co. and the American Cancer Society which shows that the lowest mortality rates are for people who have a BMI in the range of 20-25. As BMI increases over 25 for males and 24 for females so too does the mortality rate. A BMI of over 27 is considered to be obese (Watson 1993). From the results of the measured BMIs, both the manual and chainsaw pruners can be characterised as maintaining a healthy weight for their height. The 50th percentile New Zealand male in the 20 - 30 year old age group has a BMI of 24 and a WHR of 0.83 (Wilson, Russell and Wilson 1993).

The aggregate results for both the WHR (0.81 and 0.82) and the BMI (22.51 and 23.11) from the chainsaw and manual pruners respectively, show neither group has symptoms indicative of excessive body mass or of central obesity. Hence the research subjects used in the research can be thought of as being physically similar.

The Effect of Individual Characteristics on the Determination of $V_{O_2(max)}$ and *%HRR*

All pruners in the study drank coffee or tea while having their breakfast before work. Toner *et al.* (1982) studied the effect of caffeine on maximal oxygen uptake and heart rate. They found that an hour after a dose of 350 milligrams of anhydrous caffeine, maximal oxygen uptake and maximal heart rate increased by an average of 1400 $ml.min^{-1}$ and 5 $b.min^{-1}$ respectively. However, during submaximal exercise, Toner *et al.* (1982) found that caffeine did not significantly affect the cardiovascular system. As pruning is a submaximal task, caffeine intake is not thought to have significantly increased either pre-work resting heart rates or working heart rates.

Fifty percent of the pruners in the sample smoked cigarettes while at work. The proportion was evenly split between the chainsaw and manual pruners with half of each group being 'smokers'. The subjects who did smoke cigarettes were not asked to refrain from smoking before work as the researcher felt this was an imposition that would not be appreciated by the (voluntary) research subjects.

Smoking has an adverse and immediate effect on the cardiovascular system (Hirsch *et al.* 1985). Heart rate increases after inhalation of cigarette smoke due to higher concentrations of carboxy-haemoglobin in the blood. Haemoglobin has 200 times the affinity for carbon-monoxide than for oxygen (Rodahl 1989). Higher concentrations of carboxy-haemoglobin decrease the oxygen carrying capacity of the blood (Rodahl 1989). This decrease in the oxygen carrying capacity must be compensated for by the sympathetic component of the central nervous system to meet the oxygen demand of working muscles. This is achieved by increasing cardiac output (Green *et al.* 1986).

An increase in heart rate due to cigarette smoking as outlined in the previous paragraph could have led to an increase in the pre-work resting heart rate and hence a reduction of the sensitivity of the *%HRR* index. For the calculation of the *%HRR* index, pre-work resting heart rate was used as a base figure (see section 3.7.2 for formula).

There is an inverse relationship between pre-work resting heart rate and *%HRR* *ceteris parabus*. Therefore, as the pre-work resting heart rates of pruners may have been affected by a cumulative effect of nicotine and caffeine for the cigarette smokers in the sample, and by caffeine alone for the non smokers, it follows that the *%HRR* at work may also be directly affected by these drugs in an inverse manner. All the pruners in the sample drank tea or coffee before work so there will be no disproportionate effect due to the intake of caffeine alone. Whether in fact pre-work resting heart rates were affected by as much as 10 $b.min^{-1}$ due to the combined effect of caffeine and nicotine as opposed to the singular effect of caffeine was thought to be questionable.

Given that all of the pruners in the sample drank coffee or tea before work and that the effect of smoking on the parameters included in the calculation of *%HRR* was thought to be questionable, the inter-individual differences in the pre-work resting heart rates induced by the intake of caffeine and / or nicotine were taken to be negligible.

The effect of smoking on the estimated V_{O_2} (max) of each of the four subjects who smoked was minimised prior to the V_{O_2} tests by asking subjects to refrain from eating and smoking before the tests. This request is standard procedure for any fitness test according to Åstrand and Rodahl (1977). As all tests were performed between 5 am and 6:30 am in the morning, soon after waking and before breakfast, it is unlikely that the subjects had eaten or smoked since going to sleep the previous night. Therefore the effect of smoking (and eating) is not thought to have interfered with the estimates of V_{O_2} (max).

Circadian rhythms affect exercise pulse rates and athletic performance. Faria and Drummond (1982) tested for circadian effects on resting heart rate, body temperature, maximal oxygen consumption and perceived exertion with 31 subjects. Treadmill tests were performed twice in each of 12 two hour time frames which were spaced 48 hours apart. Faria and Drummond (1982) found a systematic but non significant rise in V_{O_2} (max) which mirrored the circadian effects on resting heart rate and oral temperature which peaked in the late afternoon. Faria and Drummond (1982) cite two studies of $V_{O_2(max)}$ estimates based on heart rates by Ribisl *et al.* (1977) and Klein *et al.* (1968). In these studies a similar circadian pattern was found. As all the subjects in the current research were tested once in the early morning, there was not thought to be any error introduced due to the effect of the subjects' bodies being in different phases of their individual circadian rhythm.

As the ages of the subjects involved in the pruning study varied from 16 years to 31 years a correction factor for age was applied to all subjects' estimated V_{O_2} (max) tests (see section 3.4). This correction factor accounted for the general trend of maximal heart rate to decline after the mid 20s which has a direct effect on the oxygen carrying capacity of the cardio-vascular system (Åstrand and Rodahl 1977).

Absolute V_{O_2} (max) estimates in $l.min^{-1}$ were multiplied by the appropriate age correction factor prior to being divided by body mass to obtain relative $V_{O_2(max)}$ estimates in $ml.kg^{-1}.min^{-1}$.

In this study V_{O_2} (max) was estimated using the Åstrand and Rodahl (A-R) nomogram. This nomogram, which is based on data from a group of 86 mixed ability male and female young physical education students, has subsequently been applied over a wide range of ages (Legge and Banister 1986). Legge and Banister (1986) investigated the validity of the A-R nomogram in a cohort of 39 male subjects of mixed ability aged from 20-29 years of age. Legge and Banister (1986) constructed their own nomogram based on experimental data they obtained. The nomogram is based on a relative heart rate response they term ΔHR (read as 'Delta Heart Rate'). Apart from this fundamental difference their nomogram appears to have the same basic structure as the A-R nomogram although the test protocol differs. The age range of Legge and Banisters' subjects corresponds relatively closely with the age ranges of the pruners involved in this study and hence their nomogram may provide a better estimate of true V_{O_2} (max) than the A-R nomogram.

Legge and Banister (1986) calculated V_{O_2} (max) estimates using both the A-R and the Legge-Banister (L-B) nomograms and compared these to measured V_{O_2} (max). The correlation coefficient for the A-R nomogram was r = 0.80 SE_{est} = 0.51 while predictions from the L-B nomogram for the same subjects correlated with measured V_{O_2} (max) at r = 0.98 SE_{est} = 0.17. On the basis of this experimental data the possible error in predicted V_{O_2} (max) would have been lower if the L-B nomogram and protocol had been used in the manner described in Legge and Banister (1986). Further work physiology studies on male workers should consider using the L-B nomogram to predict V_{O_2} (max) on the basis of cycle ergometry.

Despite the limitations of predicting V_{O_2} (max) on the basis of cycle ergometry, Rodahl (1975) reports that estimated V_{O_2} (max) is accurate within the range of ± 15% of actual V_{O_2} (max). On the basis of the evidence presented for and against the use of the A-R nomogram it is accepted that the subjects' V_{O_2} (max) estimates were valid. On this basis comparisons can be made.

Summary

The subjects involved in the two study groups had similar weights, heights, measures of fatness and habitual caffeine and nicotine intake patterns. The average estimated V_{O_2} (max) of the chainsaw pruners in the study group was 48.7 ± 3.1 $ml.kg^{-1}.min^{-1}$ compared to 53.9 ± 2.9 $ml.kg^{-1}.min^{-1}$ for the manual pruners. No statistical differences were found between the average V_{O_2} (max) estimates of the two study groups ($p > 0.05$, two sided). Given that the two study groups had similar individual characteristics, comparisons can be made of the physiological cost associated with each method of pruning.

5.2 Hazard Analysis

Firstly this section will discuss the differences in the observed hazard frequencies and perceived hazard frequencies. The section will discuss the hazard ratings for the evaluation of 'risk', any temporal effects on hazard frequency and then the 'risk score'. Finally the two retrospective accident history surveys which were carried out will be discussed along with data from CHHF's accident reporting scheme.

5.2.1 Observed versus Perceived Frequencies of Hazards

The ratings of frequency used in the risk score were taken from continuous time study data in the field and then rated in the manner of Fine (1971). To compliment this data and to assess the relationship between actual and perceived hazard frequency rates, hazard frequency ratings were included in the risk score questionnaire. Reports of perceived frequency obtained using the questionnaire were considerably lower than the ratings derived from the frequency data collected during the continuous time study. This mismatch of perceived hazard frequency and actual hazard frequency has been noted previously (Tapp *et al.* 1990, and Parker 1991, Parker *et al.* 1994, Sanders and McCormick 1992, Gaskin and Parker 1992).

5.2.2 **Hazard Frequency and Ratings**

The section begins with a discussion of each of the hazards monitored during the continuous time study. The section will then comment on limitations of the data and the validity of the results. The section then goes on to examine hazard frequency at different periods of the day. Finally the section will amalgamate the results of the hazard analysis and discuss the basis for using a risk score.

Ladder hazards

The category of ladder hazards covered a range of hazards which implicitly involved the pruning ladder. Definitions for these hazards can be seen in section 3.6.1. Even though different hazards are represented within this category, the example of Coleman (1981) was followed and it was concluded that falls from ladders were a diverse set of events which could be studied as a statistical aggregate.

The observed frequency of ladder hazards between the chainsaw and manual pruners was not significantly different ($p > 0.05$). Also, there were no significant differences in the frequency of ladder hazards between the morning and afternoon periods for either group in the study. However, the frequency of ladder hazards was high for both groups in the study. A ladder hazard was occurring at a rate of once every three trees.

With the benefit of hindsight, the use of the generic hazard category 'ladder hazards' would have been broken down into more specific components. The ladder hazard category included coming down the ladder two rungs at a time and those occasions where the ladder would twist or become unstable in the original definitions used in the study design. When the study was being designed, it was thought best to limit the hazard categories so that data collection would be manageable. As the study progressed into the second and third weeks of data collection it became apparent that more hazard categories could have been included to include each of the differing types of ladder hazards.

Descending Ladder Two Rungs at a Time

One chainsaw and one manual pruner consistently descended the ladder two rungs at a time. In both cases these pruners were the tallest pruners in their respective study groups (187 cm and 185 cm). While it is possible that this association was purely by chance it is still worthy of discussion.

Descending the ladder two rungs at a time may have been encouraged by the spacing of rungs on the ladders which pruners use. Designing for the 'average' has been a source of mismatch in the design of equipment in the past (Sanders and McCormick 1992). A study to relate anthropometric dimensions of the pruning population to the design of pruning ladders currently in use would reveal if there is a case for product differentiation. Three sizes of ladder to cover the 5th - 34th percentiles, the 35th - 64th percentiles and the 65th - 95th percentiles of ladder users would allow better coverage of the population within a restricted (economic) number of product runs.

Although there may be a case for the design of a range of ladders to accommodate the optimal step heights for the pruning population, Bloswick and Chaffin (1987) did not find a need for any deviation from the standard one foot apart (at an angle of 70^{o}) rung design in their sample of ten subjects.

Comments were made from some pruners that the rungs on the ladders became slippery when wet and that the rungs gave them sore feet. Most boots worn have relatively soft soles which tend to slip on the round (pipe) steel rungs many of the ladders have. Boots that are both slip resistant and hard soled could help alleviate some of these problems. There may also be a need for better rung design in terms of comfort and safety. A detailed review of these design areas is outside the brief of this thesis. For design guidelines refer to Juxptner (1976) for rung design, Chaffin and Stobbe (1979) for optimal rung separation, and Bloswick and Chaffin (1987) for optimal ladder slant, ladder width, toe clearance, and slip resistant hand and foot wear. A study by Cohen and Lin (1991) of ladder fall accidents found that specific ladder use and working condition variables were stronger predictors of ladder falls than the individual characteristics of the accident victims. Application of research into feedback and grip characteristics of varying rung designs in combination with commonly used work boots may improve comfort, safety and productivity.

Ladder Twists

There were occurrences where the ladder would twist at the base while the pruner was up the ladder. This occurred while there was an uneven distribution of weight on the ladder due to hill-slope or branches hindering correct placement of the ladder[19]. This caused one of the spiked legs of the ladder to come out of the ground[20]. The causation of this type of accident is multiple. The risk of falling was exacerbated by the wet slippery conditions and the soft ground in combination with the ladder twisting. On those occasions where the researcher noted ladder twist, the pruners would grab the tree and take as much of their weight off the ladder as possible. To reduce the frequency of this hazard requires management intervention. Forest managers should ensure that trees are pruned both to the correct height on the second lift, and to the correct stocking rate (sph) on the second lift. This would secure high pruners a safer working environment. Training of pruners in safe ladder placement and use should also be performed to help reduce the number of ladder fall accidents.

Sliding Down Ladder

The practice of sliding down the ladder by holding onto the side rails and resting the feet on the side rails was not encountered until after the study period began. Similarly, those times where the top of the ladder could not be firmly placed against the stem of the tree due to the pruner having to perform what are known as 'double' or 'triple' lifts was not encountered in the pilot study. A decision was made in the

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[19] When the previous ('second' or 'medium') pruning lift has not been pruned to the correct height, or when the pruners are required to perform 'double lifts' ie. to prune from 2 - 6.5 m, the ladder cannot be placed flush against the stem of the tree due to branches being in the way.

[20] While no pruners in the research group fell due to this hazard, there was one occurrence when another pruner in the crew the researcher was working with fell due to the ladder twisting.

field to include both of these hazards in the study under what was to become a generic hazard category for 'ladder hazards'.

The occurrences of sliding down the ladder were only observed for the manual pruners within the study group. To slide down the ladder, both hands need to be free in order to hold the side rails of the ladder. In the case of the chainsaw pruners in the study group, one hand was always required to hold the chainsaw while coming down the ladder. However, when the retrospective survey was being conducted in the Hawkes Bay area it was noticed that one gang of chainsaw pruners had clips on their belts to hold the chainsaw as they ascended and descended their ladders.

Cutting large branches above head

There were no statistical differences between the manual and chainsaw pruners in the observed frequency of cutting large branches off directly above the head. Also there was no statistical difference in the frequency of this hazard between the morning and afternoon periods in the study. The frequency of this hazard was no more specific to either group in the study.

The recording of the frequency of cutting large branches above the head was a relatively subjective measure. What was considered a 'large branch' was anything that looked large and heavy enough to cause the pruner to either be injured if the branch hit him, or large enough to possibly cause the pruner to be knocked off the ladder. The estimated diameter of such a large branch was 3.5 cm or more.

There may have been occasions where the hazard was not perceived by the researcher. There may also have been instances where a hazard was recorded when in fact the branch in question was not directly above the head of the pruner. This could have happened if the view of the pruner was not clear or the event was simply misinterpreted. When the subject could not be clearly seen due to poor positioning or when there was substantial undergrowth or other (unpruned) trees in the way, a note was made on the Husky Hunter field computer to delete the hazard data from that particular cycle. However, every effort was made to observe and enter all relevant data events.

In the case of the manual pruners, the outcome of cutting branches above the head may be more severe than for the chainsaw pruners as manual pruners do not currently wear safety helmets. In terms of frequency of occurrence this point is insignificant, but in terms of the possible consequences of this action it is not. This was partially reflected in the risk score questionnaires taken around the pruning work force in the Hawkes Bay area. Manual pruners rated the consequences only slightly higher than the chainsaw pruners (5 vs 4.6) on the 25 point scale they were given. It would seem *prima facie* that the increased risk that is accrued from not wearing a helmet is countered by the greater severity of injury resulting from any contact with the chainsaw. Hence the validity of the risk score questionnaire as regards to the consequences of cutting branches above the head is at least reasonable.

