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# INVESTIGATION INTO THE EFFECTS OF USING A HARNESS DURING MANUAL PRUNING OPERATIONS

**Prepared by Liz Wright**



Sala Street
Private Bag 3020
Rotorua
New Zealand
Phone
07 348 7168
Fax
07 346 2886

Leading Edge Forestry Solutions

For information, please contact Liro, Private Bag 3020, Rotorua, New Zealand.

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## SUMMARY

Variations in worker postures, during manual pruning from a ladder are associated with use or non-use of a harness. Biomechanical analysis indicates potentially hazardous increased back and trunk ranges of movement, when pruning with a harness. When pruning without a harness there is potential for serious injury from a fall and also potential increased static work, another risk factor associated with musculoskeletal injury.

Task analysis of manual pruning in this study suggested no difference in productivity between pruning with or without a harness.

Subjective opinions from workers in this study showed no major differences in fatigue or discomfort levels, when pruning with or without the harness. Physiological measures showed no differences in workload associated with either method of manual pruning.

Design of harnesses and lanyards varies throughout the industry, with no one design consistent for use during manual pruning. The different types each appear to have potentially beneficial and detrimental characteristics.

Protection from a fall with the harness types currently in use is only achieved once the worker attaches the harness, at the top of the ladder. No protection is offered whilst climbing or descending the ladder, or during pruning activities whilst part way up the ladder.

Further research into harness and lanyard design and use specifically for silvicultural operations would help reduce the disadvantages of harness use, whilst also reducing the potential of falls from the top of the ladder.

Further research is needed to ensure ladder design and use are appropriate for pruning operations, and ultimately to produce alternative ways of pruning which reduce or eliminate the risk of falls.

# INTRODUCTION

Occupational Safety and Health Service (OSH) interpretation of the health and safety legislation (Duty of Employers In Relation To Heights) requires that workers wear a fall restraining device such as a safety harness when pruning off the top of ladders at a height above 3 metres (*Duty 21 of Health and Safety in Employment Act: to provide means to prevent the employee from falling*). There has subsequently been disagreement within the industry about whether use of a harness/fall restraint device does in fact reduce risk of injury, with resistance from some forest companies and contractors and support from others. Prohibition notices served to a number of silvicultural contractors accelerated the dispute. Recent liaison between the Forest Owners Association (FOA) and OSH resulted in a six-month trial period (July 1999 to January 2000) whereby exceptions are made for certain conditions.

This study aimed to provide objective data on use of harnesses, with measures of biomechanical and physiological effects and productivity recorded along with subjective information. This information will contribute to our ability to make informed decisions about the effects of harness use when ladder pruning.

# BACKGROUND

The Health and Safety in Employment Act is geared around protection of the workforce and is supported by guidelines and codes. The employer has general duties that relate to specific hazards, including working above heights of 3 metres, and this has been interpreted by OSH to require that employees should use a fall restraint device when working above this height. Recently a six-month trial has been agreed to, which allows workers to work without a harness if:

- A ladder with a $30cm^2$ working platform is being used
- The ladder has a supporting chain (midway, which is secured around the tree)
- The ladder has pointed feet
- The worker holds appropriate training modules.

Compulsory harness use is required for those undergoing training and also for any chainsaw pruning from a ladder regardless of height. Harnesses or belts must be provided where requested by employees (even if the above conditions are met).

There has been considerable interest from forest companies and contractors as to the real effects of harness use. This interest in harness use and falls from ladders also prompted trials and subsequent improvements in ladder design (hence the use of chains). Prior to the legislation, the use of harnesses was popular with some companies, but not with others. There are a few key issues associated with using harnesses. The use of harnesses has been reported to increase cycle time (the time taken to complete the pruning operation per tree) with one study showing a 9 % increase (Scott, 1997), which along with the cost of provision of equipment will result in subsequent increases in production costs.

