Technological Advances in the Analysis of Work in Dangerous Environments: Tree Felling and Rural Fire Fighting

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Abstract

Ergonomists have always been interested in studying work and especially the safety aspects of work. Studying work in dangerous situations is an area that presents particular challenges to the researcher and potentially to the worker.

The objective of this study was to explore the use of new technologies in facilitating the field study of people engaged in dangerous work situations without disrupting the work or adding to the danger. This was achieved through the investigation of work activity in dangerous environments: tree felling and rural fire fighting. The two case studies formed the basis for an investigation into three aspects of work: first, to record, measure and understand the work (including physiological workload) of people engaged in dangerous occupations; second, to understand how hazards were identified and dealt with by individuals working in extreme conditions and third, to gain insight into hazardous work environments for the purpose of enhancing training for personnel working in dangerous conditions.

An innovative suite of equipment was developed for the study, enabling data collection that did not disturb or inhibit the individual working in dangerous, and sometimes extreme, conditions. The results of the study have shown that, through triangulation of novel combinations of recording instrumentation and video-cued reflective interview, we can gain rich interpretative insights into the working world of the tree faller and rural fire fighter and understand how they manage the hazards they confront in their work. This in turn enables us to develop practices designed to minimise or avoid physical risk to the worker, Furthermore, the annotated video collected in the forests and at fires can be utilised as an authentic resource for training of both workers and trainers.

My study has highlighted the value of, and need for, research that is situated in real work environments, and that captures the multidimensionality of workers' activities without impeding or altering their behaviour.

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1 Introduction to the Study

1.1 Background

Dangerous work situations, by their very nature, are worthy of attention from ergonomists as it is important that we work to understand and reduce the risks inherent in physically demanding work situations. These work environments are typically difficult to study comprehensively, especially as the presence of the ergonomist in the field is likely to impede work and even exacerbate already precarious work situations. Thus, for their own and the safety of others, and because they can collect data in a controlled environment, ergonomists turn to their laboratories as a proxy - sometimes focusing on only a few variables of interest, and sometimes designing complex and challenging experiments in attempts to replicate the complexities of the actual work environment. However, no laboratory can hope to capture all conditions of the field and, indeed, it is questionable whether researchers in some cases even realize what the key factors are.

Laboratory experiments are constrained by limited or complete lack of access to 'real' work situations/conditions, but the limitations can be further compounded by the lack of 'real' subjects. Experiments are frequently carried out with participants who are not members of the target worker group, but who are willing to enact certain practices that are the object of study at the time. Examples of this approach are students engaged in physiological studies, walking on treadmills dressed in fire fighters' protective clothing pretending to be fire fighters (e.g. Dreger, Jones & Peterson, 2006) or riding stationary bicycles and dressed as fire fighters (e.g. Chou, Tochihara & Kim, 2008). In such studies, the duration of the work that the subjects are engaged in is short in comparison to the typical work day of actual workers. For example, rural fire fighters may be in the same, unwashed, clothing for days working 10 to 12 hours every day. Laboratory studies cannot capture this long duration exposure to work. Furthermore, the motivational environment of the seasoned professional surrounded by his or her work crew cannot be recreated in the laboratory.

Hence, ergonomists are potentially vulnerable in terms of the acceptability of their findings to workers and those that manage them. Moreover, the uptake of recommendations for improvements to work or equipment design in real work environments may be limited. How then can some of these limitations be overcome so that research findings can be perceived as both meaningful, and also useful for improving worker safety, comfort and productivity? I believe that this study helps to answer this question by engaging in research with workers as they carry out their normal work activities in the field.

Of course ergonomists frequently move into the field to observe and record, and analyse work situations with the motive of improving work conditions, design and productivity (e.g. van der Molen, Sluiter & Frings-Dresen, 2009). Yet, progress in terms of observing people within hazardous environments has been stymied, not only for the reasons outlined above, but because technology and technological applications have been awkward and difficult to implement without disrupting the normal work activity of the people being studied (Kirk & Parker, 1994; Parker & Kirk, 1993).

With technological developments, however, have come increased portability and sophistication of equipment. The consequent ability to remotely monitor a range of activities and physiological responses means we now have opportunities available to the ergonomics researcher that were not available in the past. The current study makes use of a number of techniques such as observations and remote monitoring of emergency and extreme work-related situations. Data collection in this research undertaking is further enhanced by the simultaneous recording of events via digital video. This additional dimension helps provide rich, intimate insights into the work of two types of worker ‘on the job’, sometimes working under extreme conditions. Thus the current study contributes to the fundamental aim of ergonomics as a discipline – to the: “Methodologically explicit field research [that is so] vital for the core purpose of ergonomics, investigating and improving interactions between people and the world around them” (Wilson, 2000, p. 563).

The research study reported in this thesis explores work done by two groups of workers whose work, by its nature, can present life and death situations and decisions. The context reflects my particular interest to better understand the nature and challenges of extreme, often dangerous physical work. The two case studies presented are those relating to rural fire fighters employed by the New Zealand Department of Conservation and Rotorua District Council and tree fallers employed by logging companies contracted to various New Zealand forest management companies.

1.2 Cases studies

1.2.1 Case study 1: Rural fire

Rural fire fighters are daily poised to expect the unexpected. They are highly trained in procedures appropriate for a range of situations. However, every situation has unique characteristics, and responses must be similarly novel and tailored for the often complex and certainly dynamic circumstances found in a rural fire. They may engage in routine and arduous mopping-up after a fire has been contained – applying water to hot spots and exposing, with hand tools, material burning underground. It is dirty, slow, unglamorous work. Alternatively, they may be engaged in a high speed initial attack – travelling quickly across rough terrain in four-wheel drive fire engines, applying water to a raging fire and keeping out of harm's way. Fire fighters are understood by the public to put their lives on the line, and in the popular imagination, in the wake of September 11 terrorist attack, may even enjoy 'hero' status. What is not commonly known by the public is that fire fighters must work, often in chaotic circumstances, in a coordinated way to ensure their own and their colleague's safety. They must communicate with each other and make decisions while battling to extinguish the fire.

1.2.2 Case study 2: Tree falling

Forestry workers are not necessarily understood to be routinely facing danger in the same sense as fire fighters. However, tree fallers are exposed to hazards for eight hours each day, 40 to 48 hours each week. Each year tree fallers are killed at work in New Zealand. In the 12 month period 2005-2006 six tree fallers, out of a total tree faller workforce of approximately 1000, were killed (Department of Labour, 2010 http://www.osh.govt.nz/resources/stats/fatals/index.shtml). In addition to working in an environment filled with hazards, tree fallers' work is physically demanding, involving, for example, carrying a heavy chainsaw, fuel and other equipment on steep, untracked terrain. To remain safe requires a high level of situational awareness to the hazards present in the forest environment – disturbed branches falling from above, rotten trees collapsing, heavy mobile machinery, steep terrain, wood under tension exploding when cut and so on.

While sharing some of the work characteristics of fire fighters, tree fallers differ from fire fighters because their work is solitary: tree fallers must work alone because of the risk to others nearby from falling trees. Individually each of these two cases represents a different set of situational characteristics, physical and mental challenges, and thus together they present a rich basis for research.

1.3 Research aims & thesis structure

The overarching purpose of this research is to explore the use of new technologies in facilitating the field study of people engaged in dangerous work situations, without disrupting the work or adding to the danger. To this end, the aim is to explore the efficacy of new technologies to study work in dangerous environments.

Associated aims are:

- To record, measure and understand the work (including physiological workload) of people engaged in dangerous occupations;
- To understand how hazards are identified and dealt with by individuals working in extreme conditions;
- To gain insight into hazardous work environments for the purpose of enhancing safety training for personnel working in dangerous situations; and
- To explore the value of reflective interview as a tool to establish ways decisions about possible courses of action are made.

After having introduced the research in Chapter One, Chapter Two presents a broad overview of the ergonomics literature relevant to the current study. Here I will draw on several themes, including the history of ergonomics research, as well as ergonomics research practices and limitations associated with these. I also present research into technological solutions to work investigation and research into humans at work in dangerous environments. Further detailed discussion of the relevant research is also presented in Chapters Four, Five and Six of the thesis.

The literature review is followed by a chapter outlining the broad research design. Chapter Three first expands on the aims of the investigation, before setting out the rationale for framing the research within a case study format. It then introduces in some detail the occupational groups under scrutiny. Next I discuss the notion of a mixed method approach, and expand on the actual observation techniques and data analysis approaches used in this study.

The next two chapters present the two case studies. Each of Chapters Four and Five reviews briefly some of the contextual issues and provides deeper insight into some of the investigation methods employed. These chapters also present the first level of analysis. In Chapter Four I investigate tree felling and begin with a review of relevant logging industry injury statistics. Then I discuss the various research approaches that attempt to understand possible causes for accident occurrence. I then present a field study using unobtrusive observation methods: to identify successful hazard identification and mitigation strategies, to determine why experienced tree fallers were more productive than inexperienced tree fallers and to use the study to develop appropriate training material.

In Chapter Five I review the research associated with rural fire fighting and then present a field study, using unobtrusive observation, of rural fire fighting which measures the physiological workload and fire suppression productivity under real operational conditions. The aims of this study are to develop methods to measure work load and productivity of rural fire fighters and to provide input to guidelines for fatigue recommendations and productivity standards.

Chapter Six introduces a new element to the research study. Here, two participants (one rural fire fighter and one tree falling trainer) are asked for their observations, and to reflect on the work situations captured in the video and audio recordings of workers performing their tasks. The fire fighter views video of his own experience at a fire. The tree falling trainer views video of another tree faller at work. These reflections present new insights into the ‘lived experience’ of the participants and serve to embellish the understandings obtained in the previous stages of the research. The conclusions, presented in Chapter Seven, draw together all the elements of the two case studies.

2 Measuring work: Technological innovations and challenging situations

2.1 Introduction

Ergonomists are interested in establishing the capacities and limitations of humans at work. To do that they typically obtain information on such variables as oxygen consumption, body temperature, heart rates, work patterns, worker outputs and various environmental measures. In the past, collecting field data, especially under hazardous conditions has presented a challenge to ergonomists.

This chapter will refer to existing scholarship in order to describe three dimensions of the study of work. First, I will briefly present the historical background to the study of work over the last two centuries. Second, I will describe the technological advances that have made possible the study of work in dangerous occupations. Finally, I will review the literature related directly to dangerous work and show that there has been little opportunity for workers, in dangerous occupations, to reflect on their experiences in a systematic way.

2.2 Historical trends of work measurement

Charles Babbage (1791 – 1871) was a pioneer in the observation and quantification of work (Lewis, 2007). In his book *On the Economy of Machinery and Manufactures* (Babbage, 1832) he provides the reader with a guide for conducting a meaningful ‘plant tour’ and “[his] guide comprised a set of structured questions” for the investigator (Lewis, 2007 p. 258). For example Babbage (1835 XII, p. 117) states that: “ care should be taken: for instance, if the observer stands with his watch in his hand before a person heading a pin, the workman will almost certainly increase his speed, and the estimate will be too large.” Thus, even in 1835 the presence of an investigator was seen as potentially biasing studies of work.

Before that time ‘rules of thumb’ were used to estimate production (Hough & White, 2001). Frederick Taylor is described as the first person to provide a scientific basis for designing and performing work and is often referred to as the father of 'scientific management' (Shepherd & Stammers, 2005). Frank and Lillian Gilbreth were also major contributors to scientific management and acknowledged leaders in the study of work. Price (1990) stated that Gilbreth impressed Taylor, who incorporated Gilbreth's work in *The Principles of Scientific Management* (Taylor, 1911) and used Gilbreth's bricklaying achievements to illustrate the efficacy of the stopwatch technique he called the 'keystone' of scientific management (Taylor, 1911). Also, it has been claimed that Taylor had an approach that could be somewhat aligned with a modern ergonomics approach, consulting and informing the workforce and having open forums with management and staff to get cooperation with his projects (Price, 1990).

The Gilbreths' had a more sophisticated approach to the study of work than Taylor called 'micro-motion study' (Price, 1990). Individual workers' operations were filmed with a motion picture camera against a grid background while a clock displayed the time. By examining the film with a magnifying glass, Gilbreth could determine the times of each worker's movements to one-thousandth of a second. He could then compare movements and determine the best movements which would become standard for that task.

Frank Gilbreth demonstrated to the unions that, by replacing the fallible human observer and the stopwatch with the camera and clock, he could provide scientific and unbiased measures of work (Price, 1990). Gilbreth installed his micro-motion equipment in a 'betterment room' at the New England Butt Company, Providence, Rhode Island, a factory where braiding machines used in the manufacture of shoe laces, dress trimmings and electrical wire insulation were made. The workers in the betterment room worked, however, in isolation from their peers – a practice at odds with modern ergonomics practice where ergonomists want to disrupt work as little as possible.

Surprisingly, Gilbreth actually completed most of his observations at the Butt Company by conventional stop-watch time study before his micro-motion laboratory had been completed. Improvements in productivity reported by Gilbreth had actually been due to assigning time consuming elements to other workers (Whitaker in Price, 1990). In 1923, Eastman Kodak introduced new spring-driven cameras, 16 mm safety film and simple 500 watt lights which made micro-motion study cheaper and easier to conduct (Barnes, 1931). Alongside these examples of the application of scientific management, should not blind us to the controversies surrounding the work of both Taylor and later proponents (see Kanigel, 1997; Wren & Bedeian, 2009).

There were no significant developments in work study between the 1930s and the middle 1960s. This was partly due to the research of people like Mary Parker Follett, Chester Banard and especially Elton Mayo who concluded that work is a social activity and that the qualitative dimension of work could not be accommodated within the scientific management theories (Gilbert, Jones, Vitalis, Walker & Gilbertson, 1995; Wren & Bedeian, 2009). Nonetheless, advances in technology during the Second World War brought about some advancement in instrumentation and a renewed desire to measure human work activity.

In the 1960s analysis of work was refined with the introduction of multiple regression, linear programming and the introduction of the computer to assist in the measurement and analysis of work (Whitmore, 1975). In recent years, the greatest advances in the study of work have been the utilisation of new observation, recording and measurement technologies. Ergonomists, while recognising and discarding some of the more controversial aspects of work study have nevertheless adopted some of the principles of this approach when observing work.

2.2.1 Task Analysis

“Task analysis involves the study of what an operator (or team of operators) is required to do to achieve a system goal. The primary purpose of task analysis is to compare the demands of the system on the operator with the capabilities of the operator, and if necessary, to alter those demands, thereby reducing error and achieving successful performance” (Kirwin & Ainsworth, 1992, p. 15).

A useful task analysis method is Hierarchical Task Analysis (HTA) where a task is expressed as a goal that the operator is required to attain, such as “Fell trees in a stand". This is then redescribed as sub-goals and then a plan drawn up to govern when each sub-goal will be carried out (Shepherd and Stammers, 2005). However, in challenging work situations it can be difficult to get direct access to the operator and record their work in sufficient detail for analysis. For that reason, measuring technologies have been developed which can assist the investigator to collect data.

2.3 Measurement technologies

2.3.1 Early timing of work

Initially, work was measured by observation and subjective judgment rather than electronic technologies. Later, spring powered clocks were used to time the duration of tasks. Next, ciné film was used to record work with a clock displaying seconds with a sweep hand in the field of view. Another innovation came about when a grid was placed behind the worker to allow easier measurement of the range of motions of the subject's body (Price, 1990).

Segur, in the 1920s " made use of the Kymograph, an electrically controlled pen moving in sympathy with the input and tracing the results on a moving paper-tape" (Whitmore, 1975, p. 21). As was mentioned above, Frank and Lillian Gilbreth pioneered the use of ciné and still photography for the study of work and the use of micro-motion (slow-motion) cinematography and the cyclegraph and chronocyclegraph (Whitmore, 1975). Stroboscopic photography was exploited in the 1930s by investigators of work (Shaw, 1960). Subsequently, mechanical methods were developed to trigger movie-cameras to record work, and in the 1950s tape-recorders were utilised to gain a rapid verbal recording of the elements of work (Whitmore, 1975, p. 21). One such system was Tape Data Analysis to verbally record maintenance work as it was occurring (Whitmore, 1975).

2.3.2 Physiological monitoring

The technologies mentioned above were all related to timing and recording work movements. The reactions of the body to work could not be measured other than by manual palpation of the heart pulse. Starting in the 1960s, with the introduction of Socially Acceptable Monitoring Instruments (SAMIs), attempts have been made to develop methodologies and instrumentation that would be acceptable to research subjects, and would not interfere with the work flow. At the December 1966 meeting of the Physiological Society Goldsmith, Miller, Mumford and Stock (1967, p. 35P) reported that the "ideal of accurately assessing human energy expenditure in an unencumbered subject is not yet attainable". He went on the report that the SAMI heart rate counter of Baker, Humphrey and Wolff (1967) could offer a promising indirect approach. At the same meeting Hunt and Marcus (1967) reported the use of a SAMI to measure the physical activity of bus conductors and bus drivers.

The SAMI devices of the 1960s were sophisticated for their time but appear incredibly primitive to us today. The transistor had only recently replaced the valve and the level of innovation required to design lightweight data collection devices was indeed impressive, considering the technology available. Baker et al. (1967) reported that the data (for example, number of heart beats over the recording period) was stored in a sealed miniature electroplating cell (E-cell) in which silver was plated on to a gold electrode in proportion to the charge passed through it. A replay machine gave a numerical readout of the stored charge. The SAMI instruments were powered by small mercury cells with a life of about two months.

Baker et al. (1969) reported heart rate and temperature SAMIs had improved so that they could be applied and adjusted by comparatively inexperienced personnel. Advances in electronics and the general availability of integrated circuit operational amplifiers in the 1970s were incorporated in SAMI designs. The SAMI E-cell was replaced by an integrated circuit (Crane, 1978) which greatly increased the data storage capacity and accuracy. It could be argued that SAMIs were the first self-contained 'wearable' physiological recording devices and have been superseded by a stream of ever improving physiological recording devices.