However, the chainsaw pruners rated the likelihood of actually being injured by cutting large branches directly above the head considerably higher than the manual pruners, (7.5 vs 4.8) on the 10 point scale for 'Probability' shown in Appendix 3. Much of this higher rating may be due to the fact that when pruning branches manually there is not the sudden release of tension that there is when pruning with a chainsaw. Hence, in manual pruning there is generally enough time to see the direction and approximate speed of fall of the branch and take evasive action when required. Evasive action would normally include moving out of the trajectory of the branch or grabbing hold of the tree stem. A common preventative strategy used by the pruners in both groups is to twist the pruners or angle the chain bar in order to control the direction of fall of the branch. At times there will be a much greater reaction time needed to take evasive action due to any sudden release of tension, the likelihood of which is greater for chainsaw pruners. Hence, there may be a greater proportion of an individual's reaction capabilities taxed during an incident involving cutting branches above the head for the chainsaw pruners. The effect of sudden release of tension was reflected in the answers of pruners to the risk score questionnaire. Comments to the same effect were also made by many of the chainsaw pruners during the administration of the risk score questionnaire and during the study proper.

Given the considerations outlined in the above paragraphs, the comparison of the frequency of cutting a large branch above the head between the two groups is valid. The components of the risk score questionnaire were appropriate for the hazard of cutting large branches above the head and provide an impartial measure of the risk involved for those times when this hazard occurs.

Cutting Across Arm or Leg

The hazard of cutting across the arms or legs with the blade of the saw was observed significantly more often ($p < 0.05$) for the chainsaw pruning group in the study. When the risk score was calculated, the exposure component was derived from the frequency data collected during the continuous time study in the field. The resulting ratings of exposure were 6 and 7 for manual and chainsaw pruners respectively on the 10 point exposure scale (p-3 Appendix 3).

The ratings given by both the chainsaw and manual pruners to the consequences of cutting across the arm or leg with the saw was approximately equal. However, the chainsaw pruners did rate their chances of actually being hurt from this hazard as being far higher than the manual pruners. This higher rating for the probability of being hurt was pivotal in the resulting risk score for chainsaw pruners given the risk score component of 'cutting across the arms or legs' was double that of the manual pruners (ie. risk score = 363 vs 175 respectively). It would seem that chainsaw pruners are aware of the acute risk involved in operating the saw too close to body parts.

The hazard of cutting across the arms or legs with the saw may be more specific to chainsaw pruners than to manual pruners. This is simply because the use of the jacksaw by the manual pruners is limited to a few times a day as and where it is needed, that is, where the branches are too big for pruners. Given the limited exposure of the manual pruners to the blade of the saw it is notable that the frequency of this hazard for the manual pruners is not lower. There is a need for training beyond simply reading FIRS module 2.4 'Silvicultural Pruning' as it was noted in the field that most of the manual pruners had their hands and wrists precariously close to the action of the blade when they were using the jacksaw. Further discussion appears in the section covering the hazard of holding onto the branch being cut.

Although the exposure to cutting across the arms or legs with the saw is far greater for the chainsaw pruners this does not mean that the comparison of this hazard is not valid. The hazard is applicable to both chainsaw and manual pruning irrespective of the frequency of occurrence as it has the potential to injure. The chainsaw pruners have continuous potential exposure to the hazard of cutting across the arms or legs with the saw while the manual pruners have somewhat limited exposure. Given this consideration, the risk score accommodates different outcomes of the hazard and provides a sound basis on which to evaluate the risk of being cut due to cutting across or near the arms or legs.

Over reaching from ladder

The observed frequency of over reaching from the top of the ladder was significantly higher ($p < 0.05$, one sided) for the chainsaw pruners in the study group. The hazard of over reaching was noted when the pruner stretched up onto the toes in order to reach a high branch.

The length of a typical set of pruners (closed) is around 70 cm and the length of a typical pruning chainsaw is 56 cm. When the handles of the pruners are fully opened before cutting a branch, their effective total length decreases from 70 cm to 48 cm. When the handles of the pruning tools are opened to their full extent, pruners must also be spread their arms wide apart. This further reduces the effective height that the pruner can reach from the top of the ladder to cut a branch off (Thompson 1970). Hence when the pruners are in use, they are actually shorter than the chainsaws. Given this fact it would seem that the manual pruners will have a greater propensity to over reach from the top of the ladder in order to prune to the required prescription. However, the hazard frequency data from the continuous time study do not support this argument. The difference in effort required to prune high branches between the manual and chainsaw pruners may explain why the difference in hazard frequency exists. When a chainsaw pruner is pruning the top whorl of a lift, it is easier to prune an extra few branches as the chainsaw is already in an elevated position. For a manual pruner to prune any such branches would require not only that the pruners and arms be lifted and fully opened again, but also that considerable effort would need to exerted from an unstable and awkward position. It is thought that the difference in the observed frequencies of over reaching is due to the different degrees of effort that must be put into performing this action.

The consequences of over reaching from the ladder were rated slightly higher (4.19 vs 3.94) by the manual pruners. It is thought that this higher rating reflects the increased risk of a fall and somewhat less so the risk of developing musculoskeletal injuries for manual pruners. This is due to having both hands on their pruning tools and not being able to hold onto the tree for stability while over reaching. During the administration of the risk score questionnaire there seemed to be less awareness of the risk of musculoskeletal injury than for falling off the ladder associated with over extension of the shoulder complex.

Ratings for likelihood of being injured due to over reaching from the ladder were greater for the chainsaw pruners than for the manual pruners (7.43 vs 6.25), although not statistically so. This was the case for the ratings of 'likelihood' for all the hazards included in the study. The generally older age and greater experience of chainsaw pruners than the manual pruners which will increase their experience of accurate risk perception.

When chainsaw pruners prune a high branch they generally do so using a one handed operation of the saw. This allows for a higher upward reach higher than is possible when using two hands on the saw. In contrast, manual pruners must have both hands on the handles of their pruners to prune a branch. This limits the height the manual pruners can prune to and increases the risk of falling from the ladder. The latter risk is not as great for chainsaw pruners who will generally have the option to hold onto the tree or a branch with one hand as well as one leg or both.

The criteria for over reaching was whenever the pruner reached up high enough to make him stand on the tip of his toes. The hazard was recorded whether or not the pruner was holding onto the tree for enhanced balance with either the hands or by wrapping one leg around the stem of the tree. The action of holding onto the tree gives an increased sense of security and increases the propensity to reach above the shoulders. Hence there was an increased likelihood that the chainsaw pruners would over reach. This was reflected in the hazard frequency data.

The risk of musculoskeletal injury may be greater for the manual pruners. Not only do manual pruners have to extend their upper limbs further than chainsaw pruners, they also have to produce muscular force from sub-optimal shoulder angles to cut through branches. The optimal force-producing angle of a joint is around midway through that joint's range of motion (Chaffin and Andersson 1984). The joint angles around the shoulder and elbows at which manual pruners must produce force, should leave them more susceptible to musculoskeletal disorders of the shoulder and elbow complexes. However there is no evidence to support this from analysis of the limited (small sample size) data provided by the HSE questionnaire nor from the site specific breakdown of the BPD data (section 4.4.2).

The LIRO accident reporting scheme (ARS) forestry data base shows that of the 66 pruning accidents reported in the 1993-1994 period, 25 (38%) were sprain or strain injuries. There were no identifiable chainsaw pruning accidents in the strain and sprain categories which were reviewed. Of these 25 injuries, only 4 were specifically recorded as being caused by over reaching. There were a further 6 records of strain injuries which did not identify over reaching but had been incurred while manually pruning branches. These statistics show that musculoskeletal disorders are a significant source of injury among forestry pruners.

There has not been any research in New Zealand forestry into the causation of musculoskeletal diseases. Further research using electro-myographic techniques and biomechanical analysis would yield valuable information on the percentage of an individual's maximal strength which is being used to perform manual pruning. The use of these techniques would both identify where and how musculoskeletal disorders are developing, but also they would help in designing tools which are both energy efficient and safe for manual pruners to work with.

The risk scores for chainsaw and manual pruners for the hazard of over reaching are 170 and 204 respectively. The difference comes from the chainsaw pruners rating the consequences of over reaching lower and the likelihood of being injured from this hazard higher than the manual pruners, although not statistically so. The risks involved in over reaching are considerable for both groups of pruners.

Cutting branch too close to stem

The observed hazard frequency of cutting the branch too close to the stem was significantly higher ($p < 0.001$, one sided) for the chainsaw pruners in the study groups. The chainsaw pruners' perceived frequency of this hazard was lower than the observed frequency, 3 vs 8 on the ten point scale used in the risk score questionnaire. The manual pruners rated their frequency of cutting the branch too close to the stem as 3.15 while their actual frequency was 4.5. There is an obvious mismatch between the perceptions of the chainsaw pruners and the actual frequency of this hazard.

The ratings that were given for the severity of consequences due to pruning a branch too close to the stem were 3.5 and 3.92 for manual and chainsaw pruners respectively. The ratings for the likelihood of being injured from pruning the branch too close to the stem were also similar: 5.38 vs 7.80 for manual and chainsaw pruners respectively. While not significantly higher these two ratings warrant further explanation.

The higher perceived likelihood of being injured from the hazard is conceivably due to the fact that when a chainsaw comes into contact with a branch under tension, it will normally contact the top of the branch where the tension will be greatest. This is more likely to cause a sudden release of tension and the branch will effectively 'snap' off. This sudden release of tension will be associated with the branch falling straight downwards rather than in an arc as with a slower release of tension. When the branch falls straight downwards it may hit the pruner off balance possibly resulting in a fall from the ladder. The risk of this happening to a manual pruner is less. This is due to two factors. Firstly, when a manual pruner prunes a branch the cutting area of the tool (pruners) is usually below the branch where it is in compression as opposed to the top of the branch where tension is present. This means that tension is holding the branch and inhibiting it from any sudden release. Secondly, when either the jacksaw or the pruners are used, the chance of a sudden release of tension is less likely as the action of the cutting blade has far less shear force than that produced by the chainsaw.

Although the hazard of cutting branches too close to the stem is more specific to the chainsaw pruning operation than to manual pruning it is a "significant hazard" and so should be included in a comparitive hazard analysis using risk scores. This factor is accounted for by using the risk score as frequency of occurrence, likelihood of injury and the severity of any injury all make up the overall 'risk' involved with any hazard. Comparisons made using the risk score are realistic. That there is a higher risk associated with cutting a branch too close to the stem for chainsaw pruning is no reason to discount the use of the risk score. While it is recognised that chainsaw pruning has a higher frequency of this hazard, and that the hazard is more specific to chainsaw pruning, the rationale behind the use of 'risk scores' is such that this factor is accounted for.

Holding onto the branch being cut

The hazard of holding onto the branch being cut was applicable to both manual and chainsaw pruning. The observed frequency of this hazard was significantly less ($p < 0.05$, one sided) for manual pruners than for chainsaw pruners. This was due to a much lower potential exposure to the hazard as explained below. In the case of the chainsaw pruners, holding onto the branch being cut was usually done to enhance balance or aid to throw the branch clear of the body as it fell away from the tree.

In order to cut a branch with a chainsaw the pruner must accurately position the tool. There is a relationship between the distance away from the body and the precision of hand movements (Grandjean 1988). Therefore pruners will attempt to perform cuts with the chainsaw as close to the body as their perception of an acceptable safety margin would allow. Most often this would mean that there is a chance of being hit by the branch as it falls away from the tree. At times, due to awkward work angles, sub-optimal working practices, and the branch being close to the body, the chainsaw pruners would hold onto the branch they were cutting. This was usually when it was perceived by the chainsaw pruners to actually enhance their own safety.

For a manual pruner to hold onto the branch he was cutting, he had to be using his jacksaw as both hands are needed to use the pruners. The jacksaw is not used as a matter of course. Rather, it is used only when the branch is assessed as being too big to be cut with the pruners. Using the jacksaw on branches is strenuous work. To ease the stress placed on the body by 'throwing' the shoulder into each sawing stroke, holding (bracing) onto a fixed object is often done. This allows a push-pull action with each shoulder moving in opposite directions and makes the movements much easier for a given stroke power. When this type of work is performed it is both dynamic and asymmetric. Biomechanical and epidemiological analyses of asymmetrical exertions indicate that these types of exertions are more hazardous than symmetrical or more static tasks (Marras 1994). Marras (1994), in a study of spinal loadings in dynamic lifting, found that twist velocity significantly increased the spinal forces in the *x,y* and *z* planes. The twist velocity of the manual pruners while using the jacksaw is high and as such this represents a risk of musculoskeletal disorders to the lower back. Injuries to silvicultural workers which are reported to the LIRO ARS show that the proportion of injury to the lower torso is relatively stable at around 14% of all injuries reported (Parker 1992,1993).

When the hazard of holding onto the branch being cut was recorded in the field no note was made of whether the pruner had his leg wrapped around the tree or not. When one leg is wrapped around the tree there is a much smaller chance of being knocked off balance by a falling branch. Once off balance at the top of the ladder the pruner may fall from the ladder. The leg wrapping technique provides considerably more stability than when the pruner has both feet on the ladder and the pruners' mass is concentrated in the same area (on the top of the ladder). The use of this technique is almost total in the manual pruning workforce as there is a need to use both hands to prune, and to lean backwards to both sight and prune branches to a high degree of quality. The leg wrapping technique is common, though less widespread, for the chainsaw pruners in the study group and other chainsaw pruners observed by the researcher at various other stages of the research.

Currently a draft certification program for chainsaw pruning is being developed which stipulates that two hands must be used when operating a chainsaw (C. O'Leary pers. comm.). This not only helps to limit the effect of any 'kickback' but also means that chainsaw pruners spend the majority of their time up the tree with one leg wrapped around the tree stem and thus have a lower risk of falling from the ladder. An exception to the leg wrapping method would be made where the stem of the tree was between the chainsaw and the body. In this situation it would be permissible to stand on the ladder with both feet and operate the chainsaw with one hand.

Further research into safety aspects of ladder pruning should take this leg wrapping factor into account. Two hazardous situations for holding onto the branch being cut could be analysed: (1) with the leg wrapped around the tree, and (2) with both feet on the ladder (or branch) using a numeric system as in the current research. Hence the differing likelihood's of the hazard event resulting in an injury could be accounted for.

The results for holding onto the branch being cut are valid in terms of the risk score. There is undoubtedly a greater potential exposure to this hazard for the chainsaw pruners as they can operate their pruning tools with the one hand. This factor is reflected in the observed frequency rating only. The consequences and likelihood ratings further account for the different methods of pruning as they relate to this hazard.

Time of Day Effects on Hazard Frequency

When considering the six hazard classes across the two groups of pruners, there was only one instance where there was a significant difference in the overall frequency of hazards between the morning and afternoon periods. This involved the hazard of holding onto the branch being cut and was significantly higher ($p < 0.05$, two sided) in the afternoon for the manual pruners only. There was no single afternoon which contributed more than any other to the increased magnitude for the frequency of holding onto the branch being cut. Branch size data from three afternoons with the highest frequency of holding onto the branch being cut were examined and no statistical differences were found between these and the rest of the sample. That the frequency of holding onto the branch being cut was greater in the afternoon (for the manual pruners) than the morning is thought to be symptomatic of the fatigue which the pruners experience.