There is potential for increased work load through carrying the extra weight of the harness, but conversely there may be reduced biomechanical demands on the body through ability to lean on the harness once attached. The local muscle activity may vary between the two methods, for example the degree of static activity in the leg wrapped around the tree when pruning without a harness.

There is also controversy as to whether the harness actually reduces risk, as a worker is only protected when working from top rung (or from the time they attach the harness). A previous study investigated incidents involving accidents and ladders, and concluded that the design and use of ladders was the key concern, as the falls were largely during ascent and descent of the ladder rather than when at the top rung (unpublished, 1999). However, the outcome of a fall from the top of the ladder (above 3 metres) even if less probable than a fall during ascent/descent, is potentially one of serious harm, therefore the resultant risk requires some sort of control.

The Forest Industry Accident Reporting Scheme (ARS) figures show that between January 1997, 1998 and June 1999 there were 44 reported incidents involving ladder pruning. Of these, 17 were unrelated to the use of harnesses (e.g. injured whilst unloading ladder from trailer). 24 related directly to pruning but of these only 4 were from the top of a ladder, with a further 10 being unclear in the description, so may have been above or below 3 metres.

Key issues are summarised as:

- Whether there is significant difference in production time with and without harness
- What the biomechanical effects on the body are for each method, for example restrained, twisting to put on harness, or better with harness as able to lean back
- Whether using harness or not, training and experience will still influence efficiency and safety of performance
- Fatigue/work load may vary between the different methods – for example increased energy expenditure of wearing harness (extra weight) or possibly reduced energy expenditure from not having static leg work when wrapping around tree
- Any subjective information from users should be taken into account, particularly reported advantages and disadvantages of harness use
- Harnesses currently used are lineman's belt and pole strap; as there are other means of fall restraint and arrest, these should be considered.

## ACKNOWLEDGEMENTS

LIRO acknowledges Carter Holt Harvey Forests and specifically the Napier based silviculture crew who assisted in this project.

## PROJECT OBJECTIVES

The project objective was to investigate the effects of harness use (lineman's belt and pole strap) on productivity, heart rates, biomechanical loadings and workers' perception of safety and fatigue.

## RESEARCH DESIGN

### *Methodology*

Four workers with manual pruning experience were studied over two days. All the workers were used to pruning with and without harnesses (lineman's belt and pole strap). The height of pruning was artificially limited so the workers' feet stayed below 3 metres, in order to both meet legislative requirements and to ensure subject safety. Each worker was provided with information on the study and completed a written informed consent. Workers completed a medical questionnaire prior to the study to ensure they were injury free and in good health. All were given the option of not participating, prior to and during the study. Weight and height of all workers was recorded and resting heart rate measured prior to commencing the trial.

Each worker performed pruning tasks both with and without use of the harness, for two hours during the same time period of the day for both tasks, over two subsequent days. Additionally, each worker was videotaped pruning from a ladder with and without a harness in more controlled conditions (specific accessible trees to allow accurate recording conditions) using two different types of harness.

### *Biomechanical 3D Analysis*

Selected worker pruning movements were videoed and analysed using Peak Motus and 3D Pan and Tilt hardware and software systems (Peak Performance Technologies, Denver, Colorado, USA). While pruning, two workers used a wire strap, one worker used a rope strap, and one worker used both the wire and rope strap. In total 393 cuts were performed and recorded for these workers.