2.3.3 Heart rate monitors

The Dutch physiologist Willem Einthoven developed the first electrocardiograph (ECG) in 1903 and subsequently was recognised with the Nobel Prize in Medicine in 1924 (Kligfield, 2002). Building on this development, a 'portable' version of the ECG, the Holter-monitor, was developed which could make a 24 hour recording of an individual's ECG on a tape (Holter, 1961). However, the device was large and heavy and could not be used easily when people were moving freely (Achten & Jeukendrup, 2003). The first self-contained, wearable and recording heart rate monitor was developed in 1978 by the Polar Electro Company in Finland (Laukkanen & Virtanen, 1998). Over subsequent years, refinements in electronics and software have resulted in a vast range of wearable heart rate recording devices by numerous manufacturers. Now investigators can purchase heart rate monitors that can record heart rate variability, record full EMG profiles and continuously record heart rate for up to one month storing the data within the heart rate monitors memory (e.g. *Zephyr Technology*). More recent developments in heart rate monitor technology have seen the devices incorporated in clothing (e.g. *Vivometrics 'LifeShirt'*).

In ergonomics research, heart rate in isolation tells the investigator little about what work is being done. A visual recording of work by video has helped to address this deficit, and is the most common method used today to understand the context of work.

2.3.4 Video

Ciné cameras and film for the study of work were superseded by video in the 1970s when video cameras and recorders became available to the consumer. Television or video, the rendering of images as an electrical signal was first achieved in colour in the late 1940s. However, the images needed to be recorded and able to be played back to be of use to study work. In 1951 Charles Ginsburg's research team at the Ampex Corporation developed the first practical video tape recorder. They recorded the electrical signal on a magnetic tape and Ampex sold the first video tape recorder for US$50,000 in 1956. The first VCassetteR or VCRs were sold by Sony in 1971.

There have been subsequent developments in video technology: reduction in size and power requirements of cameras and recorders, improvement in resolution (image clarity), low light ability, image stabilisation and high definition video. The introduction of digital video which allows recording to solid state media such as flash cards meant that the recording of work was not as onerous as in earlier years.

The greatest technical developments, which have been pivotal in my research, are the wearable miniature video camera (e.g. Mann, 1997) and the ability to record video to flash cards (e.g. Parker, Moore, Ashby, Baillie, Pearce, Anderson & Vitalis, 2009). These developments have allowed people to wear a video camera and recorder during their normal work. A bullet camera is a small light weight video camera which is attached to a video recorder by a cable. The video recorder can record up to 12 hours of video at 25 frames per second and batteries power both the camera and recorder for up to eight hours of recording (e.g. *LawMate PV-500* device).

Other recent technology developments which have made the video recording of work easier are codecs (encoder/decoder software) which can compress the video to store in a small size; increased video sampling rate – results in a clearer video signal; improved video camera light capturing sensors which provide a clearer image and improve performance in low light and rapidly compensate for changes in light levels such as moving from shade to full sunlight.

In parallel, and perhaps leading human studies, animal scientists are developing wearable video systems and other sensors for the study of wild animals. In a review of the use of video in animal ecology, Moll, Millspaugh, Beringer, Sartwell and He (2007, p. 660) state that “researchers are deploying animal-borne video and environmental data collection systems (AVEDs), which enable researchers to see what the animal sees in the field. AVEDs record the fine-scale movements as well as features of the surrounding environment and thus provide essential context for understanding animal decisions and interactions with other individuals". This is precisely the approach of ergonomists using body mounted video cameras and other sensors on humans.

2.3.5 Geographical positioning systems

Another technological development that has proven useful in ergonomics applications are geographical positioning systems (GPS). A technology that began in 1973 with the decision to develop a satellite navigation system based on existing technology of the United States Air Force and the United States Navy (http://www.maps-gps-info.com/gps-history.html). The system went through extensive testing during the next three years. Between 1978 and 1985, eleven satellites were launched into space and put into position and full operational capacity was achieved in 1995 with 24 satellites. Subsequently, more satellites have been put into orbit increasing location accuracy from 100 metres to 10-15 metres and at present can be measured within centimetres in some cases.

With the commercial development of devices to take advantage of the GPS the investigator has numerous devices to select from to record the movements of a person over terrain. Many software packages have been developed to decode and present GPS data in useful ways. The most recent has been the integration of GPS data into *Google Earth* where the path of a subject can be viewed with a three dimensionally rendered terrain model. It offers the capacity to overlay high resolution aerial photography over the *Google Earth* terrain model to create an almost photo-realistic image of the terrain which can be viewed from any angle. Additional software is available to replay the movements of a person across the terrain as a moving icon with a trail (e.g. *Active GPX Route Player*, http://hybridgeotools.com).

2.3.6 Integration of data streams

Modern technology allows the capture of vast quantities of information. For example, one hour of video recorded at 25 frames/second at a sampling rate of 2000 Hz and a resolution of 720 by 480 pixels, occupies one Gigabyte of memory. Software is needed to interpret this data and create useful information.

As is often the case, advances in this field come from the military. Sensor ensembles are being developed for military use where the outputs from sensors can be used as an aide-to-memory for reviewing when writing intelligence reports and to understand events during operations (Minnen, Westeyn, Ashbrook, Presti & Starner, 2007). The authors describe the technology used in the *Soldier Assist System (SAS)* of sensors mounted on a soldier's body to record aspects of the ambient environment and his movements. The soldier has accelerometers attached to clothing at various sites to measure body position, a commercial GPS unit, an altimeter and digital compass. A still digital camera is mounted on the soldier's helmet and takes a photograph every five seconds. A digital movie camera records MPEG-4 video at 640x480 pixels to an internal SD card. He also wears two microphones, one microphone to record conversation and a second microphone to record ambient sounds. Images and sounds can then be reviewed in context because corresponding location information is available. The authors describe the complex software developments which have allowed the automation of physical activity recognition.

Another military use of integrated data collection is to monitor the physical condition of individual soldiers. In the preface to *Monitoring Metabolic Status*, Vanderveen states:

> "The U.S. military's concerns about the individual combat service member's ability to avoid performance degradation, in conjunction with the need to maintain both mental and physical capabilities in highly stressful situations, have led to an interest in developing methods by which commanders can monitor the status of the combat service members in the field." (Vanderveen, 2004, p. 1).

The book details numerous studies investigating biological markers and monitoring technologies currently available and in need of development and the algorithms needed to interpret the data.

Being developed in parallel with military sensor systems are civilian systems developed primarily for occupational health investigations. They are referred to collectively as “video exposure monitoring” systems.

2.3.7 Video exposure monitoring

Occupational health investigators have embraced video technology since the mid-1980s. A prominent use of video technology is video exposure monitoring which involves the combination of real-time monitoring instruments, usually for gases/vapours and dust, with video of the worker’s activities (Rosén, Andersson, Walsh, Clark, Säämänen, Heinonen, Riipinen & Pääkkönen, 2005).

Real-time occupational health monitoring equipment became widely available in the 1980s. The National Institute for Working Life in Sweden linked a real-time paint fume monitoring instrument with a concurrent video recording of the spray painters in a woodwork factory (Rosén & Lundström, 1987). Having a video record of the workers activity, while simultaneously viewing the concentration of paint fumes, enabled the researcher and the worker to see the effects of different work activities on paint fume exposure. “The value of this arrangement for the occupational hygienist as well as for the worker was immediate and obvious” proclaimed Rosén et al. (2005, p. 202). A new version of the system was developed which displayed the exposure data as a bar graph in the video picture (Rosén & Andersson, 1989). The method was named PIMEX (Picture Mix and Exposure). A NIOSH team (Gressel, Heitbrink & McGlothlin, 1988) developed a system which overlaid dust exposure data on concurrently recorded video. They called their system Video Exposure Monitoring (VEM). Both systems, the PIMEX and VEM, were able to show graphically how workers’ activities could affect their exposure.

Rosén et al. (2005) compiled a list of the principal systems in current use:

- PIMEX-PC (National Institute for Working Life, Sweden);
- Exposure Level Visualisation – ELVis (Health & Safety Laboratory, United Kingdom);
- FINN-PIMEX (VTT Technical Research Centre, Finland);
- CAPTIV (INRS, France);
- KOHS PIMEX (KOHS, Austria);
- VEM (Purdue University, USA);
- Griffith PIMEX (Griffith University, Australia).

The systems differ in technical details but generally provide a video signal synchronised with the output of sensors which can be analysed and presented to participants. The greatest difficulty encountered with video exposure monitoring systems is the synchronisation of video with sensor output. Some gas, vapour and aerosol sensors have a slow or variable response time which complicated synchronisation (Rosén et al., 2005).

When used for task analysis, video exposure monitoring allows the investigator to determine exactly what task the subject was engaged in and the associated exposure concentration. For example a study of glass fibre reinforced plastic application in waste water tanks showed 46% of the total exposure to styrene was explained by activities undertaken in only 10% of the working time (Andersson & Rosén, 1995).

Visual exposure monitoring supplies solutions, and a way to test those solutions, to occupational exposure problems. Rosén (2002, p. 4) stated in his invited editorial in the *Annals of Occupational Hygiene* that “Visualisation acted as a catalyst for productive communication between process experts and occupational hygienists, and became the key to a systematic problem-solving process.”

2.4 Work in dangerous settings: Tree felling and rural fire fighting

2.4.1 New Zealand and international studies

Jermier, Gaines and McIntosh (1989, p. 16) state “A *dangerous setting* is one in which a physically and/or psychologically harmful event has some probability of occurring.” Certainly tree felling and rural fire fighting can be considered as dangerous activities. It is difficult and dangerous for investigators to be present to collect data from workers in dangerous situations. For example, loggers have been observed engaging in work (e.g. Apud, Bostrand, Mobbs & Strehlke, 1989; Kirk & Parker, 1994; Parker & Kirk, 1993), rural fire fighters have been measured while they fight real fires (e.g. Apud & Meyer, 2009). However, all these studies risk disrupting the normal work practices they have come to study. Tree fallers in New Zealand, by law, must work at least the distance of twice the height of the tallest tree apart, approximately 70 metres. Tree fallers conventionally work much farther apart than this so they are effectively working alone. An observer shadowing a tree faller will disrupt the tree faller’s normal work flow. The tree faller is required to monitor all hazards in his immediate area and keep the researcher safe. At the simplest level the tree faller will be monitoring the location of the researcher, the presence of hazards near the researcher such as broken branches in the canopy above and the presence of heavy log hauling machines which will visit the felling site to haul away fallen trees. These ‘protective’ activities of the tree faller will disrupt his normal work. There is also the temptation to engage in conversation with the researcher during breaks in the work cycle to refuel and maintain the chainsaw. However, conversation is not a normal part of the tree faller’s work cycle.

A similar situation exists in rural fire fighting. The investigator is seen as an extra fire fighter who can be utilised in the emergency situation and may be requested to carry equipment or help with fire suppression. In these circumstances it is difficult to collect data and any work data collected will not be representative of normal work.

But it is often difficult to get access to workers undertaking dangerous work. The researcher must have a background in that work or undertake training to enter the logging operation or fire ground. More often, research investigating people working in dangerous occupations has been limited to interviews with workers after the work or from simulation of dangerous work. For example, the estimation of rural fire fighter 'productivity' has been an active research area for many years because fire managers need estimates of productivity to plan the allocation of fire fighters to a fire. Too many fire fighters at a location is wasteful, too few fire fighters may not control the fire. However, collection of data from real fires is extremely difficult. Of fourteen English language papers written on rural fire fighter productivity in the period 1970 to 2003, only two used data from real fires (Lindquist, 1970; Quintilio, Van Nest, Murphy & Woodard, 1988). The remainder used 'expert opinion' (e.g. Fried & Gilless, 1989; Schmidt & Rinehart, 1982), simulated fires (no fire present) or experimental fires (where additional resources were available if the fire got out of control) to determine fire fighter productivity.

With the ability to collect video and audio from the subject's perspective through head and body mounted cameras the opportunity for reflective interview is now possible. The interview will be stimulated by real events seen from the participant's perspective. The dimension of video and audio assisted reflection has not been widely used in the study of dangerous work. McLennan, Pavlou, Klein and Omodei (2005) have used reflective interview with fire managers making decisions in a training command centre role but they have not been in positions of physical danger. Miller (2004) used video-cued recall method with intensive care medical staff who were making important decisions but again not in physical danger themselves. I am not aware of any studies using video cued reflective interview with any workers from dangerous occupations. The novel use of video cued reflective interview with workers from dangerous occupation will be explored in Chapter Six.

2.4.2 Work measurement in logging and fire fighting

The New Zealand forest industry and rural fire industry, which provide the focus for this study, are industries that have physically demanding and hazardous tasks which are difficult to measure. Tree felling in plantation forestry in New Zealand is particularly dangerous with six fallers being killed in a 12 month period 2005/2006 out of a work force of only 1000 fallers. Few reported fatal injuries have occurred to rural fire fighters in New Zealand but internationally rural fire fighters are killed, at work, every year. Both industries are characterised by extremely high physical workloads.

Logging

Work in logging operations has been conventionally measured by observers who watch the work from a distance (Murphy, 1977). Initially they were recording work with stop watches and written notes, then with field computers with data recording software (e.g. *SIWORK* and *SIFREQ* software packages from the Danish Institute of Forest Technology). Problems with this observation method are numerous, particularly for observing tree falling (e.g. Parker & Kirk, 1993); the observers become fatigued and make errors in data recording, the observers may stand a considerable distance away from the worker so are unable to see detailed activity clearly, there is a risk of injury to the observers from falling material in the forest and heavy machinery, and the presence of the observer disrupts the normal activity of the tree faller so 'normal work' is not being measured – the 'Hawthorne Effect' (Roethlisberger & Whitehead, 1939).

Rural fire

Few studies, in the English literature, have measured rural fire fighting work at real fires (Parker, Ashby, Pearce & Riley, 2007). Those studies that have measured fire suppression productivity (area of fire extinguished per unit time) at real fires have not measured the physiological workload on the fire fighter (Parker, et al., 2007). A considerable amount of research involving fire fighters at real rural fires has been carried out in Chile but published in Spanish (Apud, Meyer & Maureira, 2002). Productivity, measured by area of fire break constructed, has been measured in simulations with no fire present (e.g. Schmidt and Rinehart, 1982).

The research to date has shown that numerous problems are encountered trying to measure work at real fires. The investigator has to be available to travel to the fire with the fire fighters but cannot participate in fire suppression. In the fast moving environment of a rural fire the investigator may have difficulty observing the fire fighters who may rapidly move to another location or become obscured by smoke and undergrowth.

Thus logging and fire fighting operations are dangerous occupations that present a challenge to the ergonomist wishing to help create a safer and more effective working environment. Details of the two case studies that form the focus of this research are provided in Chapters Four and Five.

2.5 Conclusions

In this chapter I have briefly surveyed the literature with regard to three important dimensions of ergonomics research. The chapter opened by looking broadly at some historical trends in terms of how work has been studied. The discussion demonstrated the historical trend to fragmentation of work (e.g. work studies such as Taylor & Gilbreth) which is suitable for detailed analysis of work. But it was shown that the bigger system in which the person works is ignored to focus on task components and productivity. Later, there was a move to the laboratory to gain a close scientific insight into certain dimensions of work. Again, this tended to isolate certain features for special scrutiny. Considerable scientific progress was made, but the decoupling of the worker from the environment (and the actual experience) presented inherent limitations. Compounding this problem was the tendency to use simulated conditions in the laboratory and subjects who themselves were not involved in the work.

The second dimension related to technology as an aid to scientific enquiry in ergonomics. I conclude that although there may be a slight lag between the technological capacity and its uptake for ergonomics research, nevertheless the potential applications of technological advances have been recognised by scientists to further their research, and ergonomists (and their near relatives, work-study people) were no different. Starting with Lillian and Frank Gilbreth's application of motion pictures to work study, this chapter has demonstrated a number of innovative applications of technology. However, technology too has its shortcomings, and some research has been thwarted by the difficulty of recording data in the field. Despite technological breakthroughs we still do not have a good understanding of what is actually going on in the more dangerous work places and why the worker makes particular decisions.

The third dimension of the literature review dealt directly with research into people in the dangerous occupations of tree felling and rural fire fighting. Advances in technology enable not only the observation and recording of dangerous work, but also the opportunity for the operator to review his work and reflect on his actions and comment on his strategies as well as his feelings during his work. Together the three threads of research literature reviewed in this chapter form the substance that underpins the current study of rural fire and forestry workers, who frequently work under extreme conditions.

The following chapter will present the research design. In it I will set out the methods used, which exploit recent technological developments. Included there is a description of the innovative application of new technologies I developed to aid observation.

3 Research Method

3.1 Introduction

In the previous chapter I discussed the difficulties of conducting effective research into individuals working in dangerous conditions, the main constraints being contextual, methodological and technological. In this chapter I will discuss the approach adopted to overcome these barriers.

I begin by explaining the development of equipment used to aid data collection. I then move to briefly outline the case study approach, then present the two focal cases and explain why they were chosen as appropriate for this inquiry. I also provide a broad outline of the methods of data collection and analysis, including a discussion of innovative use of technology whereby physiological and geographical data and video images are simultaneously gathered. This ability to synchronise visual data with physiological responses to the situation and geographical location provides not only the means of accurately tying physiological responses to the overall work situation, but also forms the basis for reflection on the part of both the researcher and the subjects.

3.2 Research aims

As pointed out in Chapter One, the aim of this research is to explore the efficacy of new technologies to study work in dangerous environments.