The Risk Score

To provide some objective basis for the comparison of the significant hazards encountered in the two different methods of pruning, a numeric system was needed. Farmer (1983) addresses the need for a numeric system that will allow risks in the workplace to be prioritised. The hazard rating system used in the research is the 'Risk Score' of Fine (1971). This system of assigning numeric values to hazards provides safety practitioners with a method to calculate the "relative severity" (Fine 1971) and prioritise the remediation for hazards given a balanced consideration of the costs (economic) and the benefits (reduction in risk score) of doing so. For the purpose of this study only the calculation of relative severity is appropriate. The risk scores will not be evaluated in the method of Fine (1971) or Kastenberg and Cave (1990) in terms of the cost-benefit of risk reduction measures. Rather, they will form a major component of the overall cost-benefit analysis of chainsaw vs manual pruning within a frame of reference built around ergonomic concepts as outlined in section 1.1.

A limitation of hazard assessments based on risk scores is that they may not be quite as generally applicable as the authors and users of these systems believe. Fine (1971) reports that his risk score is applicable to any industry as the method of assigning components of the risk score is standardised. When considering that the components of the risk score (likelihood, consequences, and exposure) are evaluated separately for any given situation or industrial setting on the same rating foundation, some confidence can be gained in the use of the overall concept.

The ratings for likelihood of actually being injured given the hazard occurrence and for the consequences of being injured by that hazard are subjective evaluations based on expert knowledge and experience. For the purposes of this study, it was thought that the pruners could provide 'expert' ratings for likelihood and consequences as the pruners had been performing the work and dealing with the risks involved on a day to day basis. Therefore the perceptions of pruners were used to develop a risk score along the lines of Fine (1971). These perceptions were gained via a questionnaire developed by Ford, O'Leary, Kirk, Saunders and Smith (1994) which was administered to a total of 54 pruners to obtain these 'expert' ratings[21]. Hence, ratings for the likelihood of being injured and the consequences of an injury when the hazard event is encountered were performed by the people who have experience of the situation.

Experience has been shown to have an effect on the perceptions of workers with respect to their perceived level of acceptable risk (Zimlong 1985). As the chainsaw pruners are more experienced and familiar with the risks of pruning they may have a tendency to under-estimate their risks. Slovic (1978) states the level of acceptable risk for a person is affected by characteristics such as the degree to which the risk is voluntary, controllable, understood, or catastrophic. Given this, there might appear to be a case that the chainsaw pruners will under-estimate their risks more so than

[21] Of these 54 questionnaires, 30 were filled out by chainsaw pruners and 24 by manual pruners.

manual pruners. The consequences for any accident that may happen due to the hazards monitored in the study were generally rated lower by the chainsaw pruners. In four out of six hazards this was the case (see Tables 4.09 and 4.10). This is of great interest considering the severe outcomes of bodily contact with a chainsaw. Another concept which is integral to the perception of risks involved in any operation is that of the 'perceived likelihood' that an injury will result when the hazard is present.

The chainsaw pruners rated both the likelihood and the consequences of injury consistently higher than the manual pruners for each of the hazard classes in the study. The combination of these two ratings explain most of the differences in the total risk score presented in section 4.2.1. The net effect of the perceived consequences multiplied by the perceived likelihood for each of the hazards monitored is shown below in Tables 5.01 and 5.02.

Table 5.01 Consequences times Likelihood of Injury for Chainsaw Pruners

	Likelihood (L)	Consequences (C)	Net (C x L)
Ladder	3.4	4.7	15.7
Cut above	4.6	7.5	34.5
Cut across	4.3	12.0	51.8
Over reaching	3.9	7.4	29.3
Too close	3.9	7.8	30.6
Holding	3.6	10.2	37.1
		Total C x L	199.0

Table 5.02 Consequences times Likelihood of Injury for Manual Pruners

	Likelihood (L)	Consequences (C)	Net (C x L)
Ladder	3.1	3.7	11.6
Cut above	5.0	4.8	23.6
Cut across	4.4	6.7	29.2
Over reaching	4.2	6.3	26.2
Too close	3.5	5.4	18.9
Holding	3.8	6.8	25.8
		Total	135.3

Tables 5.01 and 5.02 show that the product of perceived consequences and perceived likelihood of injury is higher for the chainsaw pruners than the manual pruners.

While the chainsaw pruners rated the consequences of any injury significantly lower than the manual pruners for three out of the six hazards, they had a perception that the chances of being hurt by the hazard were greater (non significantly). A source of error in the risk score may have been introduced as the different degrees of experience between the chainsaw and manual pruners may have led to under-estimation of the consequences of an accident as perceived by the chainsaw pruners. The converse may also apply to manual pruners over-estimating the consequences of the hazards surveyed.

Another possible source of error in the results of the risk score may be due to faults in questionnaire design and wording (C. O'Leary pers. comm.). However, a detailed and 'common language' explanation of the questionnaire was given to each pruner at the time of administration in an attempt to minimise any such error. It should be noted that there are people working in the forests of New Zealand who do not have the reading or writing skills to fill out any questionnaire on their own. Researchers should be sensitive to this issue when administering questionnaires. The method of approach taken in this particular study proved satisfactory. An informal friendly approach was taken which worked well. Those who were having problems did not hesitate to approach the researcher and say so. Valuable comments were obtained from many pruners during the study irrespective of literacy.

Summary

The risk scores for the manual and chainsaw pruners provide a valid basis on which to firstly assign risk and secondly to compare risk. The risk score, as made up of significant hazards, provides valuable information for the comparison of risk between the two methods of pruning.

5.2.3 Retrospective Accident Survey

Two retrospective accident surveys were performed during the course of the research. The first was restricted to the pruners in the experimental group (n = 8), while the second was a larger survey of the pruners in the Hawkes Bay region (n = 54). The results of these will be dealt with in turn.

Firstly, a retrospective accident survey was conducted in unison with the administration of the HSE questionnaire (see Appendix 1, Q 34 - 40). This survey covered the pruners in the experimental group only. The results from this survey were that there was no significant differences between the accident frequencies of the manual pruners or the chainsaw pruners for the previous one year period. There were however statistical differences in the number of days lost due to injury ($p < 0.05$, one sided). The results of this test went against the alternative hypothesis that there would be more days lost due to chainsaw pruning accidents than due to manual pruning accidents. The sample size for this test was relatively small in comparison to the time study, quality, rated perceived exertion and body part discomfort tests which were performed. This was noted by the researcher and it was decided to determine relative accident frequencies using the risk score questionnaire which was administered to a larger sample of pruners (Appendix 3, Q 5 - 7).

As used in this research, 'accident frequencies' refers to the number of accidents divided by the number of workers for each of the chainsaw and manual pruners from October 1993 to October 1994. They are not true accident frequency 'rates' as such as they do not take account of hours worked. There are many in the pruning workforce who spend varying amounts of time planting and releasing during the course of a year. Hence it would be inappropriate to interpolate hours worked and call the data collected a true 'rate', rather they might be termed probabilities of being injured if a person was to work a typical year as a pruner including work other than pruning.

From the results of this and the previous retrospective accident survey it would seem that there is no difference in the frequency of accidents experienced by the manual and chainsaw pruners. Respondents were asked about the type of pruning that they were doing at the time of the administration of the survey as well as how long they had been doing this type of pruning. There were some pruners who had recently changed from manual to chainsaw pruning but none of these pruners had had an accident in the last year. Controlling for this variable allowed better comparisons of the rate of injury experienced by the chainsaw and manual pruners. The length of time spent pruning in the retrospective time period (as opposed to planting or other activities) was not asked of the pruners, so again frequency 'rates' cannot be quoted.

There may have been instances of under reporting of chainsaw pruning accidents by pruners in the Hawkes Bay area at the time of the retrospective accident survey. Comments from different chainsaw pruners the researcher has talked with indicate that if they had to go back to manual pruning they would give the job up altogether. It was well known in the pruning work-force that the legal status of chainsaw pruning is in question. It is reasonable to infer that if a lower frequency of accidents is reported for chainsaw pruning than manual pruning, then the likelihood of chainsaw pruning being allowed to continue by the Department of Labour's Occupational Safety and Health service will be greater. However, the researcher was given no reason to believe that pruners were consciously under reporting events while administering the retrospective accident surveys.

From the viewpoint of this research it is unfortunate that the LIRO ARS has no means of discriminating between manual and chainsaw pruning accidents except where a specific tool is identified as the final cause of the injury. This is not to say the tool caused the injury, rather that the tool was the item that transferred the energy which produced the injury. Examination of the ARS data base indicated more manual pruning injuries had been reported than chainsaw pruning injuries. However, there are also far fewer chainsaw pruners and no rates can be given on which to base comparisons as there is no information available on the exact or even approximate number of manual or chainsaw pruners.

CHHF has an accident reporting data base which does discriminate between the two methods of pruning. However, as the two methods of pruning are interchangeable there is no accurate way to find out how many hours are spent pruning either with a chainsaw or with pruners in order to calculate lost time injury frequency rates (LTIFRs) beyond the reasoned estimation given by Brian Saunders. Nor is there any method to find out how many people were employed in manual or chainsaw pruning in the period from October 1993 to October 1994.

Examination of CHHF's accident reporting data base shows that there were 10 LTIs for pruning in the period from October 1993 to October 1994 (B. Saunders, pers. comm.). There is an extreme difference in the estimated LTIFRs between the manual and chainsaw pruners. Firstly, this may be due to the chainsaw pruners having far more experience of the forest environment and consequently a better understanding of the hazards. Secondly, in general, the manual pruners are younger than the chainsaw pruners and as such do not have the same mobility in terms of vehicle ownership that (the older) chainsaw pruners have. This means that the manual pruners cannot meet a doctors appointment unless they remain in town for the entire day for treatment of minor injuries (B. Saunders pers. comm.). Chainsaw pruners can take the necessary time off work to see a doctor and return to work the same day in their own vehicles. As such there is no LTI recorded. This has implications for the average severity shown in Table 5.03 as short duration LTIs to see a doctor decrease the average severity. These factors limit the statistical validity of the LTIFRs given below in Table 5.03.

Table 5.03 Accident Reporting Data Base From CHHF (Central)

		Manual	Chainsaw
No. of Lost time injuries	(Oct 93 - Oct 94)	6	4
Average Severity.	(No. days lost)	5 days	7.25 days
Estimated LTIFR[1]	(per million hours)	173.7	48.1

[1]LTIFR = Lost Time Injury Frequency Rate.

The results of the retrospective accident survey and the estimated LTIFR show broad similarities in that there appears to be a lower injury rate for chainsaw pruners than for manual pruners. However, due to the method of collection of the data, to be able to say categorically that the LTIFR for chainsaw pruners is lower would be inappropriate. The industry needs to have better reporting procedures and must call for contractors to supply information not only on the number of days worked but also the type of work being done to allow for better analysis of accident data.

The severity of chainsaw pruning injuries is skewed due to a fractured tail bone one incurred by a chainsaw pruner (20 days lost time) when he fell off a ladder (B.

Saunders pers. comm.). The severity of manual pruning accidents is thought to be skewed in the opposite direction due to manual pruners having to take entire days off work to see doctors for minor injuries. The average severity of all pruning LTI's reported to the LIRO ARS was 4.7 days (Parker 1993) for 1991 and 1992, and 6.8 days (Parker 1994) for 1993. Parker (1993:1994) identifies ladders accidents as resulting in the most lost time per accident for pruners. This is also the case for those accidents reported by CHHF (Central). Priority should be given to improving the design of ladders and training personnel in their safe operation.

Summary

The results of the combined risk score (section 4.2.1) indicate that the risks involved in chainsaw pruning are twice that of manual pruning. However, it has been shown that two of the significant hazards that were monitored are more specific to chainsaw pruning than to manual pruning. Therefore, the total risk score must be interpreted with due caution and consideration in this respect. These issues aside, there would seem to be a far greater potential for injury associated with chainsaw pruning than for manual pruning. This is not however reflected in the results of the retrospective accident history survey which was administered to the pruning work-force in the Hawkes Bay area. Conclusions and recommendations on these topics will be presented in the following two chapters.

5.3 Physiological Costs

Introduction

The physiological cost of pruning work in terms of *%HRR* was found to support hypothesis 2a that 'Chainsaw pruners and manual pruners will experience the same relative heart rate response' (section 3.1). However, hypothesis 2b that 'There will be no relative difference in the Rated Perceived Exertion (RPE) for manual and chainsaw pruners' was not supported by the data collected in the field.

Percent Heart Rate Range

For the purposes of the %HRR, resting heart rate was used as the basis of the index as explained above in section 5.1. Limitations of using this approach in the applied setting have already been discussed (section 5.1).

There were no statistical differences between the average %HRRs of the chainsaw and manual pruners in the study. This finding supports hypothesis 2a that there will there will be no difference between the relative heart rate response of the chainsaw and manual pruners. This hypothesis follows on from what has become known as 'the natural effort limit'. Lundgren's theory was tested and again supported by Vik (1982) with fallers and planters. It has now also been supported with pruners in the current research.

Previous work has studied the physiological cost of pruning (Hartsough and Parker 1993a,b, Kirk and Parker 1994) and their results point to pruning as having a 'moderate' to 'heavy' workload classification within the classification system offered by Rodahl (1989). This study points to high ladder pruning as having as workload classification as 'heavy' to 'very heavy' within Rodahl's (1989) classification system.

There were only two pruners whose heart rates were in the 'very heavy' category. Both these pruners were manual pruners and both were the only subjects in the study who were under 20 years old. These two pruners will have the highest theoretical maximum heart rates and hence should be able to sustain higher heart rates than the older pruners. Perhaps inexperience and sub-optimal work techniques led to these two pruners having to work 'harder', in the physiological sense, and hence elicit a greater heart rate response to their work. There is no evidence to support these ascertations of inexperience and sub-optimal work techniques and the higher working heart rates of these two subjects is attributed to inter-subject variability.

Elevation of Resting Heart Rate

The elevation of resting heart rates due to physical exertion has been studied in the past (Brouha 1967). Brouha (1967) found that recovery pulse was linearly related to the sum of work pulse, hence both the intensity and length of work will affect the recovery of a person's resting heart rate down to within its normal homeostatic range. Elevation of resting heart rates is an indication of an unpaid oxygen debt due to physical exertion and is also associated with anaerobic metabolism (Grandjean 1988). Anaerobic metabolism occurs when the energy demands placed on the musculoskeletal system are such that they exceed the capacity of the individual to equal them without recruiting anaerobic metabolic processes which lead to a build up of waste products in the active muscles.

Aerobic metabolism converts potential chemical energy into mechanical energy (physical work) and has the waste products of water and carbon dioxide (CO_2). The waste products from aerobic metabolism are quickly and efficiently exhausted through the lungs and excreted through the urine. This is in contrast to anaerobic metabolism where the waste products require further oxidation prior to exhaustion and excretion. When the energy demands of muscular work exceed the capacity of a person to meet these demands, anaerobic metabolic processes will provide the energy for continued exertion. This however places the person in a state of oxygen debt. The body's way of repaying this debt is to oxidise the waste products of aerobic metabolism. This is achieved by increasing the flow of oxygen to the affected muscles. The cardio-pulmonary system delivers this oxygen to the affected areas via diffusion of oxygen to the blood through the lungs and by subsequently pumping this oxygen rich blood to the muscle. Hence recovery from anaerobic metabolism can be measured and will be associated with increases in respired oxygen, expired CO_2 and heart rate. Of these parameters, heart rate is the most practical to measure in the applied setting.

Both the before work and after work resting heart rates of subjects were measured according to the protocol outlined in section 3.7.2. This allowed the assessment of whether there was any significant rise in before work resting heart rates at the end of the day. Analysis of data collected in the field shows a general trend toward significantly higher resting heart rates in the afternoon. Table 5.04 shows the percentages of these trends where the total number of samples is 12 for both groups in the study. Unfortunately a relatively large proportion of the data did not meet protocols which were set by the researcher for the evaluation of resting heart rates. These protocols included whether there were at least five minutes worth of data off the heart rate monitors in either the morning or afternoon, and that a full work day had been completed.