### *Productivity and Task Analysis*

Productivity was measured in terms of the number of trees pruned during the period of study. Each "tree time" was comprised of time spent performing each sub-task (see Table 1) recorded using Husky Hunter field computers. Some were measured manually with a stopwatch (due to mechanical failure of a computer).

| WORK ELEMENT | START ACTION | FINISH ACTION |
|---|---|---|
| Walk/select | Putting foot on the ground, having climbed down ladder | To worker putting first foot on rung of ladder |
| Up | From first foot on rung of ladder | To taking pruning loppers from pouch |
| Prune | From loppers out of pouch | To when loppers are put back in pouch at end of pruning task |
| Down | From loppers in pouch | To putting foot on the ground having climbed down ladder |
| Operator, personal or mechanical delays | Recorded time for any delay during the above tasks, such as stopping for a drink, distraction etc | |
| Harness on and off | Recorded only during stopwatch task observation, and from general operator observation of workers pruning during the study days and on video | |

*Table 1 Task elements*

### *Heart Rate, Discomfort and Fatigue*

Resting heart rates were taken the evening prior to the study. On the study days, heart rates were monitored at one-minute intervals using heart rate monitors (Polar Electro, Finland). Subjective information on body part discomfort (BPD) and on level of fatigue was taken at intervals during the recorded pruning periods. Figure 1 shows the scale used to indicate subjective fatigue levels, developed from Legg et al (1991) and used in the forest industry by Kirk (1996). BPD surveys were based on those used by Ford (1995).

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

*Figure 1 Subjective assessment of fatigue scale*

### *Subjective information and opinions*

Demographic worker information and their opinions on use of harnesses for pruning was recorded via informal interviews and short written questionnaires. Closed questions sought opinions on feelings of safety with and without the harness, using a scale ranging from "very unsafe, unsafe, no opinion, fairly safe, very safe". Open questions sought for opinions on aspects of harness use.

### *Air Temperature*

Air temperature and humidity was measured at intervals during the two days using a hygrometer, to establish any variations in environmental conditions.

## RESULTS

### *Productivity and Task Analysis*

Each worker was studied pruning for between 56 and 117 minutes (adjusted to account only for productive time, with delay time removed) at approximately the same time on each consecutive day, during with and without harness pruning tasks. None of the task requirements produced risks greater than those normally encountered during normal pruning, and all pruning was carried out with the feet below 3 metres, with ladder heights varying from 2.5 to 3 metres. Air temperatures varied between 2° and 14° C, with similar conditions for pruning tasks with and without the harness. Productivity was compared for harness versus non-harness pruning, using average time taken per tree, with no major differences from the data collected (Figure 2).

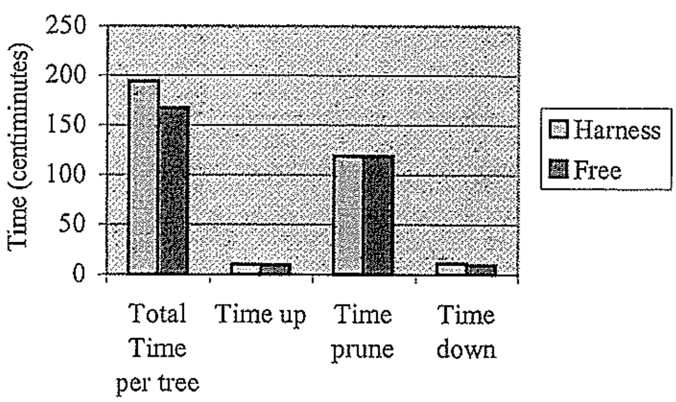


*Figure 2 Average time for work elements*

The time spent putting the harness on and off was incorporated within prune time. Where the stopwatch was used, the harness on/off time was evaluated separately. Harness time was also observed using video recordings of the workers, outside the task analysis period. Average time spent putting the harness on and off was 5 seconds (from two workers). It is likely that this is longer than normal as the workers had not been manual pruning for a few months prior to the trial so described themselves as out of practice. There was also an observed difference (outside recorded analysis periods) between the use of two different types of harness (shown in Figure 3) whereby the synthetic rope type lanyard seemed slower in comparison to the wire one. This was corroborated by the video analysis, which showed times to attach the strap around the tree ranged from 4 to 13 seconds with the wire strap, compared with 13 to 47 seconds for the rope strap.