Associated aims are:

- To record, measure and understand the work (including physiological workload) of people engaged in dangerous occupations;
- To understand how hazards are identified and dealt with by individuals working in extreme conditions;
- To gain insight into dangerous work environments for the purpose of enhancing safety training for personnel working in dangerous situations;
- To explore the value of reflective interview as a tool to establish ways decisions about possible courses of action are made.

3.3 Data recording ensemble and analysis development: 2004 - 2008

The unique combination of data collection equipment used in this research took some years to develop through a process of trial and error because a 'commercial off the shelf' data collection ensemble for dangerous work did not exist. I had been measuring work in logging operations for some years (e.g. Parker, Bentley & Ashby, 2002; Parker & Kirk, 1993; Parker, Sullman, Kirk & Ford, 1999) and was aware that my presence disrupted the normal flow of logging activities. I knew this because I had been employed as a professional tree faller and logger for 18 months in 1984 and 1985. Whenever an observer came on site we had to alter our work to ensure their safety.

Inspired by the wearable ensembles of data collection equipment being developed by the United States Army Warfighter Physiological Status Monitoring program (Buller, Hoyt, Ames, Latzka & Freund, 2005) and the Massachusetts Institute of Technology Media Lab (http://www.media.mit.edu/resenv/) I developed a wearable ensemble of sensors to measure logging work. The first prototype, in 2004, comprised a miniature security video camera recording to a portable MPEG2 magnetic tape 'camcorder' carried in a backpack with a 'gel-cell' to power the camera (Figure 3.1). Total weight of the equipment was almost 5 kg and too cumbersome for unobtrusive use. But the components of the system were readily available and simple to fit together. The system was first used to collect data with a very experienced tree faller who had an interest in new technology (Figure 3.2). Care was taken to discuss with him all the possible risks of working with the added encumberence of the ensemble. He made suggestions, such using Velcro for quick release, which were incorporated in later versions of the ensemble.

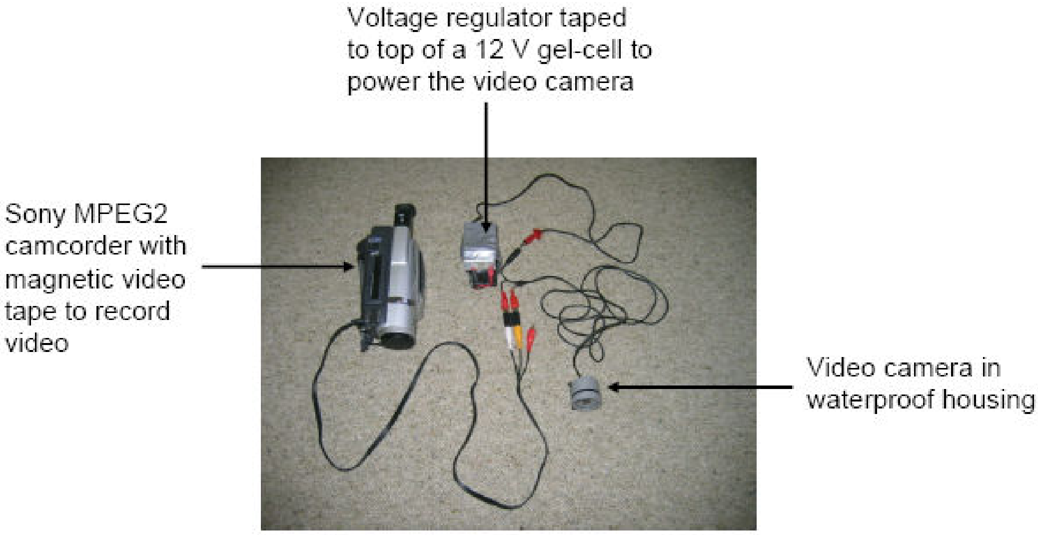

Figure 3.1 - First wearable video recorder system constructed in 2004.

Figure 3.2 - First use of the early prototype data collection ensemble comprising numerous cables, batteries and recorders to record tree felling.

The second wearable video recording ensemble comprised a digital video recorder developed for indoor use which was modified to run on a 5 volt battery (Figure 3.3). The video camera was a purpose built ‘bullet’ camera which was powered by it’s own battery. A container had to be developed which would hold the recorder and battery securely and prevent the fragile connectors coming loose (Figure 3.4). A colleague, David Riley of the United Kingdom Health and Safety Executive developed a cardboard, duct tape and cable tied container which could fold over enclose the equipment in a protective enclosure (Figure 3.5).

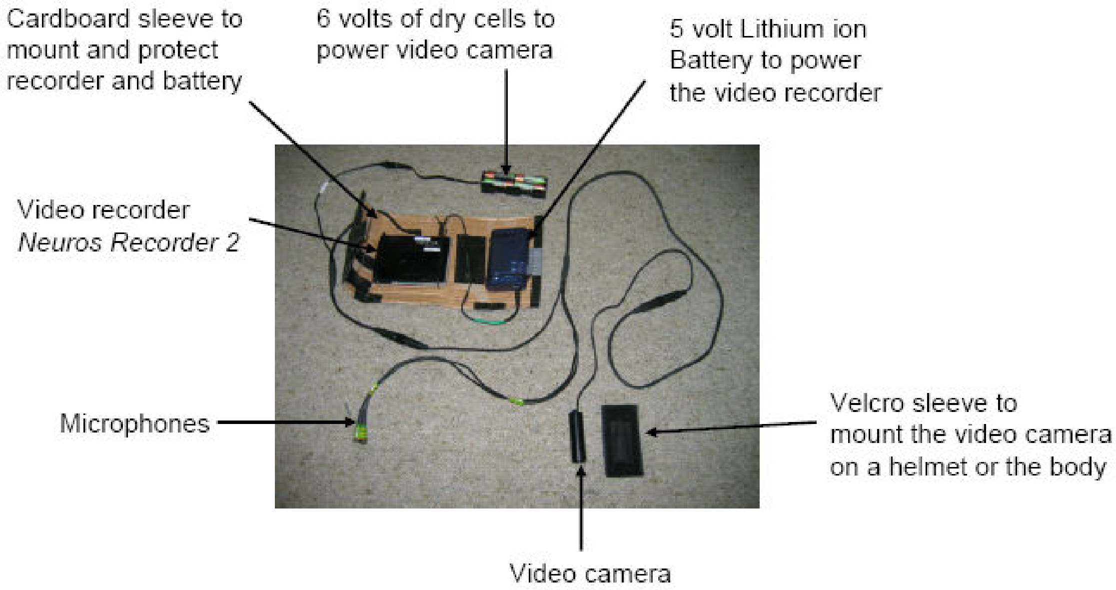

Figure 3.3 - Second wearable video recorder system constructed in 2006 and used at Fire 1.

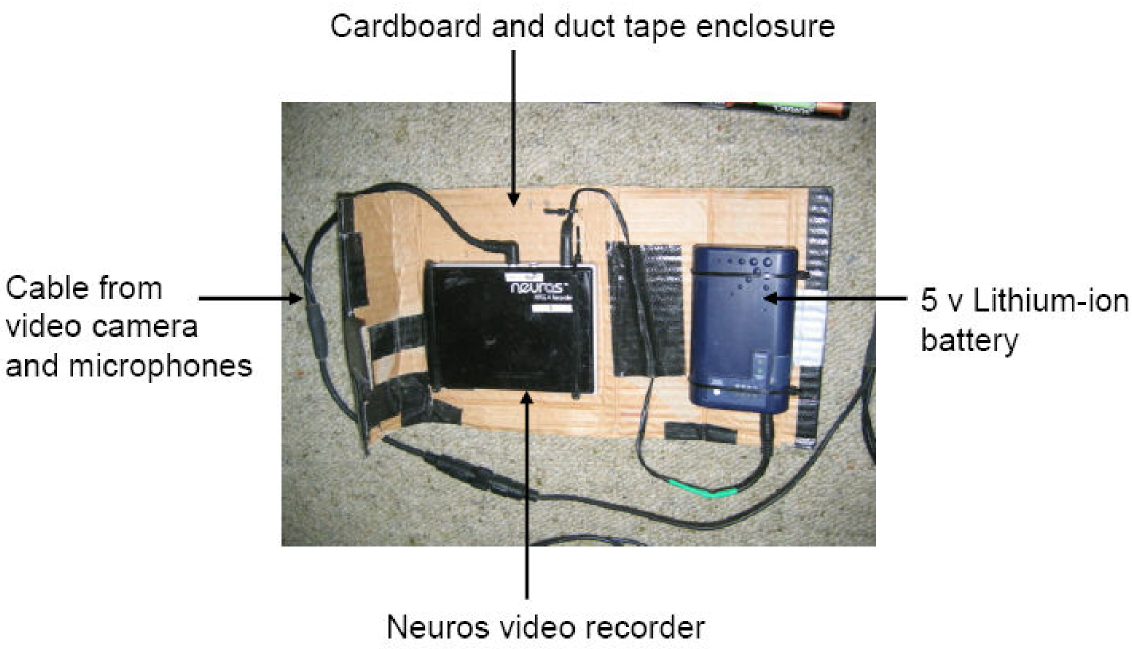

Figure 3.4 - Detail of the video recorder and battery layout in the cardboard enclosure.

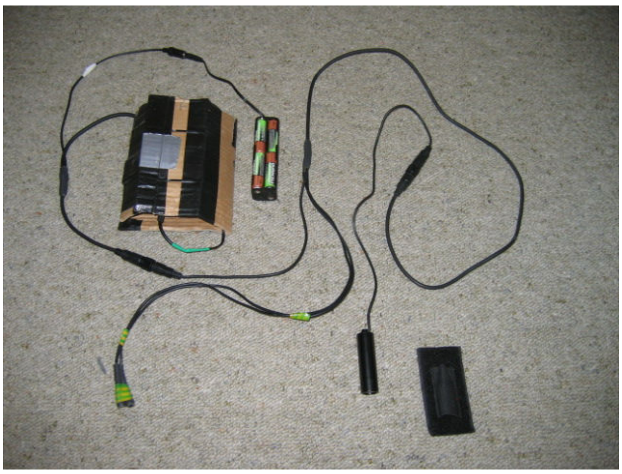

Figure 3.5 - Cardboard enclosure folded to protect the battery, cables and video recorder.

The third wearable video recording ensemble comprised a commercial purpose built digital video recorder (Lawmate PV500) with an internal battery which could power both the recorder and video camera (Figure 3.6). This ensemble is considerably smaller and lighter than earlier ensemble and has an integral video screen which allows the user to check the video camera is functioning.

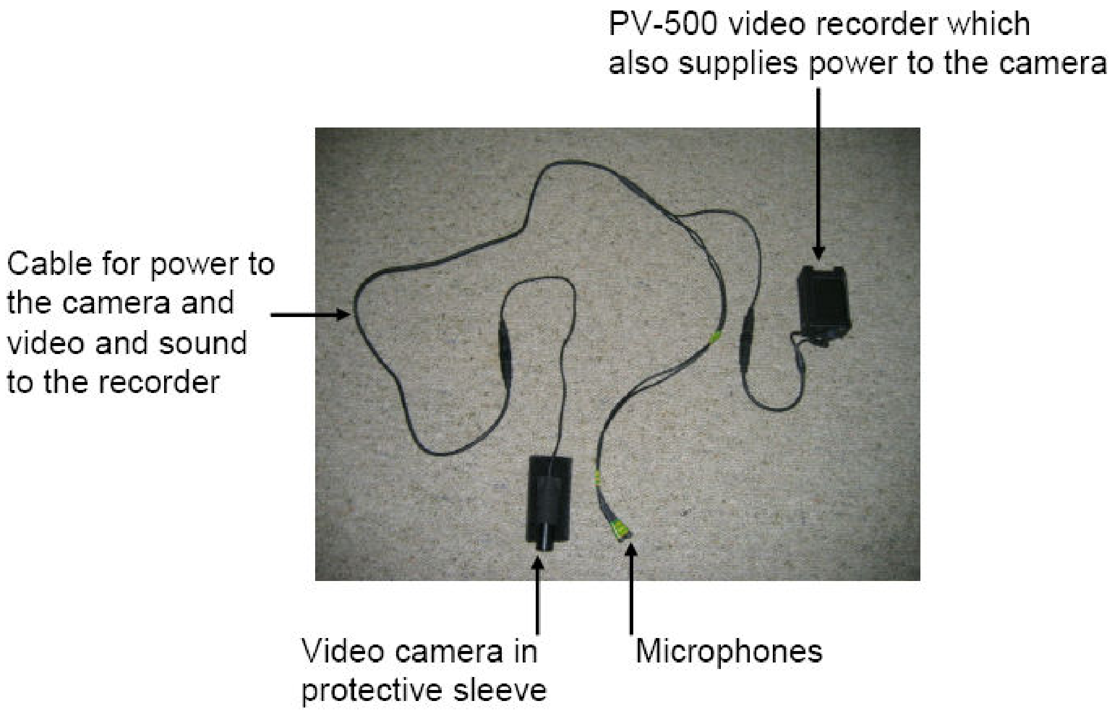

Figure 3.6 - Third wearable video recorder system using a Lawmate PV500 digital video recorder which also powered the video camera.

Further trials of different cameras, video software, video recorders and power supplies resulted in the ensembles used to collect the data reported in Chapters Four, Five & Six. All prototype data collection ensembles were tested in a simple repeatable trial – I would wear the prototype ensembles while mowing the lawn with a petrol powered lawn mower at home, ensuring I collected data sets with a broad range of heart rates, moving video images of manual work, loud noise to test microphones and simulate chainsaw noise, a highly repeatable GPS track and a very electromagnetically 'noisy' environment to test electrical interference. Using the data collected from these early trials, I was able to develop methods to synchronise data streams and format them for input to the analysis software *Noldus Observer XT*. There was considerable trial and error needed to synchronise and format data streams from the many types of data collection devices I trialled.

3.4 The case study method

The case study method adopted for this study enables me to address the research aims within two "bounded systems" (Creswell, 1998, p.61). These systems consist of two work groups, each representing a different industry context.

While previously regarded as scientifically suspect, by the 1970s and 80s the case study had become popular as a form of research, "both in its own right and as an element in large-scale research designs" (Simons, 1996, p. 225).

One of the most well-known proponents is Yin (1994) whose widely accepted definition of case study suggests that it is an "empirical inquiry that investigates a contemporary phenomenon within its real-life context; when the boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used" (Yin, 1994, p. 3). Although some would beg to differ (e.g. Stake, 1995), according to Yin, the purpose of the case study is analytic generalisation. He claims that the same criteria common to all research methods are relevant to the case study method. More explicitly, these criteria are construct validity, internal validity, external validity and reliability (Yin, 1994, pp. 36-38). Thus Yin's concern is with case study as a methodological choice which parallels quantitative experimental research.

The case study is also characterised by the capacity for it to embrace multiple research methods, techniques and sources of information (Creswell, 1998; Creswell & Plano Clark, 2007). This feature serves to reinforce the value of the case study and its logical choice for the current research, in which I employ a mixed method approach collecting both quantitative and qualitative data (Creswell & Plano Clark, 2007; Teddlie & Tashakkori, 2003). The combining of diverse methods within the design of a single case serves to strengthen the study and add substance to the conclusions (Creswell & Plano Clark, 2007).

In this research, a sequential explanatory strategy is employed whereby the first phase consists of data collection involving video capture (tree felling and fire fighting), heart rate measurement (fire fighting) and GPS tracking (fire fighting). Analysis of the phase one data is mainly quantitative. The second, qualitative, phase of the study consists of reflective interview data collection and analysis. The data from these phases are integrated during the interpretation phase of the study. Overall, the purpose of this mixed methods approach is to use "qualitative results to assist in explaining, interpreting and further examining the findings of the quantitative study" (Creswell, 2003, p. 215).

3.5 Selection of the focal organisations

As mentioned earlier, the rural fire sector and the forest industry were chosen as the focus of the two case studies as both have workforces that are sporadically, and sometimes routinely, exposed to dangerous conditions at work. There were, however, a number of other circumstances that underpinned the choice of participant organisations. These circumstances included my own familiarity with forestry, as a worker who was seriously injured and, recently, as a researcher. The New Zealand Rural Fire Authority (NZRFA), the New Zealand forest industry and the New Zealand Accident Compensation Corporation (ACC) had all expressed an interest in safety and productivity of workers in dangerous tasks. In my role as a professional ergonomics researcher, I was commissioned by ACC to carry out a study of the differences in tree felling technique, hazard identification strategies and productivity of experienced and novice tree fallers. I was also engaged by the New Zealand Fire Service Commission to attempt to measure the physiological workload and fire suppression productivity of rural fire fighters at real fires.

3.6 Sample selection

Broadly, the research population of the study consisted of tree fallers and rural fire fighters. For convenience, the workers were selected from the Bay of Plenty region of the North Island of New Zealand where there are many forests and easy access to logging and fire crews.

Tree fallers for the study were all full time professional loggers working for various logging contractors in the Bay of Plenty region. The study participants were selected by their availability and level of experience: five tree fallers had more than five years felling experience and five had less than one year's experience.

One fire fighter participant was a Department of Conservation (DOC) employee and the other was a Rotorua District Council employee who, as part of their responsibilities, were engaged with rural fire fighting activities. Because of the unpredictability of their occupation and their fluid work groups, selection of fire fighters was different to that of tree fallers. Fire fighter participant selection was determined on the basis of the fires they were attending. A willing fire fighter who was engaged in front line fire suppression operations was selected and the data collection ensemble fitted to them. After detailed consultation with felling and fire managers I was confident that the tree fallers and fire fighters participating in the studies were engaged in tasks that were representative of those occupations.

3.7 Data collection

The fieldwork for this study occurred over the years 2007 to 2008 and, as previously mentioned, took place in two phases: phase one related to the collection of mainly quantitative data in the field; phase two consisted of qualitative interviews that required participants to reflect on the recorded field experiences.