Table 5.04 Percentage of Afternoons with a Significant Elevation in RHR

	n	Morning RHR significantly higher?	Afternoon RHR significantly higher?	No significant difference	Data did not meet protocol
Chainsaw	12	16.7 %	16.7 %	25.0 %	41.7 %
Manual	12	8.3 %	33.0 %	25.0 %	33.0 %

There were no statistical differences in any of the categories between the chainsaw and manual pruners. On the basis of sample data, manual and chainsaw pruners have an equivalent oxygen debt. This provides further evidence for Lundgren's natural effort limit. Similar oxygen debts (stress response) as estimated from elevated resting heart rates infer similar relative stress on the cardiovascular and musculoskeletal systems for these two groups of physically similar subjects. This is to be expected in light of the fact that the chainsaw and manual pruners experienced the same relative heart rate response to their work and is further support for hypothesis 2a.

RPE

The results from the RPE analysis are shown in Tables 4.16 and 4.17. RPE values were correlated with heart rate recordings in the manner set out in section 3.7.3. The responses given by the manual pruners correlated moderately with heart rate data in both the morning and the afternoon periods of work. This was not the case for the chainsaw pruners in the study for the afternoon period. It can be seen from Table 4.16 that there is a large difference in the correlation of RPE with HR for the chainsaw pruners in the afternoon period.

While there was a general trend towards lower correlations of RPE and HR in the afternoon, the effect was very pronounced for the chainsaw pruners. In general, they over estimated their actual exertion as measured by heart rate. There were significant differences ($p < 0.05$, one sided) in the afternoon correlation coefficients between the chainsaw pruners and the manual pruners. The only other significant differences were for the correlations of HR versus RPE between the morning and afternoon periods for the chainsaw pruners ($p < 0.01$, one sided).

Pandolf (1978) delineates between local and central factors in the rating of perceived exertion. Local factors include feedback from the working muscles and/or joints while central factors are sensations or feelings involving the cardio-pulmonary systems. There were no significant differences in body part discomfort between the manual and chainsaw pruners in the afternoon which discounts the effect of local factors as these local factors can tend to dominate over central factors when rating perceived exertion (Pandolf 1978). With this factor accounted for, other factors to explain the disparity in the RPE of chainsaw pruners in the afternoon can be explored.

The drop in the degree of association between HR and RPE for the chainsaw pruners in the afternoon periods relative to the morning periods is striking and may be due to the effect of social isolation. Giefing (1993) discusses the effect of monotony on tree pruners in that monotony increases feelings of tiredness and muscle pain. These factors will impact more on the perception of exertion by pruners than objective physiological measures of exertion. Also, Giefing (1993) states that working time may have an influence over the change in the relative domination of stress factors.

Studies on social isolation and loneliness have shown them to be significant stress factors (Rodahl 1989, Johnson *et al.* 1989). When social isolation is combined with heavy physical work there is a greater chance of the development of cardiovascular disease than in a reference population. This is due to increased blood pressure and stress hormones among other things (Johnson *et al.* 1989).

The feeling of tiredness dominated over the objective physiological measure of heart rate for the chainsaw pruners in the afternoon. There was a similar though not nearly so marked effect with the manual pruners. The manual pruners had more social contact and seemed to be constantly talking and joking with each other during the work day. The chainsaw pruners had no such contact except during the lunch break and even then at times they would only stop long enough to eat, refuel their chainsaws and have a cigarette. Whether the chainsaw pruners had shorter lunch breaks when the researcher was not present is not known. Chainsaw pruners may have sought social contact with other pruners more often in the absence of the researcher. Nervertheless, it seems reasonable to conclude that chainsaw pruners have far less social contact than manual pruners.

The noise from the chainsaw and hence the need to wear hearing protection is the root cause of the social isolation and so is inherent in the job of chainsaw pruning[22]. There is no conceivable way to stop the social isolation of chainsaw pruners while they are working except perhaps to have two way radios inside the earmuffs with a microphone near the mouth. This technology is available and is being developed for use in New Zealand forests.

Thermal Environment

The thermal environment was monitored with the CR-21 weather station. However this piece of equipment proved to be unreliable and its use was discontinued. This led to an incomplete data set for the WBGT index temperature. Accordingly, those WBGT index temperatures that were available were regressed against the 3 pm dry bulb temperatures and relative humidities at Napier airport. This method proved inaccurate.

Grandjean (1988) states that for heavy work a WBGT index of 25°C should not be exceeded. If this temperature is exceeded the worker will be prone to heat stress or strain. The study was carried out in the winter months and the researcher is confident that the WBGT would never have approached or exceeded 25°C.

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[22] All chainsaw pruners in the actual study group, and other chainsaw pruners seen by the researcher in this study wore hearing protectors while working as a matter of course. The wearing of hearing protectors is mandatory for all chainsaw operators.

Therefore there was thought to be no major disproportionate effect of the thermal environment on the physiological cost of any of the pruners in the study.

5.4 Musculoskeletal Discomfort

The results of the HSE questionnaire data as shown in Figure 4.01 do not support hypothesis 3a that manual pruners will experience a higher prevalence of musculoskeletal disorders than chainsaw pruners. Rather than rejecting the hypothesis outright, judgement is reserved in this case.

Hypothesis 3b that 'manual pruners will experience more body part discomfort (in more areas, to a higher level) than chainsaw pruners was tentatively upheld on the basis of sample data.

5.4.1 Health and Safety Executive Questionnaires

Some of the discomfort experienced by pruners in the study was explained as being due to past injuries some of which were work-related although not from the pruning task. Johansson (1994) stresses the importance of controlling for musculoskeletal disorders which originate outside the work place in comparative studies. The administration of the modified HSE questionnaire to the pruners in the study did control for exogenous variables outside the work place due to the inclusion of the retrospective accident survey (see Appendix 1). Inclusion of controls for the influence of non work-related factors was called for by Dickinson *et al.* (1987). This approach has been tested by Johansson (1994) and in the current research. Injuries which were not related to the task of pruning were described by the research subjects. The results of the HSE questionnaire are believed to be both reliable and valid. Rigorous statistical testing of the results was not possible due to the size of the sample, and it is tentatively inferred that there are no differences in the prevalence of musculoskeletal discomfort or disorders during the past year and the past seven days between the chainsaw and manual pruners.

5.4.2 **Body Part Discomfort**

The results from the body part discomfort questionnaire are presented in section 4.4.2. The aggregate results show that there were statistically significant ($p < 0.05$, one sided) increases in the BPD experienced by manual pruners when measured before and after the work day. There was no such significant rise for the chainsaw pruners in the study. A site specific breakdown of the body part areas with the most frequent and severe BPD was given in section 4.4.2 and connections were drawn between the BPD ratings given by the pruners and areas highlighted in the HSE questionnaire as having musculoskeletal complaints. The BPD survey results will now be discussed.

Reports of discomfort after work were most frequent among the manual pruners. The main areas of this discomfort were in the hands and forearms. Most of these reports were from the same subject who also identified this area in the HSE questionnaire. The injury was work-related. Despite the influence of inter-subject variability, which must be expected in any sample, there is still evidence that there is a greater increase in the BPD associated with manual pruning when measured before and after the working day.

Musculoskeletal pain or discomfort are feedback mechanisms to warn against disease, damage or the limitations of the body (Stuart-Buttle 1994). Stuart-Buttle (1994) cites Boussenna *et al.* (1992) as stating that the BPD experienced by subjects is positively correlated to the torque at the joints. Thus the greater the torque around a joint, the greater the BPD will be and hence the likelihood of musculoskeletal disease. Manual pruning requires the application of considerable force through the upper torso, hands and wrists. The manual pruners keep hold of their tools while pruning requiring a considerable amount of grip strength. The intensity and duration of this gripping action leads to muscular fatigue in the forearms and discomfort associated with vaso-constriction in the palms of the hands. Manual pruners use a 'biting' action of the pruners by 'snapping' the handles of the pruners together in order to maximise muscular dynamism and the force-velocity relationships of the muscle groups involved. While this action is a good way to avert muscular fatigue, it does not take into account the impact loading on the soft tissues of the palms nor the repeated application of large bending moments (or torque forces) around the wrists. In a study of dynamic trunk motion, Marras (1994), concluded that 'there appears to be a strong relationship between loading frequency and injury risk'. The finding of Marras (1994) is thought to be applicable to the wrists and hands.

Chainsaw pruners generally work with smoother movements and hence do not have the impact loading on the palms of the hands and joints that the manual pruners encounter in their work. They do however have to sustain grip strength while pruning and they are exposed to hand-arm vibration. This introduces static and mechanical (vibration) loading to the small muscle groups and structures of the hands and forearms. Pruning chainsaws do, however, have the same vibration damping features as modern felling chainsaws.

5.4.3 Summary

In general, as pruning is performed on a tree by tree basis, the work is intermittent and may allow adequate recovery from any static loading of working muscles. There may still be fatigue in the working muscles at the end of the work day due to the combination of static and dynamic loads placed on the musculoskeletal system, but there was no cumulative effect shown up in the morning BPD scores as the week progressed. The results from the BPD survey suggest that manual pruning is associated with a greater increase in BPD than chainsaw pruning during the work day. This provides evidence in partial support of hypothesis 3b that 'Manual pruners will experience more Body Part Discomfort (in more areas, to a higher level) than chainsaw pruners.

5.5 Productivity

Elements of the production cycle for the chainsaw and manual pruners in the study were determined and are shown in Table 4.19. Actual production rates were calculated in trees per hour and can be seen in Table 4.20. The number of trees pruned per hour is affected by a number of factors. The total tree pruning cycle, irrespective of the method, involves selecting the best quality tree to be pruned in the immediate area, walking to the tree that has been selected, placing the ladder below the tree, climbing the ladder, pruning the tree, and finally descending the ladder. These factors were grouped into walk time, prune time and total cycle time.

Walk Time

Walk times were recorded. The difference in walk time between chainsaw and manual pruners was highly significant (53 versus 87 centiminutes) as shown in Table 4.19. This can be attributed to the distance walked, the hindrance encountered over this distance, and the ground slope encountered during the walk from one tree to the next. These elements were recorded by the researcher in the continuous time study in the manner set out in section 3.9.

The distance walked between trees was significantly less ($p < 0.01$, one sided) for the chainsaw pruners than the manual pruners (see Table 4.19). Some error in the estimation of the distance walked between trees may have been introduced in the study by the researcher. The researcher assessed the distance walked between trees subjectively. Approximately every 1-2 hours the researcher 'recalibrated' his assessments by both estimating and measuring (with hip chain, see section 3.9) the distance walked between trees. These 'recalibration' checks allowed for a reference on which to continue estimating the distance walked relatively accurately.

Ideally each distance walked from tree to tree would have been measured. However, this operation was not performed as it would have caused the researcher to miss some actions of the research subjects which should be included in the hazard analysis such as slipping while ascending the ladder. If any bias was introduced into the study from the subjective assessment of distance walked it would have been systematic and standardised across all research subjects. The researcher was confident that any errors in the estimation of walk distances were small.

Theoretically, there should be only minimal differences in the distance walked between trees. All operations were pruning to the same prescription of approximately 300 stems per hectare from an initial stocking rate of around 325 stems per hectare. Given this fact, it might be implied that the manual pruners were less efficient in their choice of walking path (5.9 ± 0.59 m vs 8.1 ± 0.52 m) and hence walked unnecessarily further. However, there are intervening variables that make this implication less likely to be true. The significantly greater hindrance, hill slope and generally 'rougher' country the manual pruners encountered may have led to them choosing to walk along paths which were not optimal in terms of a straight line distance, but may have been optimal in terms of ease and speed of walking between trees.

Another factor which must be considered is that three out of the four manual pruners in the study cohort worked for the same contractor in the same forest compartment during their involvement in the study. Due to the steep terrain and heavy going in this particular compartment the pruners were instructed to stay together and perform sweeps over what looked to be the best path with respect to the terrain. At the end of many of these sweeps a relatively long walk would be made to the start of the next sweep. The same process was observed for the chainsaw pruners albeit far less often. It is proposed that this increased walk distance is a function of both the organisation of work and the roughness of the country. The relative influence of these two factors is not known and could be a topic for further production research.

Hindrance

Hindrance has been identified as having an effect on the time to walk between trees and the effort involved in walking between trees (Vik 1984, Kirk and Parker 1994:c). Walk distance and walk time was influenced by the greater hindrance encountered by the manual pruners ($p < 0.001$, one sided).

Hill-slope

The effect of hill-slope on walking speed (Li *et al.* 1989), productivity (Vik 1984), and physiological workload (Fibiger and Henderson 1984, Li *et al.* 1989, Vik 1984) has been studied. It has been shown that the greater the hill-slope the slower the walking speed (Li *et al.* 1989). Vik cites a study by Lundgren (1966) which put forward the hypothesis of a natural effort limit as discussed earlier in section 5.3. The hypothesis suggests that people at work will tend to compensate for an increased hill slope by slowing their walking speed in order to achieve a sustainable physiological load.

The average hill-slope encountered by the manual pruners in the study was significantly greater than that for the chainsaw pruners ($p < 0.001$, one sided). This fact in combination with the significantly greater walk distance and hindrance encountered by the manual pruners led to a greater overall time to walk between trees. This greater walk time impacted directly on the productivity of pruners.

In the present study, average hill-slope was measured with a Sunnto clinometer (see section 3.9). This method may have under-estimated the effect of the hill-slope encountered when working across a hill-slope or when the profile of the hill-slope included a dip and subsequent rise. When taken as the average hill-slope between one tree and the next tree to be pruned, the limitations of measured hill-slope were thought to be both minimal and standardised across all research subjects.

Prune Time

The time taken to prune trees was determined during the continuous time study. Prune time was found to be significantly less ($p < 0.01$, one sided) for the chainsaw pruners in the study. This significantly faster rate of prune time was in spite of a significantly greater ($p < 0.05$, one sided) cross-sectional area of branching per tree (see section 4.5).

The measurement of prune time through direct observation was relatively precise. On the few occasions when either the start or the end of the 'prune time' component of the production cycle could not be directly observed by the researcher, a note was made within the continuous time study program and the cycle was deleted prior to any analysis being carried out. Hence any prune times which were in doubt were not included in the analysis. The effect of tree characteristics on prune time is discussed on page 122 and regression equations are shown in Appendix 10.

Delays

There were no significant differences in the average length of delays per cycle between the chainsaw and manual pruners. The differences in the length of time of researcher delays was notable though non significant. The chainsaw pruners had a degree of pacing built into their routine as chainsaws need refuelling approximately every hour. This hourly stop for fuel presented itself as an ideal opportunity for the researcher to administer the RPE questionnaire. This is in contrast to the manual pruners who, at times, had to be stopped and asked to rate their exertion. Thus the slightly longer delay times for the manual pruners may in part be attributable to the influence of the researcher.

Total Cycle Time

Total cycle time was significantly longer for the manual pruners ($p < 0.05$, one sided). Total cycle time is made up of prune time, all delays and walk time. Walk time is affected by the terrain, distance and hindrance. Even with the effect of these variables taken out of the equation (ie just prune time) chainsaw pruning is still significantly ($p < 0.01$, one sided) faster than manual pruning. This supports operational hypothesis 4a that 'chainsaw pruners will have a higher rate of productivity than manual pruners'.

Tree Characteristics

There were no significant differences in any of the tree characteristics measured between the trees pruned by the manual and the chainsaw pruners except for the total cross-sectional area of branching per tree. This was significantly ($p < 0.05$) greater for the trees pruned by the chainsaw pruners (156 cm^2 vs 120 cm^2).