*Figure 3 Rope (left) and wire type lanyards*

***Heart Rate, Discomfort and Fatigue***

Subjective levels of fatigue were measured at the beginning, midway and end of the recorded task and also at the beginning and end of the day, where this was not concurrent with beginning/end of task. Figure 4 summarises results during and at the end of the pruning task. Differences, although not great, indicated slightly higher level of weariness and being less relaxed with the harness.

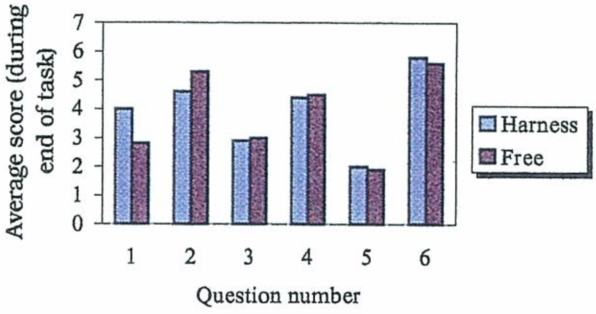


*Figure 4 Summary of subjective levels of fatigue*

There were no significant differences between working heart rates during pruning tasks with or without the use of a harness. Average heart rates ranged from 98.7 to 141.4 beats per minute (bpm). According to Rodahl (1989) this puts three of the subjects as working with a 'heavy' workload, the other being 'moderate'. Pheasant (1991) suggests that for continuous work the HR should not be more than 40 beats higher than resting level. Only one subject (subject 2) kept within this level, but as the work was over a short time, with both days involving abnormal conditions (videos etc) it may be possible that workers would work at a lower, more sustainable rate over a longer period.

| Worker | Pruning: free | Pruning: harness | Resting: smoko | Resting: (sitting) HR | HR max: 220 - age |
|---|---|---|---|---|---|
| 1 | 137.5 | 132.9 | 102.5 | 66.6 | 195 |
| 2 | 141.4 | 112.7 | 78.1 | 85.5 | 201 |
| 3 | 118.2 | 123.0 | 89.4 | 60.7 | 189 |
| 4 | 98.7 | 112.2 | 81.0 | 75.7 | 177 |
| Average HR of 4 workers | 119.8 | 121.3 | 83.4 | 72.1 | 190.5 |
| StdDev of HR | 23.5 | 15.1 | 25.5 | 10.8 | 10.2 |

*Table 2 Average heart rates*

The body discomfort charts (Figure 5) summarise reports of discomfort before and after the pruning tasks. Both methods produced reports of upper limb and shoulder discomfort, which supported the findings from the video analysis of the use of large ranges of shoulder movement and maximum effort.