Given the exploratory nature of the research and the realities of carrying out field studies the tree fallers used in the study were chosen because of their experience and availability. Similarly the infrequent occurrence of fires meant that the selection of fires and fire fighters was, of necessity, opportunistic.

Analysis of previous ergonomics research studies and my own experience revealed that past attempts have been made to observe and collect data from tree fallers working under normal operational conditions (e.g. Parker & Kirk, 1993). However the very presence of an observer introduced additional hazards for the tree faller and risk to the observer from falling trees and debris. Data that were collected from these studies was never considered a true record of work compared with the situation where no observer was present.

In contrast to the research attention directed to forestry workers, when this work began, there was no published research available that provided work information or physiological data from rural fire fighters engaged in suppression tasks at active fires. Studies had estimated workload (e.g. Heil, 2004) and productivity (e.g. Murphy & Quintilio, 1979; Murphy, Quintilio & Woodard, 1989) from simulated rural fires and some had asked the fire fighters to estimate workload and/or productivity from memory (e.g. Schmidt & Rinehart, 1982; McCarthy, Tolhurst & Wouters, 2003). However, to my knowledge, no published English language studies of rural fire fighters had been carried out at real rural fires, with no back up if the fire got out of control and with no researchers in the vicinity to alter fire fighter work activity.

The wearable camera and sensor technology developed and applied to phase one of this study serves to somewhat address shortcomings associated with previous studies. In particular, the technology provided a means to collect more accurate and unbiased data within realistic work environments. Further, the techniques employed were consistent with Kirwan & Ainsworth's (1992) lowest level of researcher intrusion. Kirwan and Ainsworth identify three levels of intrusion by observers on the observed person. The video observation of work, as used in the current study, can be described in the category 'observer unobserved', when the observer removes themselves from the workplace. This is distinguished from the second level, 'observer observed' where the observer is located at the operation and the personnel being observed are aware of their presence – an approach used when additional information has to be recorded by the observer. The greatest level of intrusion, and the furthest from the position adopted in the current study, is ‘observer participant’, where the observer takes part in the tasks alongside those being observed. Thus, the quantitative component of the study was addressed through remote data collection in the field, of workers in dangerous occupations.

3.7.1 Phase one : Quantitative data collection

Primary data sources for phase one of the study were miniature body worn video cameras. The fire fighting case utilized two additional data sources – heart-rate monitoring and GPS tracking – enabling me to more comprehensively monitor participants’ activities in work conditions that required them to be highly reactive to events, and, due to the nature of fire fighting, often highly mobile. Tree fallers generally work within a small area because they are felling all the trees in that area and work alone. Video was sufficient to collect rich data for quantitative analysis. In contrast rural fire fighters frequently change location, work with others and undertake a range of varied tasks so video recording was supplemented with heart rate monitoring and GPS location monitoring.

Video cameras

Video cameras and their associated recording units are now small enough to be unobtrusively attached to body parts or to clothing. Wearable video provides a new perspective on the work people are doing and video cameras have been attached to various parts of the human body (e.g. Mayol-Cuevas, Tordoff & Murray, 2009; Omodei & McLennan, 1994).

Heart rate monitor

My study also incorporated more widely used and conventional data collection methods. Most immediately, heart rate monitors have been used in numerous studies of work (e.g. Louhevaara & Kilbom, 2005). A heart rate sensor strap was fastened around the chest against the skin and a signal sent to a recorder mounted on a shoulder strap. Heart rate was stored in a data file which could subsequently be displayed as a line graph or analysed for more detail.

GPS recorder

A GPS recorder was used to track the movements of the fire fighters in the field. The GPS device receives signals from satellites stationed above the Earth and calculates the location of the device to with 5 to 10 m. During the study, the device recorded the location of the wearer every 10 seconds and the path and speed of the wearer could be replayed on a map. GPS recorders have been used in animal tracking studies for some years (e.g. Bishop & Last, 1995) but have only recently been utilised in tracking the movement of people for scientific study. Fenske, (2005) used GPS tracking to record the location of people in relation to agricultural spray drift and Seto, Knapp, Zhong, & Yang (2007) used GPS tracking to estimate human water-contact patterns associated with the disease schistosmiasis.

The combination of video and GPS provides geographical context to the video data and again scientists investigating animals are at the forefront of this combination of technologies (Kooyman, 2007). I am not aware of any human studies in work situations that combine GPS with video. But the potential for studying work is great. For example video can show a person is walking but GPS information can show they are walking at 3 km/hr on a slope of 20°. This is invaluable data which provides a greater depth of understanding of work but investigators should be aware of the limitations of GPS accuracy detailed by Hurford (2009).

Data collection

Thus, the data for tree felling consisted of video files from two cameras and for fire fighting consisted of a video file from one camera, heart rate records and GPS records collected simultaneously while the operators worked. First, the data collection ensemble was activated and the tree faller or fire fighter went to work. I then moved off site to a safe location and data was collected until the batteries were exhausted which was approximately two hours. In tree felling studies the data collection ensemble was retrieved when the tree fallers stopped work for a meal break. In fire fighting studies the data collection ensemble was retrieved after the fire was extinguished.

3.7.2 Phase two : Qualitative data collection

The qualitative component of the study consisted of a semi-structured interview (Singleton and Straits, 2010) comprised of several open-ended questions, which encouraged the participants to use their own words to describe their experiences and perceptions of hazards in tree felling and hazards, workload and productivity in rural fire fighting. The methodological approach applied to analyse the qualitative data was phenomenological, seeking to understand the experiences of individuals and the meaning they make of that experience related to the phenomenon under investigation (Creswell, 2009; Moustakas, 1994). In this study the phenomenon under investigation is the performance of a potentially dangerous task – tree felling or rural fire fighting. The qualitative study aims to gain new insights into the 'lived experience' of the tree fallers and fire fighters and enhance the understandings obtained in the previous quantitative stage of the research. The interviews aimed at providing a deeper level of understanding of the quantitative results and to evaluate, confirm, complement and/or better understand the quantitative findings (Kvale, 1996).

While this phase depended on the reflections of participants on their own work (fire fighting) or others work (tree felling), phase two also incorporated the use of computer technology. The participant viewed video and audio from their work (fire) or another's work (felling) and commented on what they saw. The interviews were audio recorded onto a concurrently playing video file of the helmet camera recording using the computer software program *Camtasia*. This ensured that participants' responses could be heard and their corresponding helmet mounted camera video images be seen on the screen. Additionally, I was able to revisit the video data to aid the analysis process. Verbatim transcriptions of the participants' comments were created and used in the analysis.

3.8 Data analysis

3.8.1 Data analysis: Phase one

A coding scheme was set up in the observational data manipulation software *Observer XT*. Elements for the categories were derived from observation of logging operations and discussion with forest workers. Next, the video files recorded from the helmet and shoulder mounted video cameras (tree fallers) or single helmet mounted video camera (fire fighters) were imported into *Observer XT.* For tree fallers the two video files were synchronised in *Observer XT*. For fire fighters the corresponding heart rate data file from the heart rate monitor was imported and synchronised with the video data. Coding of the video files into an event log file was performed using the *Observer XT* software. Playback speed and direction of the video file could be controlled with the *Observer XT* interface enabling repeated views of an event to ensure accurate coding. Once the whole video file was coded, the codes were saved in a synchronised event log. Because video files took up a large amount of computer memory (1 Gb/hour) they were analysed in files one hour long. A log file containing a sequential list of tasks performed by the fire fighters and their time of occurrence was generated from *Observer XT* and converted to a comma separated value (CSV) file. For fire fighter data the CSV file was imported to *MicroSoft Excel* and the tasks were matched with the heart rate file and subsequently analysed in Minitab 13.1. Tree faller video data were analysed to determine, for example, the time taken to perform various tree felling tasks and the number of trees felled per hour.

3.8.2 Data analysis: Phase two

During this stage of the analysis, I remained mindful that personal interviews are vulnerable to self-report bias (Maxwell, 1996). In spite of this shortcoming (one common to all interview situations) the rich, personalised accounts offered a valuable, alternative, complementary lens through which to consider the work phenomena under investigation.

3.9 Ethical issues

Tree fallers and fire fighters who took part in the study signed an ethics consent form acknowledging that they understood their own rights, the reasons behind data collection, and details of their own role as participants. As part of the consent process the participating tree fallers and fire fighters were told they could withdraw from the study at any time and remove the data recording ensemble at any time without giving a reason.

Additionally, special care was taken in attaching data recording devices to the helmets and clothing of tree fallers and fire fighters to ensure no additional hazards were introduced to their work environment. For example, all wires were secured by tape and cameras were attached to helmets and shoulders by Velcro which would allow the camera to pull free if it was snagged on under growth or equipment.

In phase two, participants were similarly subject to the informed consent process.

3.10 Conclusion

In the years 2007 and 2008 tree fallers and rural fire fighters were fitted with data collection equipment in order to obtain insights into their work activity under extreme circumstances. These two groups formed the core of the two case studies that will be explored in Chapters Four and Five, and those chapters will further elaborate upon the broad methodological overview provided in this chapter. Similarly, this chapter has provided an initial insight into the qualitative dimension of this study, which will be further developed in Chapter Six.

The next chapter presents a comprehensive case study of tree fallers at work.

4 Tree Felling

4.1 Introduction

As discussed in earlier chapters, it is often difficult to collect useful data from real work situations without disturbing the normal work flow. Additionally, under dangerous conditions it can be almost impossible. This is the case with forest workers felling trees with chainsaws. By adopting unobtrusive observation methods as described in this research, that take advantage of recent technological developments, the industry safety imperatives can be addressed.

In this chapter, I will review injury statistics in the logging industry and discuss the various research approaches that aimed at understanding possible causes for the accident occurrences and making the environment safer. The chapter concludes with a field study using unobtrusive observation methods whose aims were:

- To explore the efficacy of new technology to study the work of tree fallers
- To identify successful hazard identification and mitigation strategies
- To use the information gathered to develop appropriate training material.

4.2 Background

4.2.1 Tree felling: A dangerous work environment

Logging comprises three main activity areas:

- Felling (cutting the tree down);
- Breaking out (mechanically moving the stem from the stump to a cleared area to which heavy transport vehicles have road access, known as the Landing or Skid Site);
- Skid site / Landing work (the cutting of the stems into logs of certain length according to grade and the specifications required by the mills and other markets).

Tree felling is a demanding and potentially dangerous occupation (Myers & Fosbroke, 1994; Parker, Bentley & Ashby, 2002; Peters, 1991). Chainsaw users are on foot and unprotected from heavy debris which can fall from trees. Traditionally, the detailed study of tree felling required the researcher to follow the faller while he was working, recording the faller's activities and trying to remain in a safe position without getting hit by falling debris, the chainsaw or falling trees. Often the researcher, to be safe, retreated some distance away from the faller which resulted in a poor viewing position and degraded research data. Advances in technology mean that in cases such as these, unobtrusive data collection methods can be employed.

I wished to observe tree felling activities to establish what hazards were encountered and the work practices of experienced and novice tree fallers. To achieve this objective required a new method of unobtrusive data collection to be developed. This method was described in Chapter Three. In Chapter Three I also explained the reasons underlining the choice of the logging industry for the study. Here I will further elaborate by focusing on the injuries associated with this industry.

4.2.2 Factors associated with injuries and deaths in New Zealand felling

The highest logging industry injury incidences, in New Zealand, are reported for skid work (36%) (Parker & Bentley, 2000) followed by felling (20-30%) (Bentley, Parker & Ashby, 2005). The following discussion focuses on the felling activity.

In 2006, six professional loggers were killed in felling accidents. All of these logger casualties were trained, held industry qualifications, and would be expected to recognise hazards. Yet, recent publications in 2004 & 2005 by the Forest Industries Training organisation (FITEC) have concluded that the required standards for felling safety are not being met, despite the training efforts made to date. The cost of the non-compliance with industry standards is put at $7.6million per year to industry and ACC (FITEC, 2005, p. 4).

4.2.3 Injuries to tree fallers: Surveillance data

The most thorough analysis available is found in a series of studies carried out using data collected by the New Zealand (logging) Accident Reporting Scheme (ARS) between 1984 and 2003. The ARS was run by the Logging Industry Research Association (LIRA) until 1999 and subsequently the Centre for Human Factors and Ergonomics (COHFE) based at the Crown Research Institute, Scion. It maintained an accident reporting scheme for the forestry industry containing 20 years of data on logging injuries, including details of injuries sustained, days of work lost and near-miss events. Reporting was voluntary but the 16 largest forestry companies participated and accounted for an estimated 60–80% of the forestry workforce. There was also at this time, an exposures database that recorded total hours of work per month for the reporting companies, providing denominator data for analysis of injury rates.

Data for injuries sustained during felling operations were analysed. A detailed breakdown of the felling task – hierarchical task analysis (HTA) was performed (see Figure 4.1) and hazards associated with each task component were considered. The findings were published internationally (Bentley et al., 2002) and also disseminated through industry reports a number of which are available online at www.cohfe.co.nz .

Approximately one-half of the reported injuries involved lost time, with the rest being minor injuries (less than one complete day's absence from work). In total, 351 felling lost time injuries (LTI) and felling minor injuries were reported to the logging ARS during January 1996 to December 2000, accounting for 23% of all logging injuries reported to the ARS over the same period. The 173 lost time injuries reported to the ARS resulted in 2227 lost workdays. The average lost time was 13.6 days, indicating that felling injuries tended to be serious. These figures did not account for the considerable time lost due to minor injuries where less than one full day's absence was recorded.

Between January 2001 and December 2003 there were more reports – 337 felling LTI from a total of 1308 injuries to professional loggers – but fewer lacerations. Chainsaw injuries dropped from 122 in 1985 to 20 in 2003. This has been attributed to the coordinated industry effort to improve practices and the use of effective personal protective equipment (PPE) (Parker & Ashby, 2005). The proportion of injuries unrelated to the actual cutting down of the trees therefore has increased, though the authors also note that the injury rate for inexperienced chainsaw users remained greater than that of experienced users.

The large majority of felling injuries involved the faller being struck by an object, with 'struck by' injuries accounting for 84% of lost days. LTI had an average of 15.6 days lost per injury (Ashby, Bentley & Parker, 2002). Sailers (broken or dead branches that can fall unexpectedly from standing trees) are the most common agents of this type.

For those carrying out the falling, the risks are not restricted to the act of cutting down the tree, which has traditionally been the focus of safety efforts in the industry in New Zealand. Roughly a half of all injuries for fallers happen while they are doing other things, notably walking (Bentley et al., 2005), which accounted for 21% of lost days, averaging 13.9 days (Ashby, Bentley & Parker, 2002).

Due to the dynamic nature of the forest environment workers can be struck from above at any time while moving or working amongst the trees – not only while actively disturbing the canopy (Bentley et al., 2005). Around half of struck-by incidents with fallers occur in this way.

Sloped, slippery underfoot conditions and obstacles such as rocks and logs present potential hazards that must be considered by the faller in their hazard assessments – slip, trip and fall (STF) events – accounted for 20% of the injuries (Ashby, Bentley & Parker, 2002). There was a late morning peak of injuries, but this peak was greater than that observed for all types of logging injuries; suggesting felling workers undertaking heavy work may be particularly susceptible to fatigue-related injury (Ashby, Bentley & Parker, 2002).

A disproportionately high number of injuries were reported by inexperienced loggers in their first few months of logging. Inadequate decision-making skills were identified as a possible problem for these inexperienced fallers (Ashby, Bentley & Parker, 2002). However, there are no reliable data on level of experience of fallers from which to deduce exposure and incidence by experience category (Bentley et al., 2005). Twenty eight percent of injuries were to the head and face area, although eye injuries were minor – associated with an average of just eight days per incident – probably due to the use of safety helmets, visors and protective eyewear. This is consistent with the reports of debris (sailers) falling from above being a common problem.

4.2.4 Improving hazard identification: Approaches, models and measurement

Task description

The task of harvesting is increasingly being carried out by machines which both cut down and delimb the stem. However, the steeper and more difficult country, which fallers have also rated as the most hazardous, will continue to be worked in New Zealand by a person using a chainsaw - the ‘motor manual’ method (Bentley et al., 2005).

Internationally, logging mechanisation has reportedly had different outcomes, most notably in Finland where the forestry worker population halved during the early 1990s due to mechanisation, and so did the accident frequency rate (Salminen, Klen & Ojanen, 1999). It is not discussed what other changes occurred at this time that may have contributed to bringing the accident rate down to levels comparable to other industries in Finland. However terrain may be a factor: the country is largely flat, lacking the steep gullied terrain that is most hazardous for motor-manual logging and the least suitable for mechanised harvesting. Slappendel, Laird, Kawachi, Marshall and Cryer (1993) note that a number of international studies of injury rates from maintenance tasks with the introduced machinery, suggest that they are on a par with those of manual felling. The literature as a whole therefore indicates that mechanisation is not a complete solution to logging injuries.

A Hierarchical Task Analysis of the motor-manual felling task derived from a task safety analysis study in New Zealand is shown in Figure 4.1. The diagram is redrawn from Bentley et al. (2005) and shows the number of hazard identification tasks which occur before, during and after a tree is felled.