Potential existed for some over estimation of branch diameters through the inclusion of part of the surrounding branch collar in the measurement. However, the researcher is confident this was not the case and that the diameter measurements were accurate to within 5 mm.

Tree characteristics have an influence on the time taken to prune trees. The relative influence of tree characteristics can be assessed using regression analysis against the length of time it takes to prune a tree. Diameter at breast height (DBH) is the easiest tree characteristic for researchers or foresters to measure in the field. Regression analysis found DBH to be a poor predictor of prune time with an r^2 of 0.04 for chainsaw pruners and an r^2 of 0.25 for manual pruners. Stronger relationships were found between the number of branches per tree and the total cross-sectional area of branching per tree (see Appendix 10).

Appendix 10 shows that there are moderately strong coefficients of determination for the effect of total cross-sectional area of branching per tree on the time taken to prune that tree (r^2 = 0.51 and 0.59 for chainsaw and manual pruners respectively). The total cross-sectional area of branching per tree was the only significantly different tree characteristic of the trees pruned by the manual and chainsaw pruners. As this characteristic is related to prune time, the researcher has reservations about the direct comparison of prune times between manual and chainsaw pruners in this study without any consideration of the characteristics of the tree. Therefore, as the total cross-sectional areas of branching per tree were significantly different, it cannot be concluded that the pruners in the study were pruning similar trees. However, if the prune times are predicted for a range of cross-sectional areas of branching per tree with the regression equations shown in Appendix 10, it can be seen that chainsaw pruners do prune trees at a faster rate than manual pruners (see Table 5.05).

Table 5.05 Predicted Prune Time vs Cross-sectional Area of Branching

Cross-sectional area of branching per tree (cm^2)	Predicted prune time	
	Chainsaw pruners. (centiminutes)	Manual pruners. (centiminutes)
120 cm^2	107.2	171.8
150 cm^2	122.1	197.0
180 cm^2	136.9	222.1

That the area of branching per tree was both greater for the trees pruned by the chainsaw pruners and had an influence on the time taken to prune trees did not limit the application of the current research findings. When theoretical cross-sectional areas of branching per tree were run through the regression equations (Appendix 10) developed from data specific to either method of pruning (Table 5.05) it is still clear that the chainsaw pruners are faster. It is concluded that the differences in tree characteristics do not limit the findings of the research and that chainsaw pruning does have a higher rate of productivity than manual pruning as was hypothesised in section 3.1.

5.6 Quality

The rate of collar damage per tree associated with chainsaw pruning was not found to be statistically different from that of manual pruning. The respective samples were reasonably large (in the statistical sense) and provided two data sets large enough to allow the central limit theorem to be applied. Hence it can be reasonably inferred that there are no major differences in the number of collar damage events as such per tree due to the two different methods of pruning.

The rate of bark damage per tree was significantly higher for the chainsaw pruners than for manual pruners ($p < 0.001$, one sided). Similarly, the rate of coat-hangers and combined collar and bark damage events per tree was significantly higher for the chainsaw pruners ($p < 0.01$ and $p < 0.001$ respectively, one sided). When the combined rates of 'collar and bark' damage events per tree are taken into account the non significance between the rate of 'collar' damage per tree must be called into question. When the rates of 'collar' damage and 'collar and bark' damage per tree are combined, the manual pruners have a rate of approximately 0.4 collar damage events per tree versus the chainsaw pruners who have a rate of approximately 1.0 collar damage event per tree.

It is conceivable that using a chainsaw, as opposed to pruners, decreases the control of the operator over the placement of the cutting area of the tool. Even though the distance from the hands to the cutting area of the tool (chainsaw or pruners) is less for the chainsaw pruners, there is weight, reactive torque forces, problems of visibility, vibration and gyroscopic effects to be dealt with. Also, vibration decreases the relative tactility of the hands and can result in reduced quality and work performance (Radwin 1990). Hence controlling a chainsaw in a precision type movement may be more taxing on the capabilities of a pruner than controlling a static tool such as a pair of pruners. This may have led to the higher rate of quality defects witnessed in the current study.

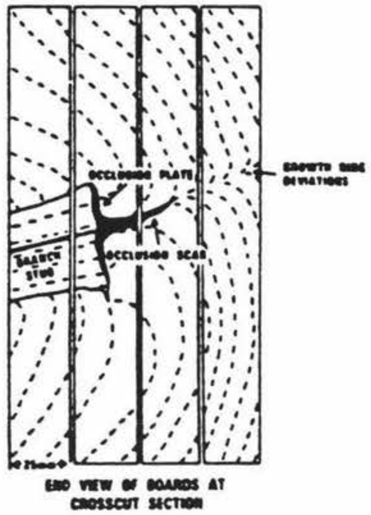
It is clear from this study that chainsaw pruning is associated with a significantly higher rate of damage per tree than manual pruning. The recovery of high quality, value-added forest products provides the rationale for the pruning of *Pinus radiata* in New Zealand (Park 1982). It therefore begs the question of to what extent do collar and bark damage and the presence of coat-hangers affect the value recovery of pruned *Pinus radiata* logs ?

Clear wood recovery from pruned *Pinus radiata* logs has been studied (Gosnell 1987, Park 1982, and Somerville and Gosnell 1987) as have the effects of various pruning and thinning regimes on predicted diameter over stubs (Knowles *et al.* 1981, West *et al.* 1987). The main consideration in the optimisation of potential value recovery is the size of the defect core. This 'defect core' is defined by Park (1982) as "... the cylinder containing pith, branch stubs and occlusion scars. It incorporates any widening effects due to stem sinuosity at the time of pruning. The size of this core was expressed as its diameter (in mm)". Sinuosity refers to any non linearity of the defect core within the clear-wood sheath.

When any branch is pruned it will take some time to heal (occlude). This occlusion over branch stubs increases the diameter of the defect core especially when a branch collar is damaged during pruning or the stub is protruding out from the branch collar as in the case of a coat hanger (Gosnell 1987). Figure 5.01 (overleaf) shows a cross-section of a branch occluding over time.

Damage to the branch collar and to the surrounding bark inhibits the rate of scar occlusion and leaves the tree more susceptible to disease (B. Saunders pers. comm.). Bark damage can lead to resin pockets within the clear-wood sheath (Somerville 1980). These resin pockets lead to a downgrading of timber recovered for use in the production of high value veneer (Somerville and Gosnell 1987). While there are markets for both 'knotty' and 'clear' veneer (Somerville and Gosnell 1987), resin

<u>Figure 5.01 Model of Branch Occlusion</u>



Source: Park (1982)

pockets and occlusion scars do not enhance the aesthetic 'knotty' appearance and still result in downgrading. Due to the combination of the risk of disease and increased downgrading of recovered timber which is incurred by pruning imperfections, it is clearly desirable for any company that is serious about quality to minimise this downgrading.

Data collected from the study supported hypothesis 5a that "Chainsaw pruners will have a higher rate of damage events per tree than manual pruners." The rate of damage per tree for the chainsaw pruners was significantly greater than the manual pruners. The downstream effects of damage caused by chainsaw pruning will have significant effects on the quality and value recovery of the final product.

5.7 Cost-Benefit Analysis

Cost-benefit analysis in this thesis will be assessed using the variables of the nine operational hypotheses (see section 3.1). Rather than assign dollar values as in traditionial cost-benefit analyses, each of the variables will be assigned weightings along a continuum ranging from -5 to +5 where -5 represents significant costs and +5 represents significant benefits of either manual or chainsaw pruning. Weightings are assigned according to two criteria: one, the relative ergonomic importance of the variable in question (as assessed by the researcher) and two, the degree to which the results are significant. A cost-benefit matrix is presented in Table 5.06.

Table 5.06 Cost-Benefit Matrix for Chainsaw vs Manual Pruning

	Chainsaw Pruning	Manual Pruning
Risk Score	- 4	0
Accident Frequencies	0	0
Severity of Accidents	0	- 1
%HRR	0	0
RPE	- 1	0
HSE Questionnaire	0	0
BPD	0	- 2
Productivity	+ 2	0
Quality	- 2	0
Total	- 5	- 3

The results of the cost-benefit analysis shown in Table 5.06 show, for the variables measured, that both methods of pruning are associated with greater costs than benefits. However, chainsaw pruning scores lower overall than manual pruning in the relative cost-benefit analysis. Had manual pruning been shown to have had a significantly greater severity of accidents, accident frequencies and greater body part discomfort (when compared to chainsaw pruners) the results of the cost-benefit analysis would have been reversed.

The cost-benefit analysis shown in Table 5.06 was performed from a ergonomics perspective. These relative weightings of these results may well have been very different had the cost-benefit analysis been performed from a forest management or total quality perspective. Indeed, other ergonomists may assign weightings different to those presented in this thesis.

5.7.1 **Cost-Benefit Decision Criteria**

This section of the thesis will discuss the two decision criteria in the cost-benefit matrix, namely the relative importance of the variable from an ergonomics perspective, and the degree to which the results are significant.

Risk Score

The risk score for the chainsaw pruners is far greater than that for the manual pruners (1421 vs 838). While the risk score for manual pruners is still high, that for the chainsaw pruners is considerably higher. The risk score represents the degree of danger inherent to each method of pruning. The higher the risk score the greater the potential harm to the person.

Within the occupational ergonomics field, the health, safety and well-being of the person is the highest priority. Therefore, the risk score must be given considerable weighting.

As this figure is substantially higher in terms of the risk the method represents, and given that the safety of the individual is paramount in ergonomics, chainsaw pruners are given a rating of -4 in this criteria.

Accident Frequency Rates

Due to small sample sizes in the study and the similarity of the results of the retrospective pruning workforce accident survey (section 4.2.3) zero weightings were givento both chainsaw or manual pruning.

Severity of Injury

The data presented on the severity of injury (Sections 4.2.2 and 5.2.3) show that manual pruning is associated with a greater severity of injury. However, as discussed in section 5.2.3 these data are limited in that there may be instances of under reporting, the LIRO ARS does not discriminate between the two methods of pruning and that the LTIFR's given by CHHF (Central) are limited in their statisistical validity. Taking these limitations into account, but also considering that the severity of injury is very important in ergonomics, a weighting of -1 was assigned to manual pruning for this variable and zero weighting was given for chainsaw pruning.

Percentage Heart Rate Range

As there was no relative difference in the heart rate response as measured by the %HRRs of the manual or chainsaw pruning groups, zero weightings were given for this variable.

Rated Perceived Exertion

The capability of the chainsaw pruners to assess their exertion as measured by RPE was less than that for the manual pruners. The interference in the feed-back loops which inform a person of their current state of exertion is an important ergonomic concept. The weighting given was - 1 for the chainsaw pruners and zero for the manual pruners.

Health and Safety Executive Questionnaires

Due to the relative similarity of the results and in combination with the small sample sizes associated with the data from the HSE questionnaires zero weightings were given to both chainsaw and manual pruning.

Body Part Discomfort Surveys

As manual pruning was associated with a significant increase in BPD (and hence the risk of musculoskeletal disease) as measured before and after work, and given that the prevention of musculoskeletal disease is an important objective in ergonomics, a weighting of - 2 was assigned to manual pruning. The weighting would have been higher had there been evidence of any cumulative effect in the ratings of BPD given by the manual pruners in the study group.

Productivity

Chainsaw pruning was associated with significantly higher productivity than manual pruning. This significance is not reflected in the weighting (+ 2) as it is tempered by the fact that productivity, as a concern of ergonomics, is relatively less important than factors which affect the health, safety and well-being of people at work.

Quality

The frequency of quality defects is significantly higher for chainsaw pruners than for manual pruners. Quality of work, while being an important objective for ergonomics, is again less important than safety and health issues and this is reflected in the rating given to chainsaw pruning (- 2).

5.8 Summary

This chapter has discussed each of the sections of the research in detail. The pertinent results were reiterated, other supporting data were presented, the limitations of the data collection and methodology were identified where appropriate, and links were drawn to other literature. Finally each section of the research was amalgamated and the cost-benefit analysis was performed. The following chapter will detail the conclusions of the research and the cost-benefit analysis.

Chapter 6 Conclusions

6.0 Introduction

This chapter presents the conclusions of the research. Initially, the conclusions will address the second level operational hypotheses, and then the conclusions will be summarised in list form as they relate to the first level general hypotheses (as set out in section 3.1) to provide a broad overview of the research. Finally the results of the cost-benefit analysis will be presented.

6.1 Conclusions (Operational Hypotheses)

Hazard Analysis

Analysis of the observed hazard frequency data and the ratings of consequences and likelihood according to Fine's (1971) risk score, supports hypothesis 1a that chainsaw pruners are exposed to more 'significant hazards' than manual pruners. The increased exposure to these hazards is not, however, reflected in higher accident frequencies for chainsaw pruners. Evidence of more 'significant hazards' is not borne out in either injury frequency data or the severity of injury data obtained in the retrospective accident surveys administered to the pruning subjects or during the Hawkes Bay pruning workforce survey. Therefore neither hypothesis 1b or 1c, ie. that chainsaw pruning will be associated with a higher accident frequency rate and greater severity of accidents, can be supported by the research.

Physiological Cost

The results of this study support hypothesis 2a that manual and chainsaw pruners will experience the same relative heart rate response. This research does not support hypothesis 2b that there will be no relative difference in the ratings of perceived exertion given by manual and chainsaw pruners. The main reason postulated for the rejection of this hypothesis is that the chainsaw pruners are socially isolated and this affects their perceived exertion.

Musculoskeletal Discomfort

There is no evidence to support hypothesis 3a that manual pruners experience a higher prevalence of musculoskeletal disorders. There is however some evidence that manual pruners experience a greater relative increase in body part discomfort during the work day than do chainsaw pruners in line with hypothesis 3b.

Productivity

The data conclusively support the hypothesis 4a that chainsaw pruners have a higher rate of productivity than do manual pruners.

Quality

The data conclusively support hypothesis 5a that chainsaw pruning will result in a higher rate of damage events per tree than manual pruning

6.2 Conclusions (General Hypotheses)

1. Although both methods of pruning are hazardous, chainsaw pruning is more hazardous than manual pruning
2. Chainsaw pruning has the same physiological cost as manual pruning
3. Manual pruning is not associated with a higher prevalence of musculoskeletal discomfort than chainsaw pruning on a yearly basis, although it is associated with a greater relative increase in BPD on a day to day basis which may lead to the development of musculoskeletal disease
4. Chainsaw pruning is more productive than manual pruning
5. Chainsaw pruning produces more quality defects than manual pruning

6.3 Cost-Benefit Analysis

On the basis of the variable measured and the ergonomics perspective adopted by the researcher the negative magnitude of the cost-benefit for chainsaw pruning is greater than that for manual pruning. As such it is concluded that chainsaw pruning is less acceptable than manual pruning when considered from an ergonomics perspective.

6.4 Summary

The findings of the research have now been amalgamated in the one place and have been presented in terms of the hypotheses the research pursued and a cost-benefit format. On the basis of the variables that were measured and in light of the cost-benefit approach taken, the research concludes that chainsaw is less acceptable than manual pruning. The research does not however allow for the general industry question ie. "Is chainsaw pruning an acceptable work method ?" to be definitively answered. Given that the research does not conclude the chainsaw pruning is unacceptable, rather, that it is less acceptable, recommendations regarding the continued use of chainsaw pruning and future research into all pruning methods are presented in the following chapter.

Chapter 7 Recommendations

7.0 Introduction

This chapter will interpret the conclusions of the research, make recommendations on techniques used if chainsaw pruning is to continue and then make recommendations on where future research should be directed to allow enhance the current state of knowledge about chainsaw and manual pruning.