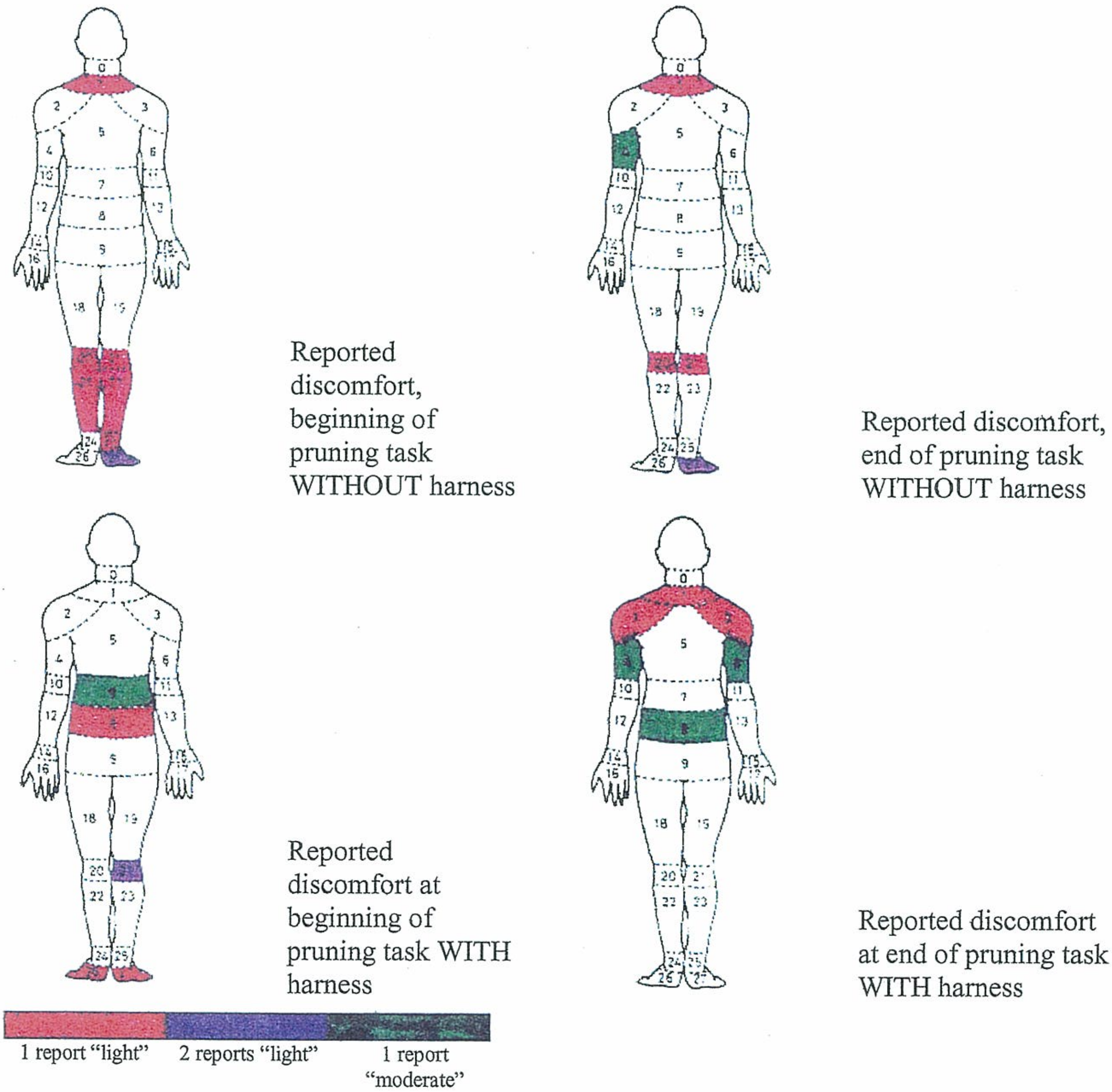


*Figure 5 Reported discomfort, before and after pruning tasks*

Without the harness there was little change in reported discomfort, the main exception being a report of moderate upper limb discomfort at the end of the session. Moderate back discomfort was reported both before and following use of the harness, and light and moderate upper limb and shoulder discomfort levels were reported following harness use. As the back discomfort was present before harness pruning started it is difficult to establish whether it is task related.

### *Postures and Static Work*

It is well recognised that static work reduces blood flow and increases the potential for injury (for example Pheasant, 1991). Observation of pruning tasks without the use of a harness showed the use of static muscle activity in the leg wrapped around the tree, potentially making this a less efficient way of working.

Arguably the effects of increased muscle loading could be reduced with experience, and there are no reports in the ARS that appear to be related directly to local damage. However, a posture involving both feet in a weight-bearing position, without one leg flexed and held around the tree, would be expected to allow for better balance as well as reduced local static muscle activity. Use of bilateral weight-bearing postures might also be expected to require less 'learning' time. Figure 6 shows a worker without a harness with his leg wrapped around the tree.