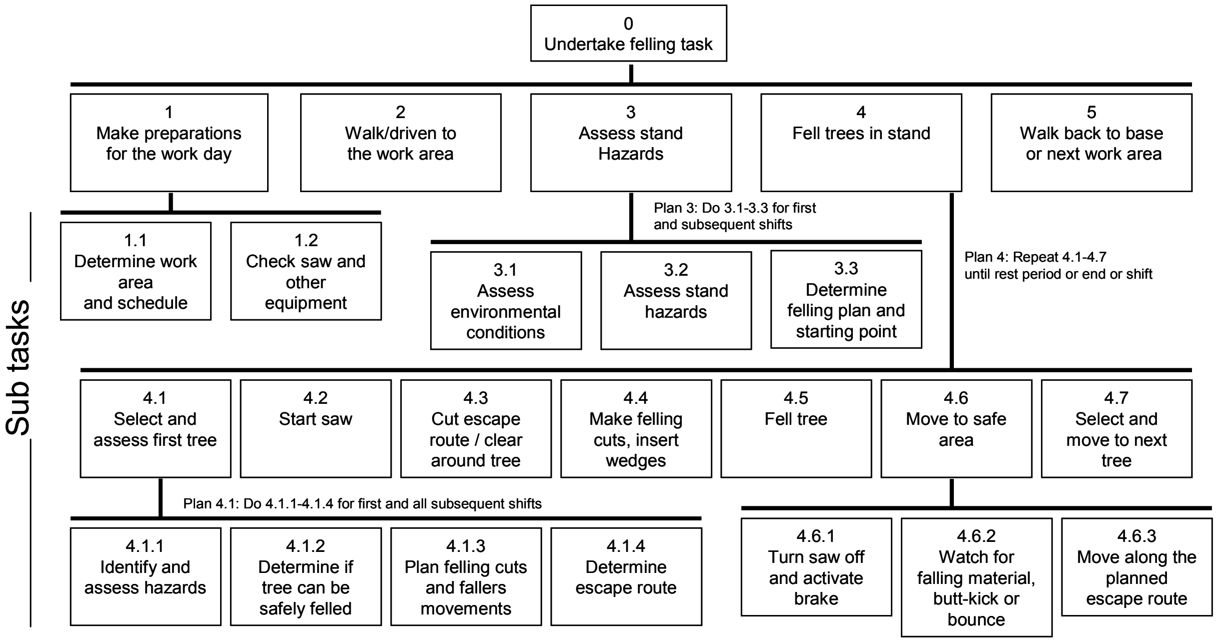

Figure 4.1- Hierarchical Task Analysis of the felling task (Bentley et al., 2005).

The various cognitive and physical tasks that confront a New Zealand tree faller were identified by Bentley et al. (2005) and are presented in Figure 4.1. Tree falling is a dangerous task and poor assessment and planning of tree felling operation can result in death. For example "Select and assess first tree" (Figure 4.1, Sub task 4.1) the faller must "Identify and assess hazards " (Sub task 4.1.1) which requires the ability to actually recognise the hazards and their potential consequences. The faller then must "Determine if tree can be safely felled" (Sub task 4.1.2) which requires thought processes to weigh up the various factors which will influence the fall of the tree once it is cut. The faller may take some time to determine the natural lean of the tree and the distribution of weight of limbs on the stem to "calculate" if the tree will fall in the required direction. He will also note the presence of other trees nearby which may impede the fall of the tree and the possible consequences when or if the tree strikes adjacent trees. He will then plan his felling cuts and stance (Sub task 4.1.3). For example he may only be able to position his chainsaw on one side of the tree because of ground slope or obstructions such as rocky outcrops. This will then reduce the options he has for escape (Sub task 4.1.4) from the tree when it begins to fall. He will weigh up whether he needs to spend time cutting an escape route through the undergrowth or be able to escape from the tree using available breaks in the undergrowth. The tree faller works in a hazardous environment and is cognitively engaged at all times to use his knowledge of the environment and motion of falling trees to anticipate hazards and plan to avoid them and maintain a productive pace of work. He is making decisions, from the available information, for every tree felled.

Risk types – the literature

Table 4.1 shows a list of the forestry-specific ergonomics literature since 1980 on the risk factors most relevant to inexperienced fallers. The methodological orientation of research studies reflected in the table is notable for the absence of systems-approach, or holistic enquiry. Instead, the literature focuses predominantly on the presence or perceived affects of individual factors in isolation.

Table 4.1- Forestry-specific ergonomics literature since 1980.

Risk type	References
Perception and decision making	Salminen, Klen & Ojanen, 1999; Tapp, Gaskin & Wallace, 1990; Klen, 1984; Östberg, 1980.
Skill and technique	Gaskin, 1990; Gaskin, 1989; Crowe, 1985; Swedforest, 1980
Experience, Education and training	Bell, 2004; Bell & Grushecky, 2006; Salminen et al., 1999; Kawachi, Marshall, Cryer, Wright, Slappendel & Laird 1994; Klen, 1988; Holman et al., 1987; Crowe, 1985; Helmkamp, Bell, Lundstrom, Ramprasad & Haque, 2004; Mujuru, Helmkamp, Mutambudzi, Hu & Bell, 2009.
Age	Crowe, 1986; ILO, 1981; Kawachi et al., 1994.

Causation models relevant to felling

The single published attempt to establish an interactive model of factors in felling incidents was by Slappendel (1995). An earlier New Zealand review by Slappendel et al. (1993) identified a wide range of factors in injury and fatality incidents in forestry. The model shown in Figure 4.2 illustrates this. A critical feature of this model in comparison to earlier more linear conceptualisations, such Heinrich's Domino Theory, is that the various factors interact in a dynamic manner (Slappendel, 1995).

According to this model, the potential for direct physical risk factors (such as a sailer falling) contributing to an injury event would be moderated by other factors, interacting to produce an overall event context. For example social, organisational and interpersonal matters on the day such as role conflict and ambiguity in commands will have a bearing on concentration and awareness of changes occurring in the natural environment around the faller (Sullman & Kirk, 1998).

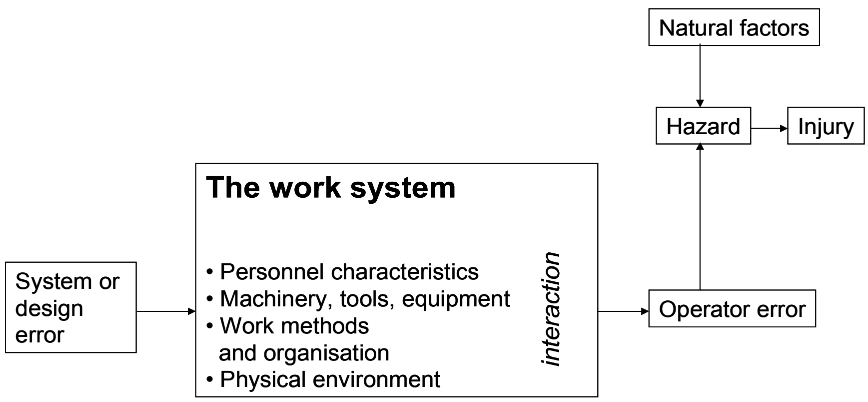

Figure 4.2 – Model of injury causation for forestry work (adapted from Slappendel, 1995, p. 241).

Slappendel's model has been well received as credible and intuitively popular within the industry – acknowledging as it does the unlimited range of thoughts and concerns that can impact upon a person's decision making at crucial times. The researcher bemoans the fact, however, that the investigation methods used in New Zealand industry generally, fail to reflect such an holistic approach (Slappendel, 1995). The systems approach disappears in the field, as the hard copy forms used for collecting data do not facilitate it, or even allow it in many cases. There is simply not the space, nor the coding structure to accommodate it.

Traditional field methods therefore present a barrier to harvesting the full benefits from the theoretical advances made. But the unobtrusive observation methods used in this research enabled me to record the activities of the tree fallers. Further, by using the verbal protocol method described in Chapter Six, I was able to obtain a more comprehensive picture of the activities and gain a greater understanding of the faller's work methods.

Inexperience and injury

Much of the faller's task involves assessments of conditions related to the environment, as well as the condition of the trees to be felled, and the likely risks that each tree and stand of trees presents to the faller. Where judgements are poor, the potential for injury is increased.

Internationally, studies have been reasonably consistent since 1980 in reporting higher incidence rates of injury for people relatively new to the job (Bell & Grushecky, 2006; Bentley et al., 2005; Ondrus, 1984). An exception is a study in Finland (Salminen, Klen & Ojanen, 1999) which found no relationship between experience and accident history. They suggest that this is explained, at least in part, by the practice of recruiting young men from farms where they will have learned the basics from their fathers in the forest during childhood so are not really inexperienced. In New Zealand, reports were mixed in the 1980s, with Kawachi et al. (1994) finding those in their first year in the forest to have lower injury incidence than between years one to three. Taking into account his and other reports of the period (Gaskin, 1989), and in particular more sensitive data drawn from the Accident Reporting Scheme (ARS) (Bentley et al., 2002), the picture clearly emerges of the first four years in logging work still producing a disproportionate number of incidents.

Between 1996 and 2000, 44% of all minor reported felling injuries on the ARS database were to workers in their first six months in the job (Bentley et al., 2005). This group also accounted for 23% of all lost time injuries. The reason for this however does not appear to be as simple as inadequacy of hazard awareness training.

Risk perception accuracy

The accuracy of risk perception by fallers in New Zealand remains unclear. Some studies both in New Zealand and overseas have indicated a high level of hazard awareness amongst fallers (Östberg, 1980; Tapp, Gaskin & Wallace, 1990). So, despite some apparent success in educating workers about hazards through various training initiatives (Hide & Tappin, 2007) the logging injury rates remain consistently high internationally.

Transference of learning to the operational setting

The ability of the individual to assess risk and identify mitigating actions when presented in isolation may not be sufficiently transferable to an operational setting, and may be increasingly compromised when workload or work pressures increase due to seasonal peaks (Bentley et al., 2005); fatigue (Bentley et al., 2005, p. 169); dehydration (Bates, Parker, Ashby & Bentley, 2001) or other factors. A number of researchers have reported peaks of incidents in the 9-11 am period (Kirk & Peterson, 1996; Ondrus, 1984; Parker et al., 2002) which suggest a common pattern of increased risk factor presence – just what that pattern is remains open to speculation.

For new recruits, Bentley et al. (2005) question the success of the processes used during the transitioning of industry entrants from pre-employment preparation through to ‘up-to-speed’ membership of a crew:

> “…inexperience is likely to be problematic for the felling task because of the importance of hazard assessment, cognition and decision making regarding the physical environment in which trees are felled and the condition of the trees themselves.” (Bentley et al., 2005, p. 172).

Information processing models

As early as 1993, mental workload of fallers was identified as a critical area of study (Slappendel et al., 1993) and according to Bentley et al. (2005), it remains under-researched. Figure 4.3 shown below (Bentley, 2009), illustrates a model used in slip, trip and fall research that has veracity in a forest setting. The model is similar in basic approach to that developed by Slappendel et al. (1995) and presented in Figure 4.2 in the range of interacting factors incorporated; but, it also includes several steps relating to perception and information processing (PIP) information.

The PIP questions posed are as follows:

- Perception. Does the person perceive the hazard or, for example, is their attention elsewhere?
- Cognition. Do they understand what they have seen to be a potential hazard that requires assimilation and a new course of action possibly determined, and do they know how to avoid the hazard?
- Decision to avoid. They know it's a potential hazard, but do they prioritise action to avoid it – or take a chance, to fulfil production targets, or get away from work on time?
- Ability to avoid. Having decided on a course of action can they implement it, do they have the wherewithal and time?

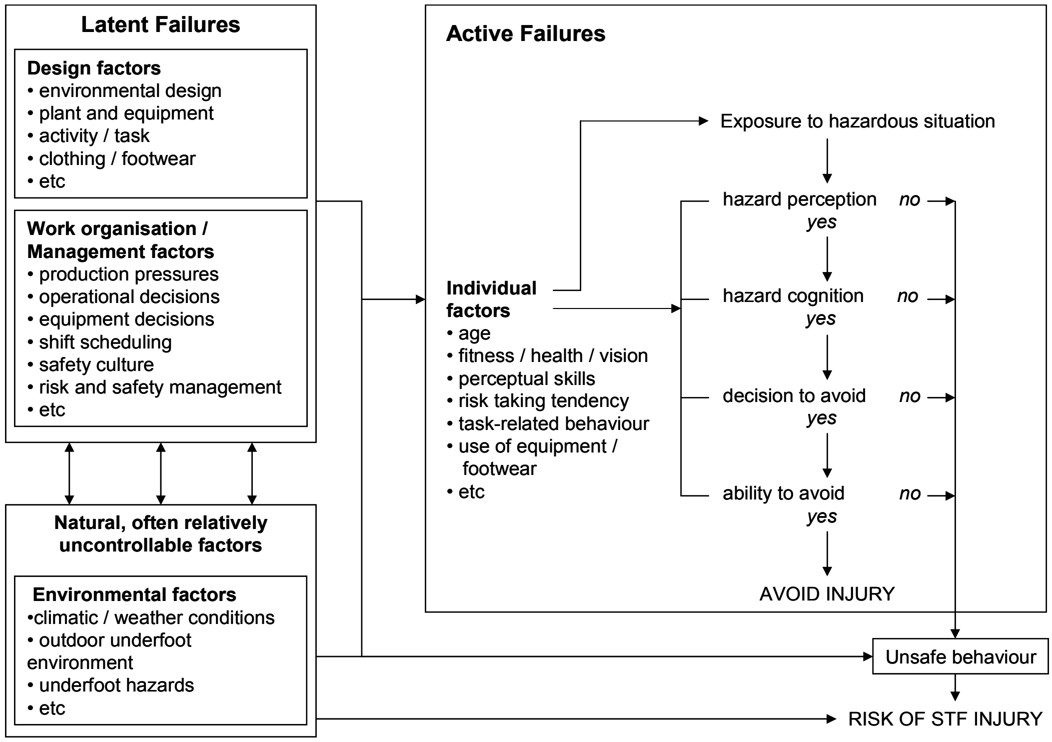

Figure 4.3 - An information processing model for slip, trip and fall analysis (Adapted from Bentley, 2009, p. 176).

A strength of this model is that it provides a framework for capturing data relating to goal conflicts, such as production demands versus established, but slower, safe practices.

Past studies indicated that, despite a high level of hazard awareness amongst populations of fallers in Sweden (Östberg, 1980) and New Zealand (Tapp et al., 1990), felling injury rates remained consistently high. The apparent successes in training workers about what to look out for, does not appear to be matched in these cases by the ability (or preparedness) to consistently apply this knowledge in the field.

In New Zealand, the reasons for the continuing rates of injury are suggested to include, “quality of initial training and assessment; complacency and sloppiness; absence of leadership; pressure; lack of responsibility, professionalism and self esteem among fallers; and crew culture and dynamics” (FITEC, 2004, p. 4). Recommendations from the aforementioned report, which reflected the views of the industry key stakeholder group in the study, include raising the recognition given and the prestige of those tree fallers that consistently maintain required standards, and improving the judgement and decision-making skills of fallers.

Design, Training and Procedures

Interventions have most commonly been confined within the categories of Design (equipment, clothing, machinery etc), Training (of fallers, not managers) and Procedures (e.g. adherence in working to checklists). This is shown in the table of remedial actions identified by the researchers Bentley et al. (2005, p. 170-171). The authors note "the importance of the quality of assessment of hazards and judgement in decisions regarding the felling of trees, whereas previous analyses and injury prevention work has tended to focus exclusively on behavioural and physical risk factors such as chainsaw use, PPE and the presence of tree hazards such as hang-ups and snags (Peters, 1991)." (Bentley et al., 2005, p. 174).

Beyond simple awareness – assimilating learning into practice

In their report of case studies investigating factors in injuries, Ashby and Parker (2003) conclude that interventions need to go beyond increasing awareness of hazards, and to influence more effectively the resultant actions that are taken. The majority of respondents in their studies explained that despite accurate identification of the hazards, they decided to respond in ways that led, as it turned out, to injury.

Klen (1988) argued that workers who have not had time to establish a complete mental working model need more time as they process each event separately. Similarly, more recently, Bentley et al. (2005) suggests that existing successes in educating the workforce need to be supported by new staff being granted more time to assimilate and apply their newly acquired theoretical knowledge in an operational setting before being required to operate at full production pace. In particular, time is needed in developing the practical ability to assess stands of trees as an interacting cluster in its environment before making falling decisions.

Ashby and Parker (2003) recommend closer supervision of inexperienced workers to ensure training is actually being put into practice – and most particularly to gauge how well they dealt with unusual conditions (less likely to have been covered in training) as they arose. Similar views were found in the earlier Massey University and COHFE study (Brook & Brook, 2000); initial training was sufficient, but the subsequent time and opportunity to assimilate the learning in conjunction with on-site experts over time, was not. Conflicts with productivity demands were again noted, as were ensuring that the decision-making of inexperienced fallers is not influenced by financial incentives, before they have acquired the skills to be able to assimilate this new factor safely.

Mental models

Mental models in an occupational ergonomics context have been defined as: "a representation of the systems with which (people) are working, and upon which they draw to assist their understanding and operation of those systems" (Wilson, 2001, p. 493).

Wilson advises that conceptual models produced in conjunction with a user will invariably be incomplete, unstable and often complex. He offers an example, suggesting that a mental modelling of a fault diagnosis in a system will vary each time the modelling is attempted for a different fault. Depending on the circumstances to be covered, the modelling could be of functional factors, spatial or causal relationships.

The mental model may be too complex to capture and portray using current methods. This may be increasingly the case as experience builds and the tree faller amasses ever more subtle understanding of the behaviour of the elements of their environment. The abilities drawn upon in predicting the way that a stand of trees will move, twist, shift weight and break as felling proceeds and wind changes are perhaps generally unexplainable. The learning has been assimilated at a level that makes it irretrievable using standard knowledge elicitation methods.

Mental models may therefore be of help in capturing and communicating basic conceptual level knowledge and setting a sound structure for more advanced experiential learning, but, they cannot be relied upon to anticipate all the questions that working in a dynamic environment will present.