7.1 Recommendations (Operations and Techniques)

1. The use of chainsaw pruning should be more strictly limited to areas with large branches,
2. Both chainsaw and manual pruners should be certified for their jobs, and a large part of this certification should involve the training in the safest techniques available at the time
3. Chainsaw pruning should be performed with one leg wrapped around the tree and both hands on the chainsaw wherever possible

7.2 Recommendations (Future Research)

Future research should be directed into quantifying actual accident frequency rates and accident severities of manual and chainsaw pruning to provide a sound basis for comparison. The easiest avenue to achieve this would be to encourage more detailed reporting to the LIRO forestry ARS by contractors and companies:

1. A complete ergonomics assessment of manual pruning comparing forest regions of predominantly large branches to regions of predominantly small branches to assess whether there is a increase in workload, hazard frequency and a need for chainsaw pruning in the first instance
2. A comparative ergonomics assessment of the two chainsaw pruning methods to quantify any reduction in risk by using the leg wrapping technique
3. Due to the high incidence and severity of ladder fall accidents reported to the LIRO silvicultural ARS, research should be directed into the safe design, use and maintenance of ladders, footwear and the interface between the two

4. Research into the possible link between social isolation, RPE, fatigue, and hazard frequency should be carried out to establish any relationship between these variables in the forest environment
5. Further applied physiological research should assess the RPE of workers as a compliment to objective physiological measures
6. Further applied 'workload' research should include BPD as a complimentary measure of musculoskeletal 'workload'

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Glossary of Terms

<u>Term</u>	<u>Meaning</u>
Accident	Common term for injury or near injury. The use of this work should be limited to acts of God as 'Accident' implies that it cannot be controled.
Aerobic	Those processes of the body that require oxygen.
Anaerobic	Those processes in the body that do not require oxygen.
ARS	The LIRO accident repoting scheme.
Breakerouts	People who tie cables around logs for extraction by either skidders or cable haulers
Catalyst	Any substance that increases the rate of a chemical reaction without being consumed in that reaction.
Calibration	A testing of equipment to ensure that it is measuring accurately.
Centiminutes	A measure of time. 100 centiminutes equals 1 minute (60 seconds). This is a decimal notation which is easier for field computers to use.
Circadian	The variation of parameters of the body during the ucourse of a day. This term comes from the latin words '*<u>circa</u>*' meaning about, and '*dian*' meaning day.
Clearfell	When a forest block is harvested by cutting down all the trees in that block.
DBH	The diameter (cm) of a tree at the height of a persons breast.
Dichotomous	Meaning at opposite ends of some spectrum or continuum of relationships. Usually used when describing opposite arguments, trains of thought or philosophical positions.
DOO	The diameter (cm) of the maximum extension of defect wood from the core of the tree.
DOS	The diameter (cm) of the largest whorl in the current pruning lift.
Electro-myography	A techniqe to monitor the electrical activity within muscles as an estimate of muscular stress and fatigue
Ergometer	A stationary bicycle on which the power output of a person can be measured.
Ergonomics	A multi-disciplinary science to improve the total social and physical comfort, safety and compatibility of people to their work, their work surroundings and the things they use at work. To make stressful jobs less stressful.
Energy	The ability to perform 'work'. Usually expressed in joules (J)
Epismology	That branch of the philosophy concerned with the study of knowledge.

Fell	To cut down a tree.
Gestalt	An organised 'whole'. The parts of the 'whole' interact according to their relationship within that 'whole' rather than just random associations between them. In other words, to only look at one or a few parts of a system is not sufficient to completly understand that system in a 'holistic' way.
Homeostasis	The 'steady state' of a organism or other system. This concept, in the physiological sense, refers to the bodily processes maintaining operation within normal (safe) limits.
HSE Questionnaire	A qestionnaire developed by the Nordic institutes of occupational safety and health and adapted for english language use by the British 'Health and Safety Executive' (HSE). These questionnaires assess the prevalence of musculoskeletal disease of a person.
Hazard	A condition or set of circumstances that has the potential to cause injury or death.
Hunter	A model of the 'Husky' range of rugged field computers which are able to be used in forest research operations.
Husky	A company which manufactures rugged feild computers for use in outdoors environments.
Lift	The individual range of pruning at any one time. First lift pruning is usually from the ground to 2.2 metres up the stem.
LIRO	The Logging Industry Research Organisation. A jointly Government-Industry funded incorporated society which performs research in the foresetry industry.
LIRO ARS	The industry wide accident reporting scheme developed and maintained by LIRO.
$l.min^{-1}$	A symbol for the number of Litres per minute.
Mass	How 'heavy' a thing is (commonly known as weight).
Maximum Voluntary Contraction (MVC)	The MVC is the maximum force that can be generated by a musle or muscle group voluntarily.
Metabolism	The processes in the body which are catalysed via the action of enzymes.
Musculoskeletal	This term refers to the muscle and seletal systems of the body and the relationship between the muscles and the bones they control.
Ontology	The branch of philosphy concerned with the nature of being.
Piece rates	A method of payment for work where a person is only paid for their output as opposed to an hourly wage
Power	A measure of energy over time (1 Watt = 1 $J.s^{-1}$)
Pruners	Tools used to manually prune trees.

Relative measure	A measure which is specific to the thing or person being measured.
Rework	To return into a forest block and prune missed or substandard trees untill the block meets the requirements specified in the pruning prescription or contract.
Risk	The probability of injury or death.
Significance	An objective method of determining whether one population parameter (ie average or standard deviation) is different to another parameter based on statistical theory.
Slash	A term used in forestry to describe the amount of vegetation at ground level in the forest.
Stocking	The number of trees per hectare of forest.
Stress	Stress as used in this thesis is 'some' load on the physical or pshychological capabilities of a person. Some of this stress is desirable for good health and performance, but any excessive stress will become strain and damagewill be done.
sph	Stems per hectare. This refers to the number of trees in a hectare of forest.
Synergy	The idea that two (or more) components of a system working together can achieve more than the sum of two (or more) individual components. This idea is paralleled in the social sciences in that society is seen to much more than the mere sum of individuals but rather a total system of social relations and individuals.
V_{O_2}	The volume of oxygen that is used by the body per minute. ($l.min^{-1}$)
V_{O_2} (max)	The maximum volume of oxygen that can be used by the body per minute. ($l.min^{-1}$). This quantity is dependant on both genetic and training factors.
Whorl	The node in the stem of the tree where branches are concentrated.
Whirling Hygrometer	Two thermometers which work together to measure air temperature and relative humidity.

Appendix - 1

Health and Safety Executive (HSE) Questionnaire

Dear Sir \ Madam

This questionnaire has been prepared by the Health and Safety Executive, which is the UK organisation responsible for health and safety at work.

We are interested in mild and severe problems affecting your muscles, ligaments, nerves, tendons, joints and bones suffered both at work and away from work. This could mean sprains, strains, inflammations, irritations and dislocation. For the purpose of this survey we are not interested in any injuries to the skin.

We would like you to complete this questionnaire about your health. All answers will be treated as strictly confidential and individual answers will not be made known to anyone other than the survey team.

How to Answer the Questionnaire
Please complete this questionnaire by answering ALL questions as fully as possible. Some of the questions require a written answer, for others you need only tick a box.

PERSONAL DETAILS

1 Date of birth — Day Month Year ☐☐☐☐☐☐

2 Sex — Male 1 ☐ Female 2 ☐

3 Today's date — Day Month Year ☐☐☐☐☐☐

4 What is your weight?

stones ☐ + pounds ☐ or kg ☐

5 What is your height?

feet ☐ + inches ☐ or cm ☐

6 Are you right or left handed?

right 1 ☐ left 2 ☐ able to use both hands equally 3 ☐

ABOUT YOUR JOB

7 What is your job title? [ ]

8 How many years and months have you been doing your present **type of work** at this site?

Years [ ] · Months [ ]

If less than one month, how many weeks? [ ]

9 Have you worked elsewhere doing a similar type of work?

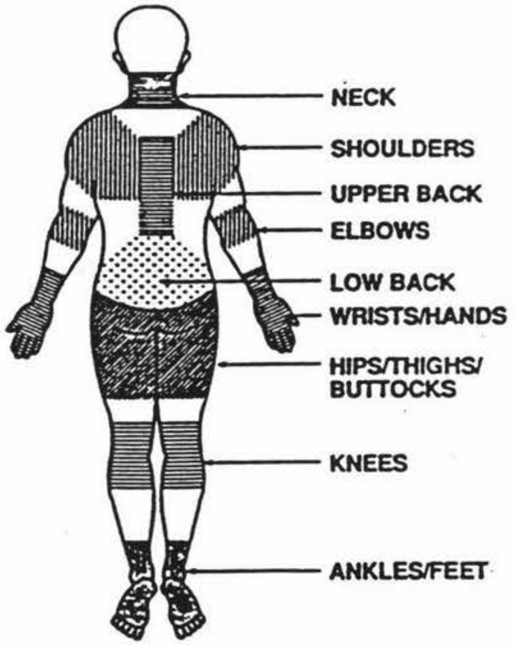
No 1 [ ] Yes 2 [ ]

9.1 **If yes,** what is the total length of time you worked elsewhere, doing a similar type of work before starting at this site?

1 [ ] Years
2 [ ] 1-2 years
3 [ ] 3-4 years
4 [ ] 5-9 years
5 [ ] 10 years or more

10 On average, how many hours a week do you work (including overtime but excluding main meal break)?

Hours [ ]



This picture shows how the body has been divided. Please answer the three questions shown opposite for each body area.
Body sections are not sharply defined and certain parts overlap. You should decide for yourself which part (if any) is or has been affected.

Please answer all questions numbered 6 to 32 by using the tick boxes ☑ - *one tick for each question*

Please note that this part of the questionnaire should be answered, even if you have never had trouble in any part of your body.

Have you at any time during the last 12 months had trouble (such as ache, pain, discomfort, numbness) in:	Have you had trouble during the last 7 days:	During the last 12 months have you been prevented from carrying out normal activities (eg job, housework, hobbies) because of this trouble:
6 *Neck* No 1☐ Yes 2☐	7 *Neck* No 1☐ Yes 2☐	8 *Neck* No 1☐ Yes 2☐
9 *Shoulders* No 1☐ Yes 2☐ in the right shoulder 3☐ in the left shoulder 4☐ in both shoulders	10 *Shoulders* No 1☐ Yes 2☐ in the right shoulder 3☐ in the left shoulder 4☐ in both shoulders	11 *Shoulders (both/either)* No 1☐ Yes 2☐
12 *Elbows* No 1☐ Yes 2☐ in the right elbow 3☐ in the left elbow 4☐ in both elbows	13 *Elbows* No 1☐ Yes 2☐ in the right elbow 3☐ in the left elbow 4☐ in both elbows	14 *Elbows (both/either)* No 1☐ Yes 2☐
15 *Wrist/hands* No 1☐ Yes 2☐ in the right wrist/hand 3☐ in the left wrist/hand 4☐ in both wrists/hands	16 *Wrist/hands* No 1☐ Yes 2☐ in the right wrist/hand 3☐ in the left wrist/hand 4☐ in both wrists/hands	17 *Wrist/hands (both/either)* No 1☐ Yes 2☐
18 *Upper back* No 1☐ Yes 2☐	19 *Upper back* No 1☐ Yes 2☐	20 *Upper back* No 1☐ Yes 2☐
21 *Lower back (small of back)* No 1☐ Yes 2☐	22 *Lower back* No 1☐ Yes 2☐	23 *Lower back* No 1☐ Yes 2☐
24 *One or both hips/thighs/buttocks* No 1☐ Yes 2☐	25 *Hips/thighs/buttocks* No 1☐ Yes 2☐	26 *Hips/thighs/buttocks* No 1☐ Yes 2☐
27 *One or both knees* No 1☐ Yes 2☐	28 *Knees* No 1☐ Yes 2☐	29 *Knees* No 1☐ Yes 2☐
30 *One or both ankles/feet* No 1☐ Yes 2☐	31 *Ankles/feet* No 1☐ Yes 2☐	32 *Ankles/feet* No 1☐ Yes 2☐

REMEMBER - Please check you have answered questions 6 to 32
THANK YOU FOR COMPLETING THIS QUESTIONNAIRE

33. Are there any comments you would like to make about your job?

Q.34 Have you had an accident at work during the last year that meant you had to take more than one day off work? Yes No

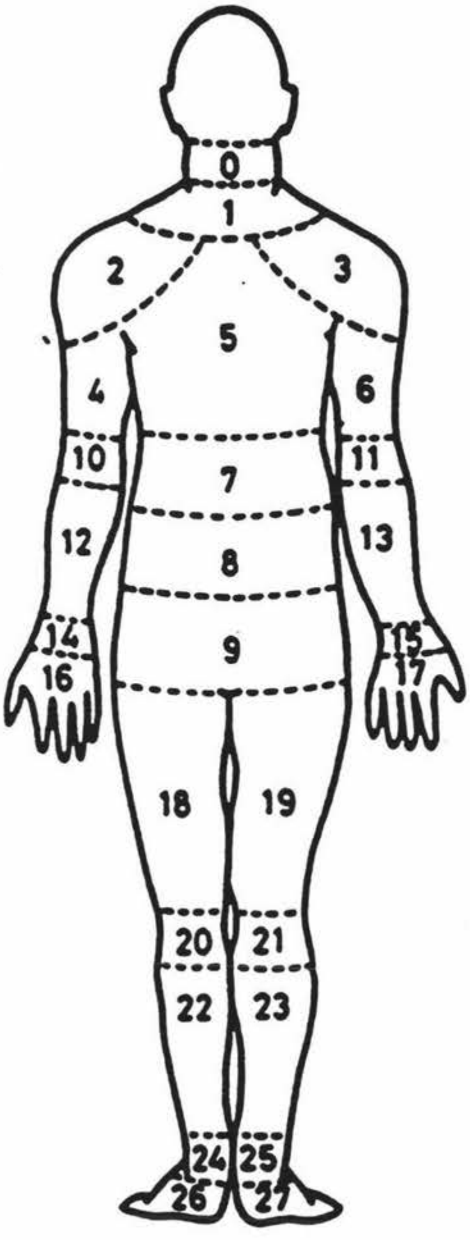
Q.35 If you have had more than one accident at work during the last year please write down how many accidents you had. Please complete a new form for each accident. (Dave has spares). ________

Q.36 What type of pruning were you doing at the time of the accident? Manual. Chainsaw.

Q.37 How long had you been doing this type of pruning? Years / months ________

Q.38 How long were you off work for? Months / days ________

Q.39 What part(s) of your body were injured in the accident? Please mark the part(s) on the diagram below and write next to the body part the type of injury you had ie broken bone, concussion, sprain, cut ect.



Q.40 Please describe how the accident happened.

Thank you very much for taking the time to complete this questionnaire.

Dave Ford.

APPENDIX - 2 V_{O_2} TESTING PROTOCOL.

HEART RATE APPROXIMATION METHOD.

CYCLE ERGOMETER.

For use in sub-maximal assessment of VO_2 (max).

PRECONDITIONS.

- Ensure the subject is free of infection and has no known heart condition.
- Ensure the subject has not eaten or smoked during the two hours prior to the test.
- Ensure the subject has not been involved in any physical activity heavier than the test during the past two hours.
- Ensure the room temperature in the testing room is no higher than 18-20^{o}C. If the temperature is higher, use a fan directed at the person doing the exercise test.
- Ensure the subject knows s\he can discontinue the test if s\he feels faint or in any unusual pain or discomfort.

PROCEDURE.