### *Biomechanical 3D Analysis*

Approximately 13.5 % of all cuts videotaped required a near-maximal or maximal effort, as ranked by the observers. Large ranges of motion of the shoulder joints were observed in a number of the cutting movements, and sawing or chopping movements indicative of either high force levels and or large ranges of motion were used in 21% of all cuts. Figure 7 shows pruning with the wire lanyard, in the video controlled conditions. In using the harness a significant amount of time was spent fastening the clip and adjusting the strap length (several cuts could have been completed in this time). A particularly long time was used for adjusting the rope strap, and in addition both hands were removed from holding the tree in order to adjust the strap, increasing the likelihood of a fall.

*Figure 6 Manual pruning without harness*

*Figure 7 Manual pruning using harness*

Use of the harness appeared to restrict the freedom of movement of the workers and as a consequence back flexion and extension and lateral trunk movements were observed to be more likely when pruning with the harness than without the harness. Large ranges of motion of the shoulder joints were used in all cutting movements using the loppers (harness and non-harness). One worker was observed to reduce the required range of motion at the shoulders and hence reduce arms and forearm movement by accentuating wrist flexion and hyperextension during the cutting motion.

### *Subjective Information and Opinions*

Worker characteristics are shown in Table 3. Health questionnaires showed that the workers carried some history of injuries and ill health, but all but one were injury free and well at the time of the study. One worker had been unwell with flu but felt well enough to return to work and participate in the study. All consented, and were able to withdraw at any stage.

| | Age | Height (cm) | Weight (kg) | Resting Heart Rate (BPM) |
|---|---|---|---|---|
| Average | 29.5 | 177.8 | 83.8 | 72.1 |
| Standard Deviation (SD) | 10.2 | 5.7 | 10.3 | 10.8 |

*Table 3 Worker characteristics*

Table 4 summarises comments obtained both from a brief questionnaire (completed by 3 subjects) and from informal interviews with all the workers. All workers reported feeling "safe" or "fairly safe" when pruning from the top of a ladder without a harness and all felt "fairly safe" when pruning with a harness. When asked whether they would use a harness given the choice, two answered "No", one answered "Yes", one declined to answer.

| Question | Responses |
|---|---|
| What reasons do you have for not using a harness? | Slows work pace<br>Harness loosens (synthetic rope type)<br>Harness hard to adjust<br>Too bulky to use<br>Feels more natural without<br>Have to carry extra equipment<br>Have to do extra work to connect to tree |
| In what circumstances might you choose to use a harness? | Working at an unsafe tree-side<br>Windy weather<br>Bigger trees where unable to get leg comfortably around the tree<br>If safer standards set up so can trust the harness e.g. with effective type of harness<br>If harness was better and easy to use<br>Good to use when learning |
| What changes might you make to improve harness use? | Harness designed specifically for pruning work<br>Better harness<br>Would use wire rope (or improved harness) type rather than 'standard' (synthetic rope)<br>Harness that does not slip |
| Other comments | Subjects in this study were mixed in opinion. All felt that with better harness design they would be less reluctant to use one. |

*Table 4 Subjective opinions of workers*

## DISCUSSION

This study had a number of unavoidable drawbacks. The group of workers was small, due to unavoidable circumstances, which limited statistical analysis of data. The workers were out of practice with both pruning and harness use, reducing the ability to apply sample findings to the worker population. Pruning did not take place during a normal working day because of the specific requirements for video recording. The removal of workers from their normal jobs restricted the length of time available to conduct the study.

However the research provided a great deal of valuable information, and a significant amount of additional information has been gleaned from other experts, users, previous research, observation and background physiological information. It is envisaged that further research should investigate alternative methods and equipment for use in manual pruning.