Commentary

This brief overview of the literature suggests that there is a limit as to how successful even the best researched and taught conventional hazard awareness training can be. A number of factors contribute to this. For example, in training we are hoping to provide the new staff with the capabilities of the best practitioners, but their highly subtle and complex mental model formed over many years is probably inextricable using current knowledge elicitation tools, and not present in graphic or written form; especially to those with little experience of the industry. Additionally assessment of how well the awareness has been assimilated is also not consistently conducted. Finally, the indicators from the field suggest that the learning is not always well applied.

A conclusion that can be drawn from this is that mental models incorporating current and future knowledge elicited from experienced fallers can provide a valuable structure for basic instruction in identifying and managing risks in the felling operations. Unfortunately, such complex mental models cannot be taught by rote, instead individuals have to build and maintain their own models. To do this, simple strategic rules have been developed and taught in other industries, most notably aviation, where individuals face similar combinations of natural and other factors and often have the need to formulate and enact decisions without consultation with others. To develop such a strategic list for felling, the first step is to begin working with experienced and successful fallers using objective data collection methods to gain insights into what strategies they employ, consciously or otherwise.

The field study described in this chapter may be a step in the right direction. The observer, a video camera, is “sitting on the shoulder” of the wearer although the view is monocular and the field of view is typically less than the human eye. What it records can be further analysed by the operator, or another expert, observing his own work and explaining his work strategies and decision making.

4.3 In-forest hazard assessment

As was mentioned at the beginning of this chapter, a field study using video observation was conducted to establish hazards encountered and work practices, among experienced and novice fallers. The findings were contrasted with previous research where the researcher was in the field observing and recording the feller's activities. The information obtained from the study would be used for training purposes.

4.3.1 Methods

The actions of eight tree fallers were recorded with two small (65 mm by 20 mm) colour PAL video cameras mounted on the tree fallers' helmet and shoulder (Figure 4.4). Video was recorded by solid state video recorders (*DV-500*) powered by an internal Li-ion battery. The video device could record one hour of 640 by 480 line PAL video per gigabyte of memory at 25 frames/second. The video was recorded at a rate of 2000 kb/second. The video recorders were carried in a pack worn on the tree fallers' back. A microphone was attached to the right shoulder strap of the tree fallers' backpacks at the level of the collar bone.

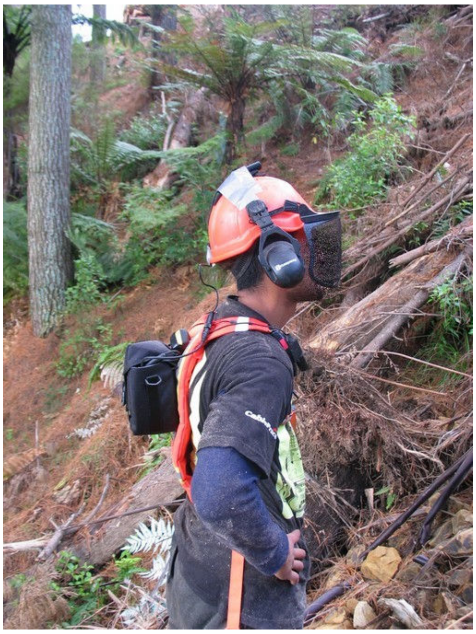

Figure 4.4 - Tree faller wearing helmet and shoulder mounted cameras while working on very steep terrain. Video recorders carried in the back pack.

The reasons for the study were explained to each worker and his informed consent obtained. A start-up sequence for the video devices was then initiated (assisted by a checklist carried by the researcher) to assist synchronisation of the data streams. The video recorders were activated in the worker's backpack. Each tree faller was then free to commence his normal activities. The researcher moved off site. Recording continued until the internal battery of the video recorder was exhausted.

In the laboratory a coding scheme was set up in the behaviour observation software package *Observer XT* using the elements described in Table 4.2. The elements were derived from previous observations of tree felling (Parker & Kirk, 1994).

Table 4.2 - Elements used to describe tree faller activities. A state event exists for a period of time and a point event is instantaneous.

Element	Event type	Description
Assess	State	Look at the tree – to assess tree weight distribution and wind direction and look at surrounding environment
Clear scrub	State	Cut undergrowth for access to tree and to place felling cuts
Top scarf	State	Insert top cut of scarf
Bottom scarf	State	Insert bottom cut of scarf
Wing cuts	State	Insert cuts either side of scarf
Backcut	State	Insert cut which cases the tree to fall
Wedge	State	Inset wedge into backcut and hit with hammer
Walk	State	Walk between trees and into and out of felling area
Sharpen up	State	Sharpen chainsaw chain and associated maintenance tasks
Refuel	State	Refuel chainsaw
Waiting	State	No obvious activity
Look up	Point	Looking at canopy of trees

The video files recorded from the helmet and shoulder mounted video cameras were imported into *Observer XT*. A visual and audio synchronisation event was located in each video file and used to lock the video files into synchronisation. Coding of the video file into an event log file was performed using the *Observer XT* observation window (Figure 4.5). The play speed and direction of the video file could be controlled with the *Observer XT* interface enabling repeated views of an event to ensure accurate coding. The whole video file was coded and the codes saved in a synchronised event log. Most video files were one hour long.

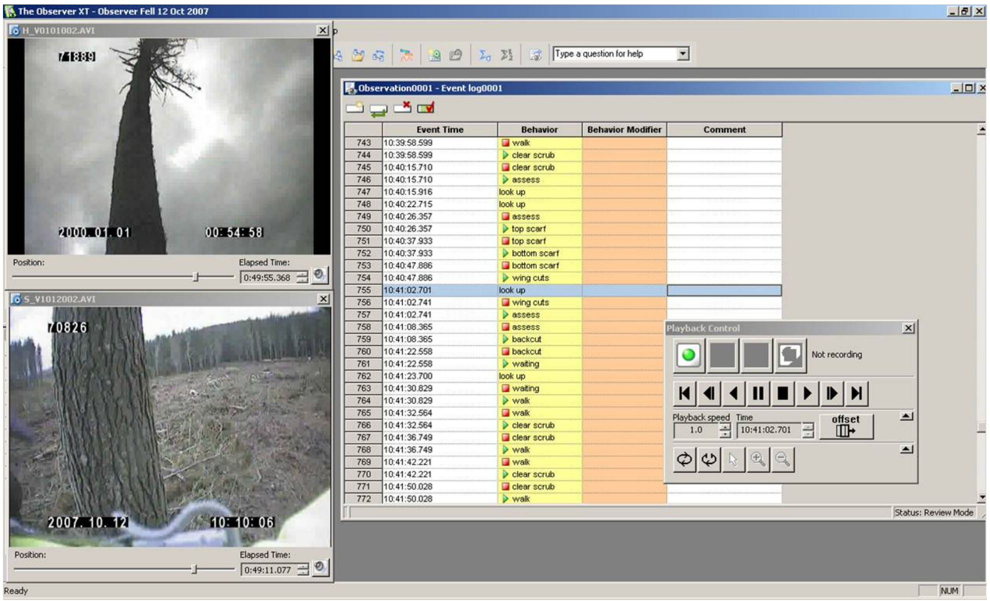

Figure 4.5 - Observer XT observation window used to code activities. The top image on the left side of the figure is from the helmet mounted camera and the bottom image is from the shoulder mounted camera.

The video files were viewed and scored four times. The first viewing coded ‘State’ elements such as ‘top scarf’, ‘bottom scarf’ and so on. The second viewing coded the ‘Point’ element ‘look up’ which could be seen on the helmet camera image. The third viewing identified hazardous events defined in Table 4.3 below. The fourth viewing was a check of coding accuracy at random points through the video file.

Table 4.3 - Hazards determined from previous studies of New Zealand tree falling under normal operational conditions (Parker & Kirk, 1993).

Hazard	Description
Flying debris	Flying debris dislodges by falling tree and falling near logger
Comeback	Tree falling backward off stump
Drop start	Starting chainsaw by illegal drop start method
Butt kick	Standing too close to butt of tree which kicks upward on falling
Wind / lean	Attempting to fell tree against a strong wind or severe lean
Eye	Having to put down the chainsaw because of dirt or wood chips in eye
Saw above	Using chainsaw above shoulder height (e.g. to remove limbs at base of tree)
Into stand	Felling tree into standing trees
Overcut	Overcutting the back cut and tree falling sideways
Drive	Felling a tree by driving a second tree on to it

4.3.2 Results

Ten tree fallers were selected for inclusion in the study. However the results of two of the tree fallers could not be included in the analysis because of corruption to their video files due to an intermittent equipment fault. The three remaining experienced tree fallers had an average of 8.3 ± 1.5 years (± SD) tree falling experience. The five novice tree fallers had 1.1 ± 0.8 years (± SD) tree falling experience. All were full time professional loggers working in *Pinus radiata* harvesting operations in the Central North Island of New Zealand.

Task element analysis

When using a chainsaw to fell trees the forest worker changes tasks rapidly (Table 4.4). Within seconds the forest worker will look up at the canopy for hazards and assess tree lean, insert the top scarf with the chainsaw, look up again for hazards and another assessment, insert the bottom scarf and wing cuts and then insert the backcut to fell the tree. The playback controls of the *Observer XT* observation window were used to start, stop, rewind and play video at half speed to ensure coding of tasks was accurate.

Table 4.4 - Example of task elements performed in one minute. This is a novice tree faller who has repeated a top scarf cut. He is looking up at the lean of the tree, branch weight distribution, wind direction and aerial hazards such as broken branches that could fall. When the tree begins to fall he will see it move relative to the surrounding trees.

Time (hh:mm:ss)	Element
14:02:04	look up
14:02:11	top scarf
14:02:23	look up
14:02:35	bottom scarf
14:02:49	top scarf
14:02:56	wing cuts
14:03:06	backcut
14:03:07	look up
14:03:11	look up
14:03:18	look up
14:03:19	waiting
14:03:20	look up
14:03:28	walk
14:03:35	clear scrub
14:03:36	walk
14:03:38	look up

Productivity

Recording of felling hazards was the principal purpose of this study; however basic tree faller productivity data were also collected. Detailed productivity related information such as slope of ground, thickness of undergrowth, diameter of trees felled, the direction of predominant tree lean or number and types of obstructions on the ground were not collected. The three experienced tree fallers were significantly more productive felling an average of 34 trees / hour compared with the five novices who felled an average of 17 trees / hour (t_6 = 4.46, p = 0.003). The actual time engaged in tree falling excluded normal delays not associated with the tree falling task such as conversation with other workers or walking to and from the felling site.

There were no significant differences in the proportion of time experienced or novice tree fallers engaged in each tree felling task (Figure 4.6). However experienced fallers tended (t_6 = 2.08, p = 0.08) to take a greater proportion of their time preparing the top scarf which is the first felling cut from which all other cuts follow. Experienced fallers tended to use a smaller proportion of their time waiting for the tree to fall or walking between trees.

Experienced fallers used a greater proportion of their time to clear the area around the base of the tree before felling and making the felling cuts (Figure 4.6). Compared with novice fallers, experienced fallers used proportionally less time sharpening their saw and waiting for something to happen (tree to fall) or walking.

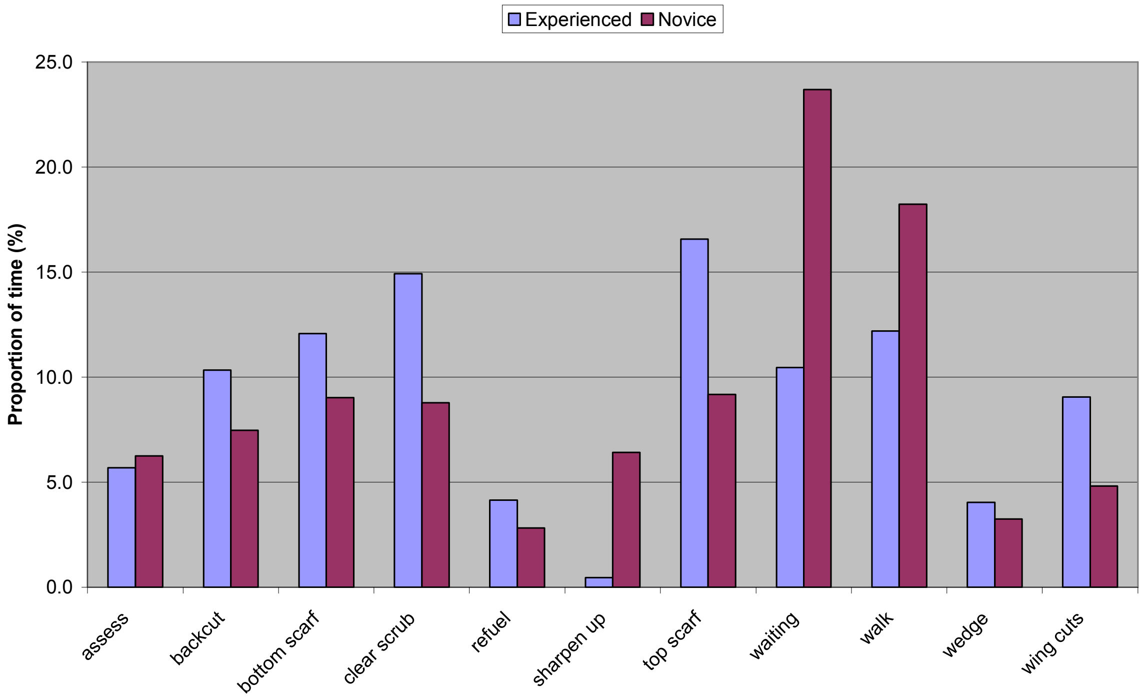

Figure 4.6 - Comparison of proportion of time experienced and novice tree fallers engage in various tree felling activities.

The task elements from the video files were presented in a time line showing the order in which each task elements took place. When timelines for a novice tree faller (Figure 4.7) and an experienced tree faller (Figure 4.8) were compared, novice tree fallers tended to have to do more rework of their felling cuts in order to match up the top and bottom scarf cuts and create a hinge for the tree to fall (which is an important component for safe felling). In contrast, the experienced fallers tended to get the cuts correct and did not have rework.

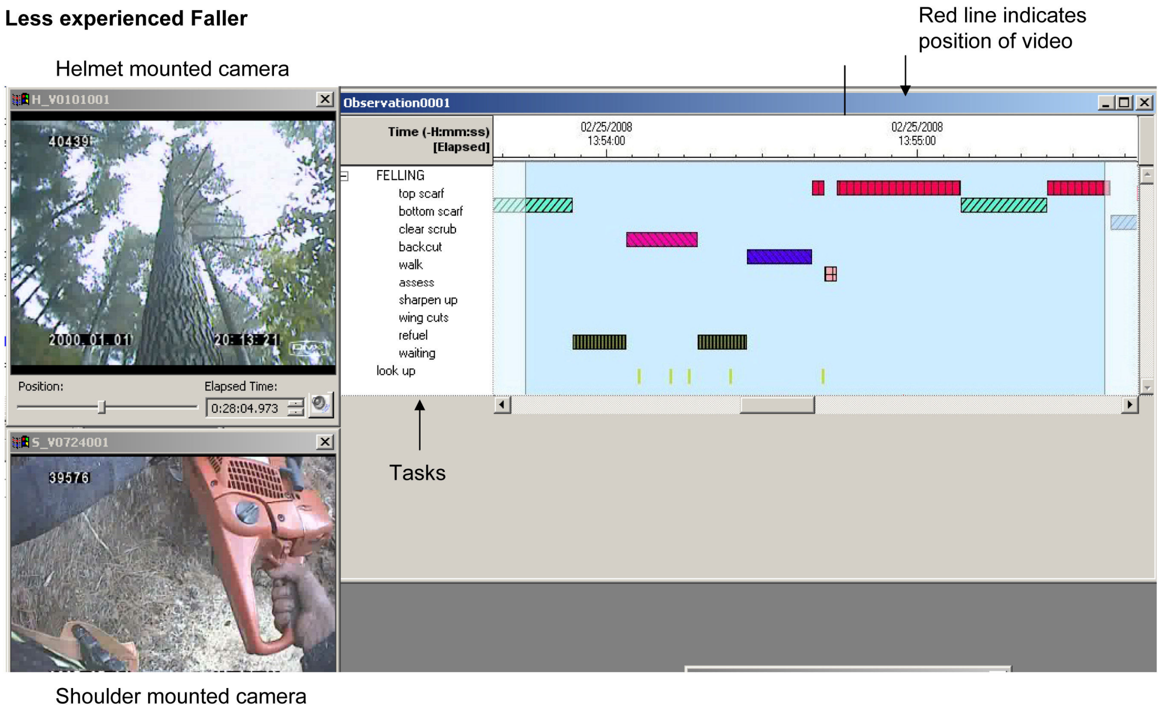

Figure 4.7 - Time line of task elements for a novice tree faller. Note the recutting of the scarf – red bar at the top of the Figure.