1. Adjust the heights of both the seat and the handle bars to a height that is comfortable for the subject.
2. Switch on the power for the ergociser. The switch is under the seat support.
3. Press the mode button on the display until the 'manual' mode is displayed.
4. Press the advance button to select manual mode.
5. Enter the age of the subject and push the advance button (this commences the warm up period).
6. Instruct the subject to pedal at a rate of 60 rpm throughout the test. The display for cadence (rpm) is in the top right hand corner of the display screen.
7. After 4-5 minutes of warm up increase the workload by 10 kilopond. This is done by using the ' + 10 ' button to the right of the display screen.
8. Wait for the heart rate to stabilise at that workload for approximately 1.5 minutes (ie when you get three heart rate readings within 5 b.min^{-1} of each other).
9. Repeat stages 7 and 8 two more times to get a final reading of workload versus heart rate. Keep a keen eye on the subjects' heart rate and ensure it **does not** exceed 150 b.min^{-1}. If the subjects' heart rate approaches 150 b.min^{-1} the workload should be decreased to keep heart rate below 150 b.min^{-1}. You should preferably try to stabilise heart rates at or near 140 b.min^{-1} for the final reading.
10. Following the final reading allow an adequate warm down period for the subject at minimal resistance and 60 rpm (say 3-6 minutes).
11. Use the attached nomogram to extrapolate the estimation of V_{O_2} (max) in L.min^{-1}
12. Transform the estimated V_{O_2} (max) in L.min^{-1} into mL.min^{-1} and divide by the subjects weight in kilograms to get V_{O_2} (max) in mL.min^{-1}x Kg^{-1}.

Appendix - 3
LIRO Pruning Study.

To: All pruners (CHHF).

From: Dave Ford (LIRO).

Hi, my name is Dave Ford. I am a researcher at LIRO in Rotorua. LIRO is doing a study comparing chainsaw and manual pruning in the Hawkes Bay. The study is looking at four main areas..

1. Safety
2. Work Physiology
3. Long term health
4. Productivity and quality.

I would like to get your input into the safety part of the study. You guys know better than anyone the hazards you face so your input into this part of the research will be invaluable.

All I'm asking from you is a little of your time to fill out this questionnaire honestly and accurately.

The bones of the system is that risk is a combination of

1. exposure to a hazard,
2. how severe the consequences may be,
3. and the likelihood that if a guy is exposed to a hazard it will actually hurt him (as opposed to a near miss).

What I want to do is to be able to compare the hazards involved in chainsaw pruning with those for manual pruning. The only way I can really do this is to assign risk scores for hazards on the basis of the following formula...

Risk Score = Frequency x Consequences x Probability.

The following questionnaire will cover the three parts of the risk score, and some general information. Your answers will be treated with the strictest of confidence.

General.

1. What method of pruning are you currently using (circle). **Manual.** **Chainsaw.**

2. How long have you been doing this type of pruning ? (years/months) ____**yrs**___**mnths**.

3. How long have you been involved in pruning work ? (years/months) ____**yrs**___**mnths**.

4. How many FIRS modules have you completed ? ________ (FIRS)
   Please circle the number(s) of the modules you have done.

   2.1-Planting and site preperation
   2.2-Forest planting
   2.3-Tree releasing
   2.4-Silvicultural pruning
   2.5-Silvicultural thinning
   2.6-Handling chemicals.

   Others (please list)

   ____
   ____

5. Have you had a lost time injury in the last year **while pruning** ? (circle) **Yes**. **no**.

6. If you have had more than 1 lost time injury in the last year please state how many.______

7. If the answer to Q 5 was **Yes**, please briefly describe the injury(s)

   ____
   ____
   ____
   ____
   ____
   ____
   ____
   ____

The following questions refer to...

- **Third lift pruning**
- **The type of pruning you're doing at the moment (chainsaw or manual).**

Frequency.

Please look at the following scale of frequencies.

0.5	1	2	3	4	5	6	7	8	9	10
Hardly ever (yearly)			Occasionally (weekly)			Frequently (daily)				Continuously (many times per day)

Enter a number you think gives the best indication of **how often** each of the hazards listed below happens. You don't have to stick to the numbers shown. For example you could write down 2.5 or 7.5, or whatever you think is closest to the real situation.

Please look at the hazards listed below and state how often you think they occur according to the 0.5 - 10 scale at the top of the page.

8 Ladder twists (for any reason). _________

9 Come down ladder two rungs at a time. _________

10 Have to do a double lift (can't get ladder against stem.) _________

11 Cut a big branch off directly above your head. _________

12 Cut across your arm or legs with the saw _________

13 Over reaching from the top of the ladder. _________

14 Pruning a branch under tension too close to the stem. _________

15 Holding on to the branch you are cutting. _________

Consequences.

Please look at the following scale of most probable consequences.

1	5	10	15	20	25
Minor cuts/bruises		Major cuts and / or sprains	Permanent disability		Fatal.

Enter the number you think gives the best indication of **how severe** the injury would be from an accident. This is to say, if something went badly wrong, what is the most likely type of injury that would occur.

Please look at the hazards below and state how severe you would expect the consequences to be if an accident happened according to the 1 - 25 scale at the top of the page.

16. Ladder twists (for any reason). __________

17. Come down ladder two rungs at a time. __________

18. Have to do a double lift (can't get ladder against stem.) __________

19. Cut a big branch off directly above your head. __________

20. Cut across your arm or legs with the saw __________

21. Over reaching from the top of the ladder. __________

22. Pruning a branch under tension too close to the stem. __________

23. Holding on to the branch you are cutting. __________

Probability.

Please look at the following scale.

0.1 1 2 3 4 5 6 7 8 9 10

Almost impossible — Unusual — 50 50 chance — Most likely

Enter the number you think gives the best indication of **how probable** each of these hazards are. This means, how likely is it that once the hazard occurs, there will be an injury as a result.

Please look at the hazards below and rate each one according to the 0.1 to 10 scale at the top of the page. Remember that you don't have to stick to the numbers shown on the scale. If you think 1.5 or 8.5 is better then write it down.

24. Ladder twists (for any reason). __________

25. Come down ladder two rungs at a time. __________

26. Have to do a double lift (can't get ladder against stem.) __________

27. Cut a big branch off directly above your head. __________

28. Cut across your arm or legs with the saw __________

29. Over reaching from the top of the ladder. __________

30. Pruning a branch under tension too close to the stem. __________

31. Holding on to the branch you are cutting. __________

Thanks for taking the time to complete this questionnaire, it is appreciated.
Regards.

Dave Ford.
Human Factors Researcher.
Logging Industry Research Organisation. (LIRO).

Appendix - 4

Borg's RPE Scale.

Please Rate Your Exertion.

6. NO EXERTION AT ALL

7.

EXTREMELY LIGHT

8.

9. VERY LIGHT

10.

11. LIGHT

12.

13. SOMEWHAT HARD

14.

15. HARD (HEAVEY)

16.

17. VERY HARD

18.

19. EXTREMELY HARD

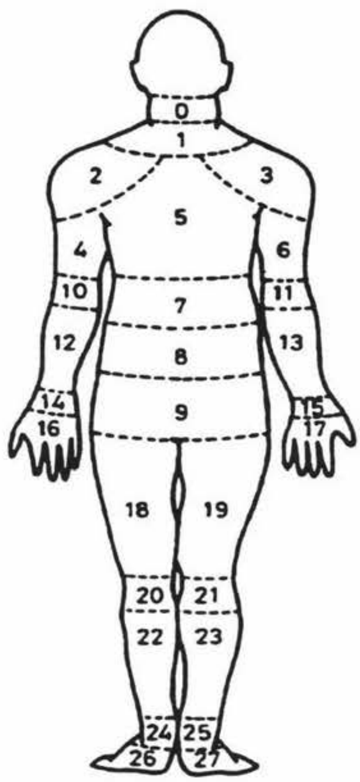
20. MAXIMAL EXERTION

Appendix - 5

Body Part Discomfort (BPD) Survey

1. DO YOU FEEL ANY DISCOMFORT AT THE MOMENT ?

2. IF SO, PLEASE SHOW ME WHERE YOU FEEL DISCOMFORT AND PLEASE RATE THIS DISCOMFORT ACCORDING TO THE 1 - 3 SCALE AT THE BOTTOM OF THIS PAGE.

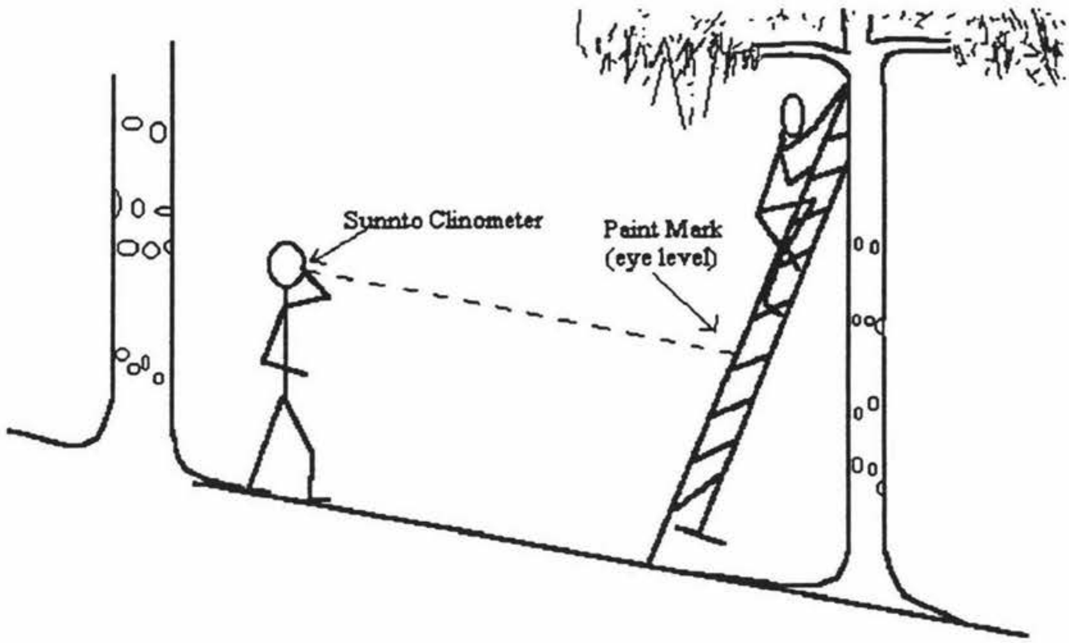


1	2	3
Just noticable pain or discomfort	Moderate pain or discomfort	Intolerable pain or discomfort

Source: After Corlett and Bishop (1976)

Appendix - 6

Use of Sunnto Clinometer



Appendix - 7

Branch Sampling Sheet.

Protocol: Measure every pruned branch. Leave a 1 line gap to delineate whorls

X	Y	Damage

X	Y	Damage

Appendix - 8

Priorities For Action

163 **DATA COLLECTION AND ANLYSIS**

RISK SCORE SUMMARY AND ACTION SHEET

Hazard Description	*Risk Score*	*Action*
Window washer on third floor, without safety belt, hangs on with one hand and leans out	1500	Immediate correction required. Activity should be discontinued until hazard is reduced
Men working in ditch six feet deep, ditch not shored, dirt is soft, subject to sliding	750	
Painters on scaffold without handrail, 30 feet high, not using safety belts	750	
Benzene used for cleaning floor of shop, a busy area, men smoke, other spark sources nearby	450	
Compressed flammable gas cylinders standing unsecured on pallet, along busy aisle, caps on	375	
Uncontrolled compressed air used in machine shop, up to 90 psi, for general cleaning	300	
Men smoking in flammable storage warehouse, no sprinkler system, highly flammable material	270	
Portable electric drill in use without ground wire, getting rough usage by several people	200	Urgent. Requires attention as soon as possible.
Compressed air receiver without safety relief valve, automatic shut-off at 200 psi, old equipment	180	
People walking past deep unguarded ditch, considerable traffic, poor lighting	150	
Heavy instruments unstable on seven foot high shelf case, subject to bumping by employees	150	
Trucks rounding blind corner without stopping, opposing traffic and pedestrians, 10 MPH limit	135	
Steps of main building slippery whenever wet, no handrail, many pedestrians daily	90	
Compressed oxygen cylinder standing unsecured near wall, little traffic or movement	85	Hazard should be eliminated without delay, but situation is not an emergency
Pedestrian and hand-cart traffic at blind corner in hallway of shop building	60	
Oxygen and acetylene cylinders stored together, caps on, good ventilation, fireproof surroundings	45	
Inadequate handrailing along outsdie stairway, occasional use every day	40	
Large propane storage tank in busy area: vehicle traffic, and high pressure air operations	37.5	
Both pedestrians and vehicles using same road. Road not always wide enough for both	37.5	
Chemicals stored in nonsparkproof refrigerators, occasionally including flammable volatile liquids	30	
Broken sidewalk, occasional pedestrian traffic, holes and loose concrete	30	
Persons near explosive building, within range of possible missiles, safe procedures in building	25	
Portable vacuum pump lacking belt guard. Pump moved around occasionally by several employees	18	
Machinist using heavy file without file handle, in daily use	18	
Workman using hammer with loose head, in use daily for odd jobs	18	

Illustration No. 1 Hazardous situations listed in order of severity of risks.

Source: Fine (1971)

Appendix - 9

Correlations of Heart Rate and RPE

Correlations.

Correlations were performed between the RPE of pruners' and their corresponding heart rate readings off the PE 3000 sports testers. Correlations were performed for individual subjects on the basis of the following list of criteria:

1. Individual days.
2. The sum of all the days in the study period.
3. All mornings in the study period.
4. All afternoons in the study period.

The following tables show each set of correlations against the instantaneous reading off the PE 3000, and the averages of the previous 2, 3, 5, 10, and 15 minutes of heart rate records. The correlation of greatest magnitude in each category in shown in bold.

Table A.9.1

8.00	All day 3 n=5	All day 4 n=5	All day 5 n=6	All days n=16	All mornings n=10	All afternoons N=6
RPE	1.00	1.00	1.00	1.00	1.00	1.00
HR instnt	-0.27	-0.12	0.40	-0.01	0.23	-0.15
HR 2min	-0.36	0.11	0.58	0.17	0.49	-0.35
HR 3min	-0.56	0.30	0.72	0.35	0.65	-0.17
HR 5min	-0.67	0.18	0.76	0.38	0.62	-0.33
HR 10min	-0.62	0.06	0.84	0.15	0.28	-0.24
HR 15min	-0.71	-0.52	0.83	0.05	-0.03	-0.48

Table A.9.2

4.00	All day 2	All day 3 n=5	All day 4 n=5	All days n=10	All mornings n=6	All afternoons n=4
RPE	nd	1.00	1.00	1.00	1.00	1.00
HR instnt	nd	0.54	0.83	0.66	0.85	0.30
HR 2min	nd	0.68	0.83	0.73	0.87	0.41
HR 3min	nd	0.72	0.73	0.71	0.85	0.44
HR 5min	nd	0.72	0.63	0.67	0.78	0.15
HR 10min	nd	0.80	0.70	0.73	0.77	0.36
HR 15min	nd	0.83	0.75	0.76	0.77	0.56

nd = no data

Table A.9.3

3	All day 2 n=7	All day 3 n=7	All day 4 n=5	All days n=19	All mornings n=12	All afternoons n=7
RPE	1.00	1.00	1.00	1.00	1.00	1.00
HR instnt	0.58	-0.18	0.15	0.19	0.24	-0.23
HR 2min	0.57	-0.39	0.29	0.24	0.42	-0.33
HR 3min	0.57	**-0.42**	0.25	0.26	0.43	**-0.34**
HR 5min	0.50	-0.19	0.33	0.32	0.45	-0.29
HR 10min	0.51	0.09	0.44	**0.37**	**0.47**	-0.05
HR 15min	**-0.61**	0.23	**0.49**	-0.17	-0.24	-0.14

Table A.9.4

1	All day 2 n=7	All day 3 n=5	All day 4 n=6	All days n=18	All mornings n=12	All afternoons n=5
RPE	1	1	1	1	1	1
HR instnt	0.90	0.84	**-0.28**	0.61	0.57	0.63
HR 2min	0.91	0.99	0.16	0.72	0.71	**0.83**
HR 3min	**0.95**	0.98	0.09	0.73	0.74	0.25
HR 5min	nd	**0.99**	nd	0.86	0.92	0.49
HR 10min	nd	0.99	nd	**0.94**	**0.99**	0.38
HR 15min	nd	0.99	nd	0.90	0.97	0.32

Manual Pruners.