The main disadvantages of harness use can be summarised as follows:

- potential increased work from carrying additional weight
- time taken to put rope on and off, with subsequent increased production time
- inconvenience and maintenance
- cost of purchase
- increased back extension, flexion and lateral flexion associated with constrained postures
- both hands used to adjust the harness at times, leaving the worker totally unsupported

Advantages of harness use include
- reduced risk of falling
- improved balance
- weight bearing on two legs rather than one
- less static work
- reduced training costs (able to start work more quickly as protected)
- reduced risk of serious injury (e.g. prevention of one fall from above 3 meters, could result in a fracture or injury resulting in lost time, need to replace or retrain further workers etc)

The constrained postures seen among the subjects in the study could be partly due to their being unused to using the harness, having not pruned for some months, and their experience was largely pruning free of a harness. The slippage and difficulty with adjustment of the synthetic rope is likely to have caused mistrust, not allowing relaxation. Some of the postural disadvantages and some of the reluctance, might be avoided with better design of task specific equipment

It is reasonable to conclude that if the disadvantages could be reduced, it would be beneficial to use a harness or some sort of fall protection device. An alternative design to those being used, or adaptation of current belts and ropes may be developed which incorporates the beneficial aspects, and reduces the detrimental effects. A more appropriate design could also increase compliance (with convenience) and limit any increase in production times. The types of harness observed in this study each had different characteristics, which could be developed into one suitable design. Use of a wire rope would allow use for chainsaw as well as manual pruning, producing consistency of methods between tasks and reducing equipment requirements overall. As cost is also an issue there is a need to ensure reduction of cost of purchase as much as possible.

Overall the belts need to be lightweight, allow for attachment of tools, and must not restrict worker movement. The lanyard must not slip, to ensure actual and perceived safety, but must be easily adjustable with one hand. A further possibility is investigation of a full- body (but still lightweight) harness which is designed around fall arrest rather than merely fall protection. The belt and lanyard method provides improved balance and some support, but is inappropriate in the case of an actual fall, where an injury may result.

Whether or not a harness is used, there is still a reliance on training. Current agreements allow those who have achieved the appropriate modules (and are therefore deemed sufficiently skilled) are then able to prune above 3 metres without the harness (if the other conditions such as ladder design are met). This does have major implications as the harness and non-harness pruning methods were shown in the study to be quite different in terms of postures and ranges of movement. A worker learning to prune with the harness may not automatically be equipped to prune safely using different postures and ranges of movement without the harness. These differences are particularly evident when observing harness free workers, who develop specific skill in wrapping their leg around the tree. If legislation continues to allow non-harness pruning use once the modules achieved, it would be necessary to require workers to train in this technique and to ensure workers learn this skill.

A major argument presented against the need for harness use is that the accident statistics indicate falls being largely during ascent and descent. Therefore the harness is not offering protection for part of the task that seems to produce the majority of the injuries. It is significant that the worker cannot attach the harness until reaching a sufficient height for a) the rope to reach around the trunk and b) make it practical, i.e. not to keep attaching and reattaching during pruning activity on the way up.

However, potential underreporting and insufficient data in reports means it is difficult to deduce which injuries may have been avoided if a harness had been used. It is still the case that if a fall did occur a serious injury may result. There are reports of up to 19 days lost (from ARS data 1997, 1998 and 1999 up until end June), from fractured legs, resulting from falls where it is conceivable that a harness may have prevented the injury. These facts also serve to reiterate that a more appropriate harness type (or some other method of fall protection) is needed to protect more fully and appropriately at any stage of the task.

The issue of where and how falls occur during manual pruning also raises the issue of ladder stability and type. This is an area that is particularly important to pursue, with data indicating that many falls do arise from ladders tipping. This topic was not within the scope of this study, but does need to be further explored. Ultimately there is a need to try and find safer ways of pruning trees to further reduce the risk. There are current initiatives in this area, such as pruning ascenders, but further research is needed to explore alternatives that are cost effective and practical.

## COLLABORATORS

The project was carried out by Liz Wright and Richard Parker from Liro Forestry Solutions, in collaboration with:
Human Performance Centre, Otago University - Dr Barry Wilson, Dr Alan Walmsley and Ms Priscilla Byrd
Cater Holt Harvey Forests, Hawkes Bay - Brian Saunders

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