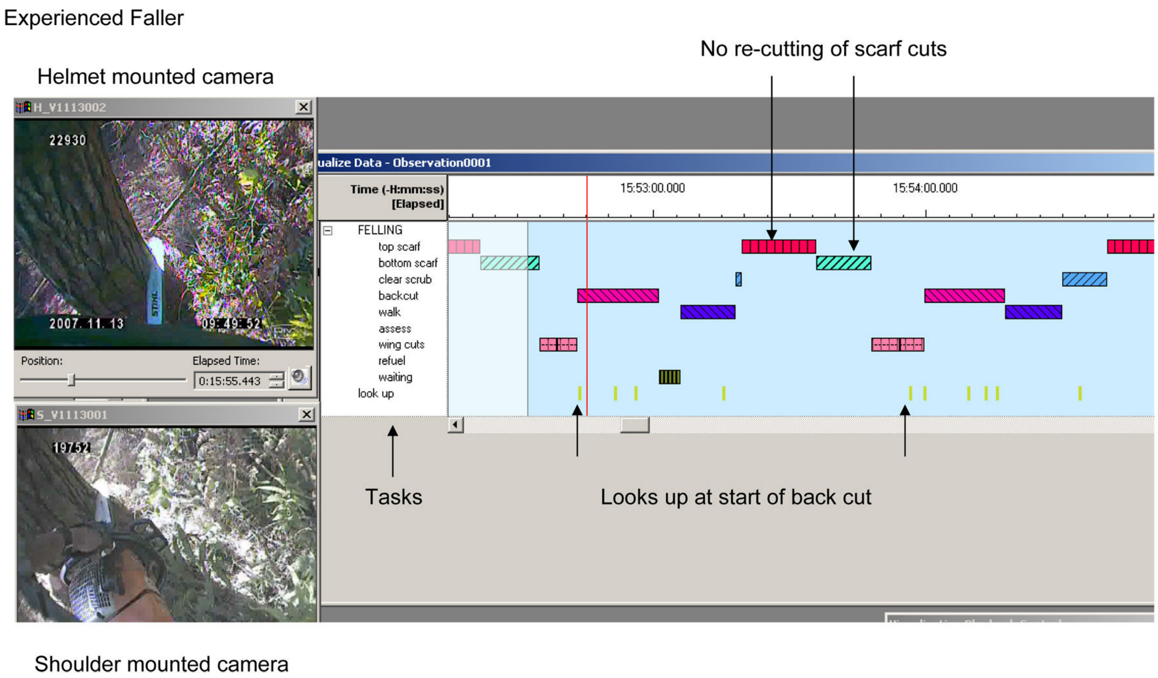

Figure 4.8 - Time line of task elements for an experienced tree faller.

Hazards

The tree fallers were wearing two video cameras and hazards were recorded from images from those cameras. Often hazard identification required a number of viewings of the same video scene. There could have been hazards which were not seen from the video files because of resolution of the cameras, low light and being outside the field of view of the camera.

The rate of hazard occurrence of tree felling hazards confronted by experienced and novice fallers in New Zealand *Pinus radiata* is presented in Figure 4.9. The greatest differences between experienced and novice fallers was in the proportion of overcutting of the back cut with 16% of trees overcut by novices compared with only 2% by experienced fallers. However with such a small sample size this difference was not significant (t_6.= -1.02, p = 0.34). Experienced fallers did not drive trees at all. Driving is where a tree is felled onto a second prepared tree to force the second to fall. Driving can be very hazardous if not done correctly and novice fallers drove 14% of the trees they felled. Novices also tended to fell trees into other standing trees (Figure 4.9 'Into stand'), more frequently compared with experienced fallers (t_6.= -0.87, p = 0.42). Experienced fallers were occasionally seen to use the chainsaw above shoulder height, (Figure 4.9 'Saw above') however novice fallers were never seen to do this.

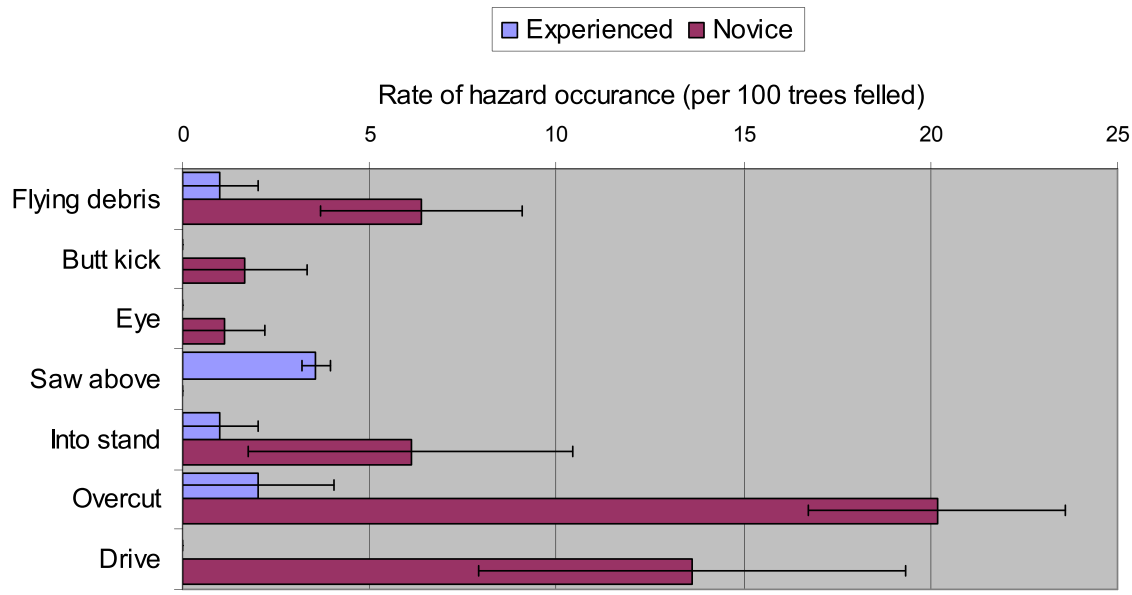

Figure 4.9 - Rate of occurrence of felling hazards (per100 trees felled) for novice and experienced tree fallers (Mean ± se).

Vision is the primary sense used to locate hazards in the felling environment. Many of the hazards fall from above so the faller is frequently looking upwards. Tree fallers look at the lean of the tree, the distribution of branches, the direction of the wind and the presence of broken branches which may fall when the tree starts moving. Figure 4.10 illustrates the view a tree faller has when standing at the base of a tree during felling and Figure 4.11 illustrates sailer hazards.

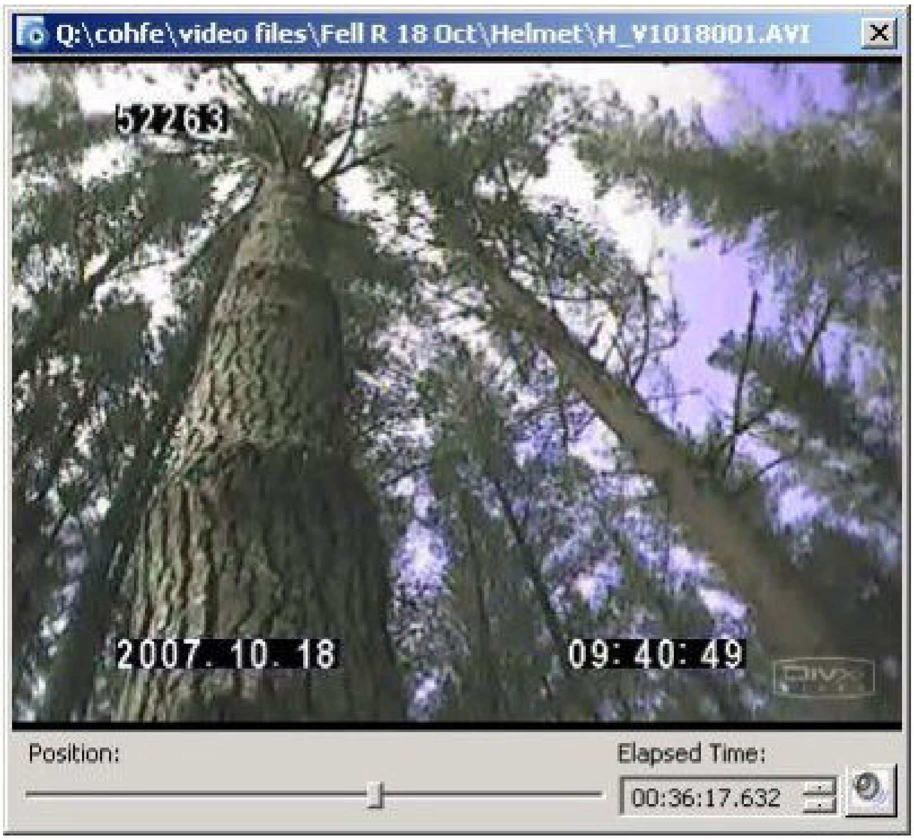

Figure 4.10 - View of a tree from the faller's perspective at felling. The faller is assessing the lean of the tree, distribution of branches which will affect the direction of fall and the presence of aerial hazards such as broken branches or clumps of cones. Image captured from the helmet mounted video camera.

Figure 4.11 - Broken branch hazards (sailers).

The number of times the faller looked up at the tree being felled and the canopy of the surrounding forest was measured by viewing the video file from the helmet mounted video camera. The temporal relationship between the look up event and other felling task elements could be determined from the *Observer XT* software.

Table 4.5 - Count of the number of times the tree fallers looked up at the canopy of the forest and the number of look up events per tree.

	Experienced				Novice					
Faller	1	2	3	Total	4	5	6	7	8	Total
Look up	218	131	168	517	110	175	111	232	236	864
Trees felled	30	23	33	86	11	8	12	18	12	61
Look up / tree	7.3	5.7	5.1	6.0	10.0	21.9	9.3	12.9	19.7	14.8

Experienced fallers looked up 6 times per tree which was significantly less frequently than novice fallers who looked up 15 times per tree ($t_6 = -2.5$, $p = 0.04$). This study did not provide data on exactly what they looked for or at in the aerial scene – but it is possible that because of their greater experience they were able to identify potential hazards more quickly and had a more efficient visual scanning process.

4.3.3 Discussion

Professional tree felling is a potentially hazardous occupation resulting in both fatalities and lost time injuries. Novice fallers, in their first few months of felling have a disproportionately high rate of injury. The current study attempted to understand what hazards are confronted by New Zealand fallers under normal operation conditions. It was soon found that conventional observation of the fallers would not result in valid data.

It is generally understood by researchers that the presence of an observer during tree felling compromised the study by introducing another hazard for the faller, who has to always be aware of the location of the observer before felling the tree. The presence of the observer also results in the faller feeling 'watched' so feeling pressured to perform either at a higher rate of work or at a higher level of skill than normal.

For this study, miniature video cameras were mounted on the helmet and shoulder of the fallers to monitor direction of gaze and use of the chainsaw respectively. The observer then retreated completely from the felling area. Fallers stated that they soon forgot about the presence of the cameras and worked at a normal pace using normal practices. They also did not have to be aware of the location of the observer because they knew the observer had moved off site. Another advantage of the cameras was the ability to analyse an event on the video file repeatedly until it was understood and to get close to the faller. This is in contrast to the traditional method of recording where the observer had to stand at a safe distance from the faller resulting in the observer being too far away (Figure 4.12).

Figure 4.12 - Tree felling observation without body worn cameras.

To my knowledge no other researchers have used multiple body mounted video cameras to observe the felling behaviour of tree fallers in such detail. The current study has resulted in an archive of 20 hours (28 Gb) of raw felling video data. Of that, eight hours of video is indexed second by second to task elements to enable detailed analysis. The video files will be able to be used for other research and training purposes.

Productivity

The experienced loggers were considerably more productive than the novice tree fallers. Experienced fallers felled 34 trees / productive hour compared with novice fallers who felled 17 trees / productive hour.

Novice fallers tended to use a greater proportion of their time to engage in 'non-productive' activities such as sharpening the chainsaw, 'waiting' and 'walking'. The experienced fallers used a greater proportion of their time cutting the first (or 'top') scarf cut, which determines the direction of fall of the tree. If the first scarf cut is not placed correctly, the remaining cuts needed to fell the tree will have to be modified until the configuration of the cuts is correct. Thus, an accurate first scarf cut is more efficient because subsequent felling cuts to not have to be modified.

Using video analysis to create detailed timelines of the fallers' task elements enables examination of their work flow. Experienced fallers in this study were faster at felling trees because they did not have to redo felling cuts. In contrast novice fallers, who have less developed skills, used more time to place their chainsaw cuts and had to repeat some cuts. It is important that the felling cuts are accurate for the tree to fall in the intended direction.

Hazards

Tree felling is an extremely dangerous occupation. The faller has to manage a wide range of hazards in an uncontrolled forest environment while maintaining a productive rate of work. The faller carries a 10 kg chainsaw which is hot (exhaust) and sharp (cutter chain) while traversing often steep terrain with debris underfoot. The faller relies predominantly on vision to identify the presence of hazards because the noise of the chainsaw prevents the use of audible cues.

The felling task introduces a new set of potentially fatal hazards:

- movement of the falling tree breaks and dislodges branches and cones which can fall from heights up to 30m;
- creepers and vines growing on the tree can pull debris onto the faller when the tree falls;
- broken branches and cones can be projected back toward the faller when the tree strikes other trees or strikes the ground;
- the base of the tree can move unexpectedly, striking the faller, when the tree hits the ground;
- if the tree has a heavy lean, the wood at the base of the tree can split and strike the faller when he is inserting the back cut;
- the tree can fall sideways or backwards to the intended direction of falling, striking the faller.

Video cameras mounted on the fallers allowed the repeated viewing of hazards in the work environment. However the faller would have had greater visual resolution and acuity than the video cameras. The helmet mounted camera allowed the researchers to gain an approximately similar view of the environment as the fallers. The video camera did not have a wide field of view so could not detect hazards in the faller's peripheral view. We presume that any hazards identified in the faller's peripheral vision were brought to the fovial view (i.e. the faller looked directly at the hazard) so it was seen on camera.

In a previous study (Parker & Kirk, 1993) tree fallers were observed from a distance ranging from of 3m to 20m and the number and type of hazards present in the immediate environment were counted. There was no video record of the felling process or of hazards. The biasing of observation data from felling observations was not recognised in the literature. However there is extensive literature dealing with the Hawthorne Effect, defined as a short-term improvement in worker performance caused by an observer being present (Landsberger, 1958). The presence of an observer during felling may have resulted in the faller not working in their normal way. The faller would have always been aware of the observer and had to ensure the observer was in a safe position before each tree was felled. The observer had to be as close as possible to the faller to see his work method but far enough away to avoid hazards. Use of wearable video cameras in this study may minimise any effect on behaviour induced by the experimental situation.

The hazard types and frequency (per 100 trees felled) of the current study were compared with a similar study in New Zealand *Pinus radiata* forests in 1993 (Parker & Kirk, 1993). In both 1993 and 2008, novice and experienced fallers differed in the rate of hazard occurrence they were exposed to. Novice fallers experienced more ‘flying debris’ hazards than experienced fallers in both years. Novice fallers felled more trees into standing trees which resulted in broken branches and cones flying back at the faller. Interestingly, novice tree fallers rated felling trees into standing trees as a low hazard. There was no evidence, in 2008, of trees ‘coming back’ – dangerously falling backwards toward the faller rather than forward or ‘drop starting’ the chainsaw. Also there were no attempts to fell trees against the wind or lean. The absence of these events indicates a higher level of training and tree felling knowledge in 2008 compared with 1993.

All fallers wore eye protection in 2008 and this is reflected in the very low rate of material getting in fallers’ eyes compared with 1993. In 2008 novice fallers felled more trees (6%) into standing trees than experienced fallers (1%). This is higher than in 1993 and may be due to a lack of knowledge, by the faller, of the hazards created by such action.

In both 1993 and 2008 novice fallers had more overcut back cuts (7% and 16% respectively) than experienced fallers (1% and 2% respectively). It may be that novice fallers had poorer skills than fallers in 1993 but more likely the video cameras mounted on the fallers, which allowed a close view of the felling cuts, resulted in more overcuts being detected. In 1993, felling cuts were viewed from a distance of more than 3m and often were obscured by the faller. If a tree will not fall over after the felling cuts have been inserted wedges are used to lever the tree over. If they cannot move the centre of gravity of the tree sufficiently for it to fall the tree can be ‘driven’. A second tree is felled onto the tree to push it over. This is a hazardous task because the two trees, once in contact, may not fall in the expected direction. Additional flying debris will also be generated. In 1993 driving was more commonly used than it is today. In that year both novice and experienced fallers drove 8% of the trees they felled. In 2008 experienced fallers did not drive any trees and novice fallers drove almost 14% of trees. On informal discussion with the novice fallers, it seems they do not have the wedging skills of the experienced fallers and used driving as legitimate solution to a tree which would not fall. Driving appeared to be slower than felling the tree with wedges and warrants further investigation.

Detailed investigation of the tree fallers glancing direction was achieved by examining the video record from the helmet mounted cameras. Fallers look up frequently because many of the hazards they are exposed to come from the canopy of the forest. They also look up to judge the direction the tree will naturally fall. While inserting the back cut the faller will look up to watch the movement of the tree against the sky and surrounding trees. If the tree appears to be moving backward, the faller must use wedges to keep the back cut open and move the centre of gravity of the tree forward to ensure it falls forward. Novice fallers looked up, per tree felled, twice as frequently as experienced fallers (15 glances / tree and 6 glances / tree respectively).

Experienced fallers appear to be more efficient in their visual scanning than novice fallers. We do not know exactly what the experienced fallers looked at when they glanced up at the canopy. They would probably be looking at changes in the normal pattern of branches. Potential hazards such as broken branches often rest at a different angle from healthy attached branches (Figure 4.11). Use of a portable eye scanner would enable investigators to determine exactly what fallers look at when glancing at the canopy.

The back cut is a potential hazard generating step in the felling process. Normally the tree has a natural lean in the intended direction of fall. The wood fibres around the outer edge of the tree are under tension. As the chainsaw severs the fibres the tension is released and the tree begins to move. The movement at the base of the tree is initially only a few millimetres but this small movement translates to considerably greater movement higher up in the tree. Loose branches and cones can become dislodged during the back cut and fall on the faller.

Potential applications

By combining video records with other sensors, training material more suited to other forestry tasks could be developed. For example skidder operation could be investigated – to demonstrate good technique – by mounting a video camera on the operator's helmet to record direction of gaze and a GPS receiver on the machine to record location. Both data streams could be synchronised and presented as highly visual training material with reference to the terrain being traversed by the skidder.

4.4 Conclusions

There were three aims associated with this study. With respect to the main one, the efficacy of new technology, I have demonstrated that wearable video cameras offer researchers a unique perspective on the work pattern of a tree faller. The ensemble does not interfere with the faller's normal methods and offers a safe way to observe hazardous work.