Table A.9.5

7	All day 2 n=7	All day 3 n=7	All day 4 n=3	All days n=17	All mornings n=7	All afternoons n=10
RPE	1	1	1	1	1	1
HR instnt	**0.83**	-0.22	nd	**0.47**	**0.75**	0.40
HR 2min	0.70	-0.32	nd	0.40	0.70	0.34
HR 3min	0.70	-0.39	nd	0.35	0.61	0.33
HR 5min	0.71	-0.61	nd	0.29	0.60	0.24
HR 10min	0.05	**-0.71**	nd	-0.02	0.63	**-0.55**
HR 15min	-0.19	-0.53	nd	0.00	0.60	-0.54

Table A.9.6

6	All day 2 n=6	All day 3 n=6	All day 4 n=4	All days n=16	All mornings n=7	All afternoons n=9
RPE	1	1	1	1	1	1
HR instnt	0.68	**0.74**	0.81	0.63	0.57	**0.68**
HR 2min	**0.77**	0.56	0.63	0.64	0.81	0.52
HR 3min	0.52	0.48	0.71	0.57	0.84	0.33
HR 5min	0.56	0.50	0.76	0.59	**0.86**	0.34
HR 10min	0.64	0.55	**0.92**	0.66	0.83	0.54
HR 15min	0.70	0.63	0.90	**0.71**	0.84	0.65

Table A.9.7

5	All Day 3 N=6	All Day 3 n=9	All day 4 n=7	All days n=20	All mornings n=7	All afternoons n=14
RPE	1	1	1	1	1	1
HR instnt	0.91	0.55	-0.31	0.57	0.62	0.63
HR 2min	0.93	0.63	0.33	0.65	0.69	0.72
HR 3min	**0.93**	0.69	0.57	**0.67**	0.85	**0.74**
HR 5min	0.91	0.69	0.66	0.65	**0.98**	0.71
HR 10min	0.89	**0.71**	**0.81**	0.64	0.94	0.68
HR 15min	0.84	0.59	0.78	0.61	0.86	0.65

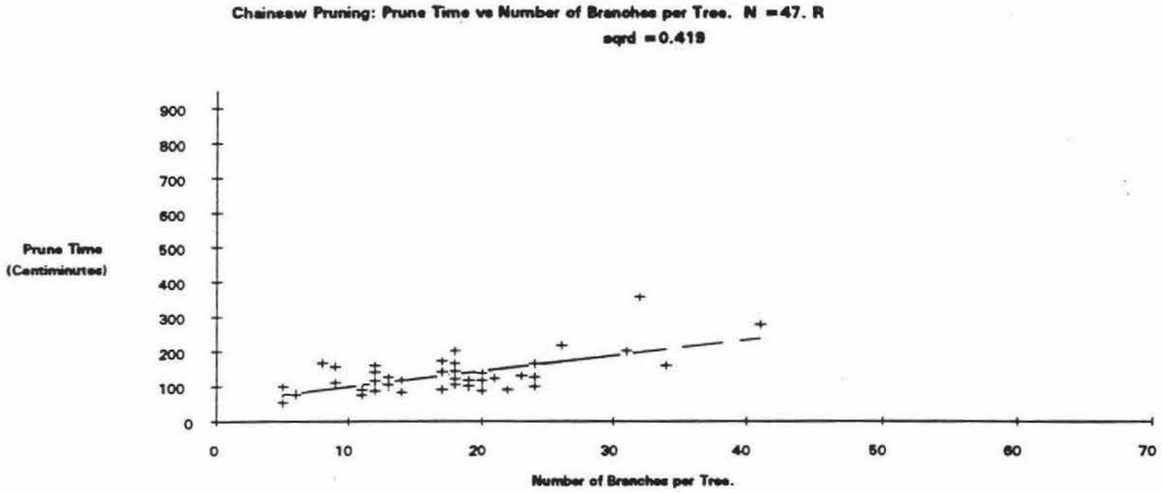
Table A.9.8

2	All Day 2	All day 3 n=5	All day 4	All days N=9	All mornings N=5	All afternoons N=4
RPE	1	1	1	1	1	1
HR instnt	nd	-0.32	nd	0.41	0.88	-0.64
HR 2min	nd	-0.05	nd	0.50	**0.97**	-0.11
HR 3min	nd	0.84	nd	0.68	0.93	0.96
HR 5min	nd	0.92	nd	0.74	0.75	0.94
HR 10min	nd	0.90	nd	0.69	0.51	0.96
HR 15min	nd	**0.93**	nd	**0.72**	0.50	**0.97**

Appendix - 10

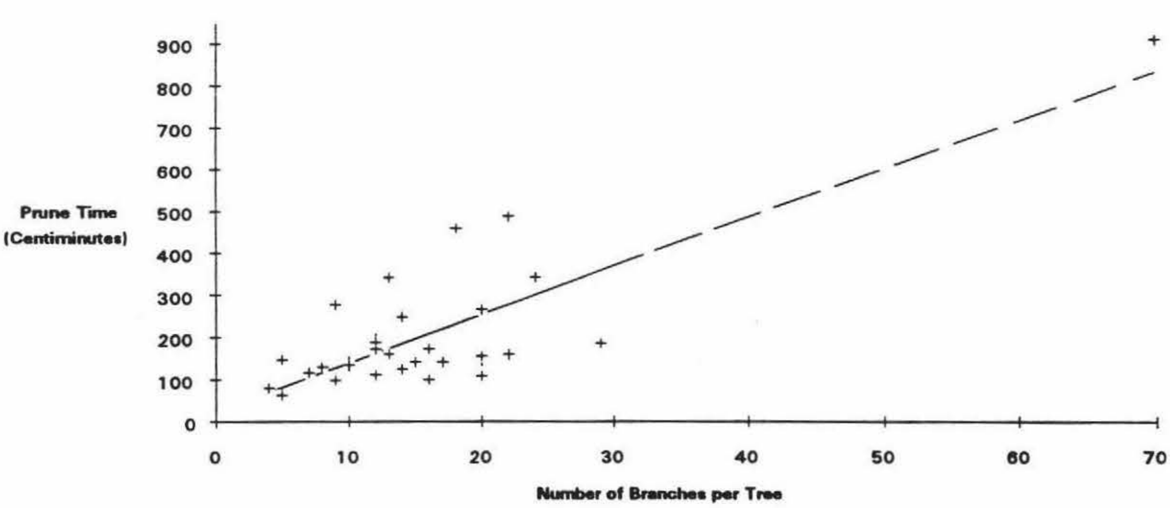
Prune Time versus Three Tree Characteristics

Scatter diagrams of raw data and regression lines are presented. The regression equation and coefficient of determination (r^2) are presented for each diagram.



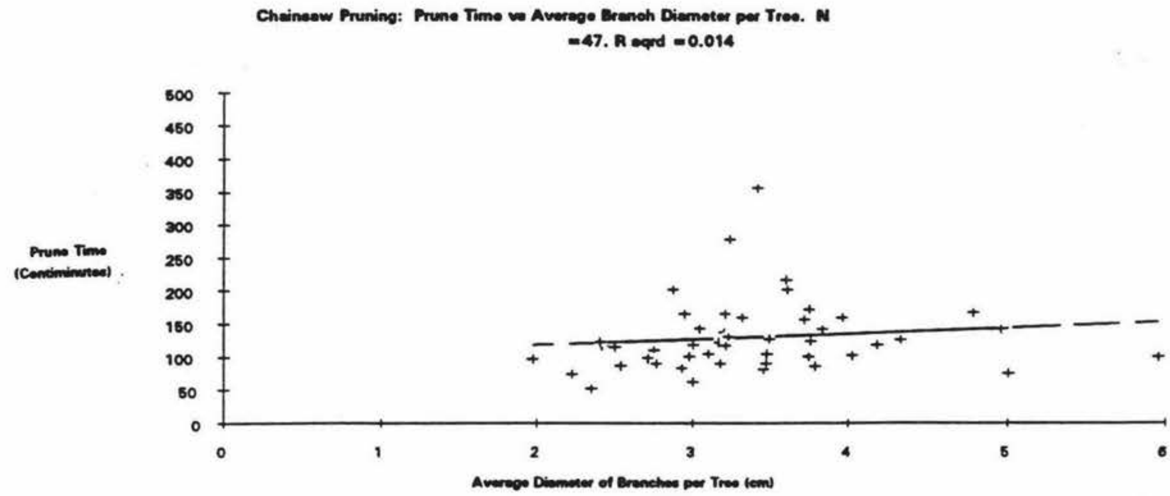
Prune time for chainsaw pruners in relation to the number of branches per tree was predicted by the regression equation...

$$y = 4.535x + 52.07$$



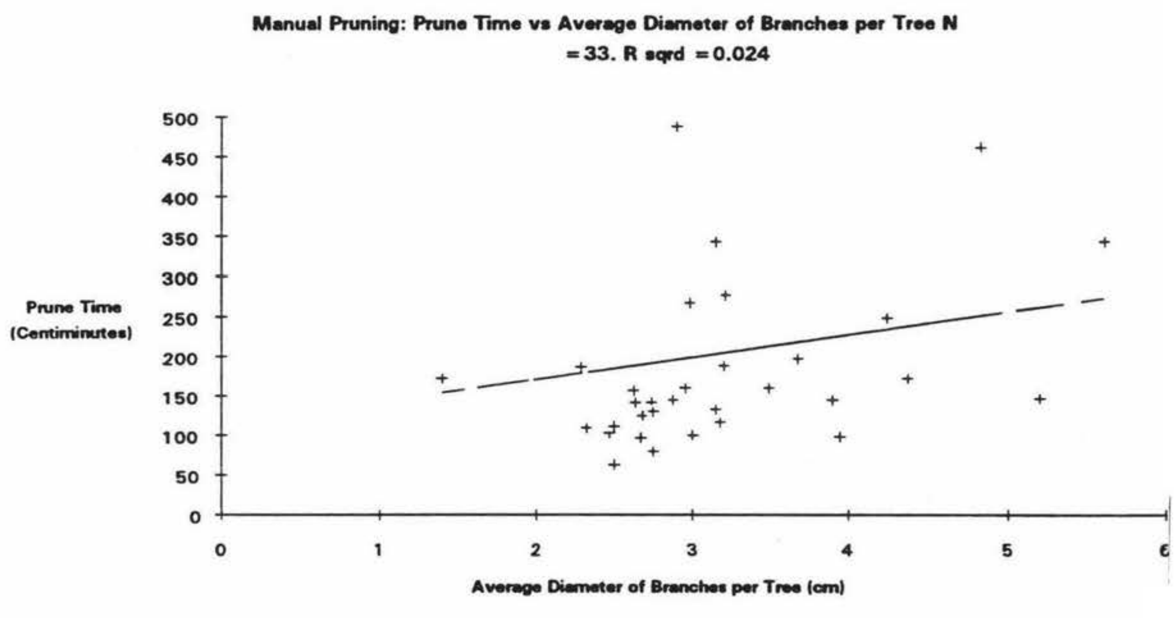
The prune time for Manual pruners in relation to the number of branches per tree was predicted by the regression equation...

$$y = 11.593x + 22.35$$



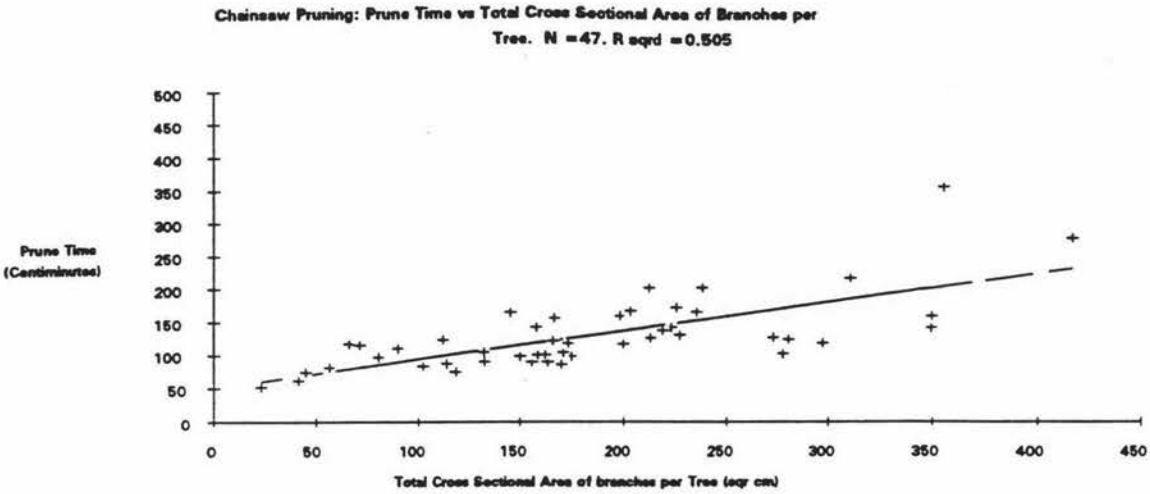
The prune time for chainsaw pruners in relation to the average branch diameter was predicted by the regression equation...

$$y = 8.469x + 100.98$$



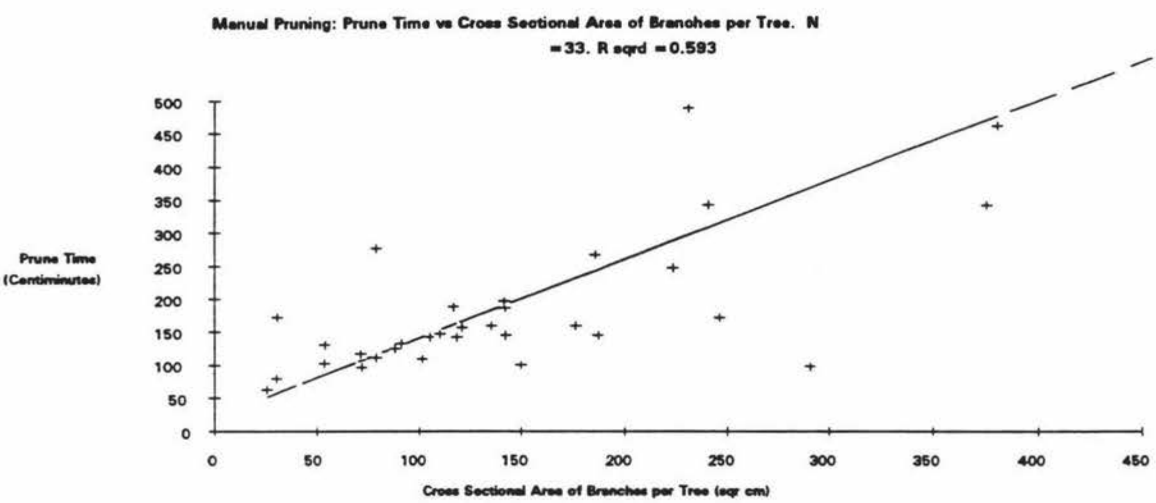
The prune time for Manual pruners in relation to the average branch diameter was predicted by the regression equation...

$$y = 28.202x + 113.97$$



The prune time for chainsaw pruners in relation to the cross sectional area of branches per tree was predicted by the regression equation...

$$y = 0.434x + 50.075$$



The prune time for manual pruners in relation to the cross sectional area of branches per tree was predicted by the regression equation...

$$y = 1.195x + 20.592$$