The recorded information proved to be valuable in addressing the other two aims. The faller relies predominantly on vision and must have a well developed visual situational awareness to locate hazards. By mounting a video camera on the faller's helmet his direction of gaze can also be recorded. Both novice and experienced fallers look up into the forest canopy frequently for hazards and to determine the movement of the tree. However novice fallers look up twice as frequently as experienced fallers. Presumably experienced fallers have more highly developed situational awareness and can 'read' the aerial environment more effectively than novices. Video material produced can be viewed by the participant for post-hoc evaluation and analysis of their own performance with a view to enhancing their safety and overall effectiveness. Alternatively, video footage can be edited to ensure anonymity of the faller and can subsequently be used as part of a more widely available training package.

This study indicates that forestry is the first industry to realise the potential of the outputs of modern sensing and imaging technology for the development of training materials to help address logging hazards. Evidence collected in this research suggests that three major hazards on which training should be focussed are overcutting the back cut, driving trees, and felling into standing trees.

In the next chapter I will present a case study of another industry in which work is characterised by dangerous and often uncertain conditions. Chapter Five focuses on rural fire and provides another set of insights into the research potential of the technology already introduced.

5 Rural Fire Fighting

5.1 Introduction

In the previous chapter, I used the tree felling work situation to illustrate an approach for collecting data in dangerous environments. These data were used to identify potentially hazardous situations, identify the differences between experienced and novice tree fallers and to develop training material.

In this chapter I will discuss the research carried out, using the methodology and instrumentation described in Chapters Three and Four with rural fire fighters in actual fire fighting operations. The main aim of the research was to explore the use of new technologies in facilitating the field study of firefighters.

I will review research associated with fire fighting and conclude with a field study using unobtrusive observation methods whose aims were:

- To explore the efficacy of new technology to study the work of firefighters;
- To investigate the possibility of measuring the work load and productivity of rural fire fighters; and
- To gain insight into aspects of the rural fire fighting task in order to develop training and data to support other safety, health and performance initiatives.

5.2 Background

By its very nature, rural fire fighting is a physically demanding and hazardous occupation. In an examination of 307 natural disaster occupational deaths in the period 1992 to 2006 the greatest number of fatalities (80) were to fire fighters fighting wildfires (Fayard, 2009). Substantial research has been carried out in laboratories where urban fire conditions were simulated (e.g. Bruce-Low, Cotterrell, & Jones, 2007; McLellan & Selkirk, 2006; von Heimburg, Rasmussen & Medbo, 2006) because urban fires are often within a structure and simulated conditions can be created. However, rural fire conditions cannot be simulated in the laboratory, because the fires are often large and part of the landscape.

The field studies described in this chapter address the problem of collecting detailed data at real rural fires using a novel suite of data collection equipment combined in an original way.

5.2.1 Fire fighter physiological monitoring

Many tasks in rural fire fighting are physically demanding (Budd, 2001; Gaskill, 2002; Heil, 2002) and result in high levels of fatigue. To date, much research work has been carried out by Australian and North American researchers to quantify total energy expenditure and associated fatigue (e.g. Cuddy, Ham, Harger, Slivka, Ruby, 2008; Ruby, Scholler & Sharkey, 2000, 2001; Ruby, Zderic, Burks, Tysk & Sharkey, 1999). However, fire behaviour, work practices, climate and equipment in New Zealand differ from those in Australia, the United States and Canada. Until now there are no published reports of studies with measured data of New Zealand rural fire fighter physiological workload.

Much relevant physiological research has already been carried out in the New Zealand logging industry (e.g. Parker, Bentley, & Ashby, 2002; Parker & Kirk, 1994) and now logging physiological research is considered known well enough to no longer be considered an active area of research by the forest industry in New Zealand. Hazards and work style in logging are considered important areas of research and were the focus of Chapter Four. Additionally, logging is recognised as one of the most physically demanding of full time occupations (Gaskin, 1990; Kukkonen-Harjula, 1984; Parker, Sullman, Kirk, & Ford, 1999) and exhibits some parallels with fire fighting tasks. Both loggers and fire fighters are exposed to environmental weather extremes, high physiological workloads and work for extended periods, often handling heavy tools in potentially dangerous conditions. Measurement of overall energy usage is remarkably similar between rural fire fighters (Heil, 2002; Ruby et al., 2002) and loggers (Kukkonen-Harjula, 1984) with both expending approximately 4700 kcal/day.

The measurement of physiological workload of fire fighters is necessary for the understanding of factors which contribute to fatigue and for providing a measure of the subsequent success of fatigue management programmes. Physiological workload also provides a quantitative measure of the physical requirements of a task. Then, if that task is modified, the effects can be measured in a repeatable and unambiguous way.

There are complex interactions among three factors: work practices, work behaviour and clothing which together influence the fire fighter's heat load and level of fatigue (Brotherhood, Budd, Hendrie, Jeffery, Beasley, Costin, Zhien, Baker, Cheney & Dawson, 1997; Budd, 2001; Budd, Brotherhood, Hendrie, Jeffery, Beasley, Costin, Zhien, Baker, Cheney & Dawson, 1997a; Gaskill, 2002). New work techniques, items of equipment and work organisation can be tested to determine if they alter the physiological workload of the fire fighter. If a new technique, item of equipment or way or organising work impose a greater physiological load it will likely not be used and further modifications and developments would be necessary for successful introduction (Budd, Brotherhood, Hendrie, Jeffery, Beasley, Costin, Zhien, Baker, Hoschke, Holcombe, Cheney & Dawson, 1997b). Tests to determine the effectiveness of such modifications cannot, however, be conducted in operational settings due to the risks associated with the extra burden. Measurement at real fires has been a longstanding gap in rural fire fighting research.

Barr, Gregson & Reilly (2010, p. 165) stated in their review of structural fire fighting thermal ergonomics:

> "No published data exist on thermoregulatory responses during real-life operations, as it is impractical and could be dangerous to kit out a firefighter with physiological monitoring equipment during hazardous events. Nevertheless, it has been possible to monitor heart rate continuously throughout the entire shift of a firefighter (Barnard and Duncan, 1975; Kuorinka and Korhonen, 1981; Sothmann et al., 1992; Bos et al., 2004). Lack of control in the monitoring and regulation of environmental conditions during real fire-fighting operations make it difficult to collect data suitable for research purposes. Consequently, research into physiological responses during fire-fighting activities is reliant on data collected during simulations of live fires performed in facilities that are used to train newly recruited firefighters."

Physiological testing in structural fire has been extensive, but also in simulated conditions. Recent non-operational studies include those by von Heimburg, Rasmussen and Medbo (2006), Bruce-Low, Cotterrell and Jones (2007), McLellan and Selkirk (2006) and Williams-Bell, Boisseau, McGill, Kostiuk and Hughson (2009).

An ever-present limitation that has until now prevented field studies of rural fire fighters is the logistical difficulty, and cost, of conducting rigorous experimentation over long periods without scientific backup (Heil, 2002). For example, the use of the doubly labelled water (DLW) test, described by Ruby et al. (2002) as the gold standard for the measurement of total energy expenditure in free-living individuals, is far more problematic in an operational environment where sampling by specialists cannot be as strictly controlled. The use of electronic activity monitors (accelerometers) that can be worn on the clothing is complicated by the need to establish validity of the algorithms through further controlled trials (Heil et al., 2004). Furthermore, activity monitors do not provide contextual information, such as what task the person was engaged in or the type of equipment they were using.

Against this background, telemonitoring has been developed. Telemonitoring is a growing area in medical (Meystre, 2005) and particularly military applications (Hoyt, Reifman, Coster & Buller, 2002). Telemonitoring is defined by Meystre (2005) as the use of information technology including audio and video to monitor patient physiology at a distance. Dating from the earliest recorded transmission of electrocardiograms (ECGs) using telephone lines back in 1905, telemonitoring is now well established in emergency services and care of the elderly. The scope of monitoring applications is predicted by Meystre (2005) to increase through the use of virtual reality, immersive environments, haptic feedback and nanotechnology. While well proven, telemonitoring medical systems are mostly designed for use in benign situations where sensors will not be damaged and where a good channel of electronic communications exists such as internet, telephone or radio communication.

For occupational applications in harsh environmental settings, the most established telemonitoring system appears to be the *Warfighter Physiological*

Status Monitoring (WPSM) program (Buller, Hoyt, Ames, Latzka & Freund, 2005). Their ultimate goal is to develop a suite of wearable sensors for soldiers to provide critical physiological information to commanders and medical personnel in real time. Biosensors, personal area networking, and data management hardware and software will provide physiological information within a broader environmental framework. Data will be used to develop models of thermal stress, hydration status, cognitive state and so on. The system aims to provide feedback to commanders on healthy soldiers that will allow the monitoring of fatigue and dehydration and therefore combat readiness. Critical reviews of the WPSM are not yet available in the peer-reviewed literature.

5.2.2 Task and performance monitoring

"The task analysis process is one of collecting information on how a task is carried out, and representing such information such that the task can be analysed to see if it can be improved, or to assess its task design adequacy" (Kirwan & Ainsworth, 1992, p. 408). While generic training documentation for rural fire fighters appears to cover every contingency, the specific tasks required of a rural fire fighter during vegetation fires cannot be totally predetermined.

Productivity of initial attack fire crews and, more specifically, of fire line construction has, however, been of interest for many years and has been the subject of numerous studies. Productivity is measured as the area of fire suppressed or area of fire line constructed per unit time. Surprisingly few studies have measured productivity under real fire conditions, and when fire has been present, it has been a controlled burn, with backup support, and not an out of control wild fire. Little new data have been published, in English, since the commonly cited studies of Schmidt and Rinehart (1982), and Barney, George and Trethewey (1992). Most of the studies have produced either limited or extremely variable data, calling into question the validity and applicability of the resulting guidelines, particularly to New Zealand conditions (Parker, Moore, Baillie, Pearce & Anderson, 2008). Current guidelines are adapted from these early studies and their usefulness is enhanced through the application of expert knowledge of the local fire conditions and experience with local fire crews who have worked together for a considerable time. But fire crews are not always working in their local environment and may be working with other, unknown crews, particularly on large, multi-day campaign fires.

Studies measuring total energy expenditure over the course of a day (e.g. Heil et al., 2004) are attractive in their simplicity but neglect to describe peaks of activity that may lead to extreme fatigue and poor decision-making, leading for example, to entrapment of fire crews. It is of course important to take into account the fact that people carrying out such tasks will burn twice the energy of more sedentary workers. Heavily equipped fire fighters can reach a level of fatigue at which they are incapable of executing the immediate task. Minute by minute, or even second by second, recording of actual workload and task demands is essential to better understand the work and productivity of the rural fire fighter.

Task analysis and performance monitoring in manufacturing, by means of direct observation with remote analysis using video and commonly available software, is reported in two case studies by Gilad and Elnekave (2006). They describe a video method to gather data in the workplace and use frozen video frames to measure joint angles of the workers under observation. The system views the worker as an actor in the scene, rather than displaying what the worker is seeing. Numerous systems with the worker as an actor in the scene have been developed in occupational health monitoring and are detailed in Chapter Two, section 2.3.7.

More advanced systems available to ergonomists working in occupational settings are those based on software used in animal behaviour studies. Most heavily reported of these is the *Noldus Observer* system from Holland. The *Observer Video-Pro* system was first reported in detail in the peer reviewed literature in 2000 (Lucas, Noldus, Trienes, Hendriksen, Jansen & Jansen, 2000) and case studies compiled jointly by the researchers and the system manufacturers can be found at www.noldus.com. Areas of study are broad and include analysis of musculoskeletal disorder risk factors in ship maintenance (van Wendel De Joode, Verspuy & Burdorf, 1997) and understanding how deaf signers read text (Ducharme & Arcand, 2009). In all those cases reported for human studies, however, the system was not used to analyse concurrent streams of physiological data and observed task data in demanding field environments. As far as I could determine there are as yet few critical assessments of the *Observer* tool for ergonomics applications (e.g. Crawford, 1994).

5.2.3 The collection of integrated data

When investigating fire fighting, physiological studies to assess the workload changes brought about by new equipment and clothing ensembles are of course just part of the process of judging suitability. The reasons for an increase in workload following manipulation of equipment or procedural variables will probably not be understandable simply from analysing patterns of total energy expenditure because total energy expenditure integrates the whole day whereas activities take up a much shorter time. Nor may simulated task studies reveal interactions that do in fact have significant bearing in operational conditions over protracted periods. To understand these important interactions other data streams, including visual and verbal records, are needed for analysis in conjunction with the physiological records.

The use of simultaneous multi-channel data collection methods is thus an important step forward in our measurement and understanding of work in real field conditions. Further, simultaneous multi-channel methods also provide opportunities for triangulation to account for factors that can influence results such as fire fighter behaviour, social interactions and events that could go undetected. With a concurrent video record, it is possible to see individuals: riding on vehicles (which would clearly distort accelerometer activity monitor results), ‘having a play’ with testing equipment during breaks (a problem with some models of heart rate monitors), removing equipment to adjust clothing layers, etc. The potential for discrediting of entire studies due to unexplainable corruptions of data are thereby minimised. It is far more likely with an integrated study that anomalies can be explained, and useful data therefore not discarded.

Some of these issues are taken up in Chapter Six where I will present a further use of data collected in the field to gain greater understanding of the context of work.

5.2.4 Commentary

The literature on physiological workload in rural fire fighting relates predominantly to simulated situations as opposed to real, out of control fires. From the literature it is clear that such data needs to be interpreted in the context of the fire fighters' actions. Increases in heart rate can occur for psychological reasons as well as in response to physical exertions for example, and so multiple concurrent data streams offering triangulation are highly advantageous. This is made all the more so by the absence of the investigator from the scene at real fires.

The concept of a methodology that combines task analysis, performance evaluation and physiological costs is therefore clearly an attractive one. Not only to provide overdue physiological field data specific to New Zealand conditions, but also to begin the process of compiling real resources describing human behaviour and responses in the stressful, risky conditions of rural fire operations that can be used in training, task redesign and equipment revision. The research described below addresses these issues.

5.3 Fire fighting field study methods

As was mentioned at the beginning of this chapter, two field studies were carried out to record work load and productivity measures of rural fire fighters. That information will contribute to guidelines for fatigue recommendations and fire suppression productivity. The first study involved a fire fighter at a steep country fire and the second a fire on flat terrain. Both sets of data were captured opportunistically.

Figure 5.1 - Data collection ensemble worn by fire fighters. Helmet camera (arrowed), GPS on shoulder strap and heart rate monitor under shirt.

The methodology developed (mostly) by me and described below, has stimulated much interest from overseas research organisations investigating work in demanding environments. More detail about the development of the technology is presented in Chapter Three. The system is able to collect up to four hours of uninterrupted video, heart rate, and Global Positioning System (GPS) data. To my knowledge, this is the only data collection and analysis system which has been used at real emergency situations.

The data collection ensemble for rural fire fighting differed from that for tree felling. Only one video camera, mounted on the helmet, was required to monitor the work activity of the fire fighter. Tree fallers wore a second camera mounted on the shoulder to capture hand activity and the chainsaw (Chapter Four). However, other sensors were required to record the activities of the fire fighters. A GPS recorder and a heart rate monitor provided additional information which could be used examine workload and productivity.

5.3.1 Video

The actions of the fire fighter were recorded with a miniature 65 mm by 20 mm colour PAL video camera (www.xtremerecall.com) mounted on the fire fighter's helmet (Figure 5.1). Different video recording devices were used at Fire 1 and Fire 2 because of advances in technology. For the study on steep country (Fire 1) a 'home-made' system was constructed. Video was recorded to a *Neuros Recorder 2* MP4 recording device adapted for field use by attaching a 5 volt battery and encasing in a custom made cardboard enclosure. Ideas for modifying the *Recorder 2* were gained by reading entries from the electronics community in the Neuros technical site http://forums.neurostechnology.com/. Video was recorded to a 4Gb compact flash (CF) memory card. The study on flat land (Fire 2) used a specialist *Lawmate PV500* portable solid state MP4 video recorder with an internal battery. Video was recorded to an 8Gb secure digital (SD) memory card. The video devices could record one hour of 640 lines by 480 lines PAL video per Gb of memory at 25 frames/second at a sampling rate of 2000 kb/second. The video recorder for both studies was carried in a pack worn on the fire fighters' back. At Fire 1, microphones were attached to each shoulder strap of the backpack providing stereo sound. At Fire 2, a single microphone was attached to the right shoulder strap and provided mono sound.

5.3.2 Heart rate

The heart rate of fire fighters at both Fire 1 and Fire 2 was collected with the *GPSports SPI10* (www.GPSports.com) integrated heart rate monitor and Global Positioning System (GPS). Cardiac electrical activity on the fire fighters chest skin surface was measured to determine heart rate. This electrical activity was monitored and amplified by an elastic chest strap worn against the skin. Conductive paste was applied to the electrodes of the chest strap before it was fastened to the fire fighter's chest. The chest strap was worn, under clothing, for the duration of the investigation period. This was four hours for Fire 1 (steep terrain) and two hours for Fire 2 (flat terrain). A heart signal receiving unit, integrated with a GPS receiver, was attached to the fire fighter's shoulder strap (Figure 5.1). This unit recorded the chest strap signal as a heart rate in beats/minute and the recording unit had sufficient memory to store approximately four hours of heart rate data. At the end of the data collection period, the chest strap and shoulder mounted recorder were retrieved from the fire fighter and the heart rate data downloaded to a computer.

The heart rate data file comprised two columns, time of data collection and heart rate in beats per minute. The heart rate file was saved as a comma separated value (CSV) file and imported into a *MicroSoft Excel* spreadsheet for further manipulation. Occasional heart rate data points recorded no heart rate because of interference with the signal transmitted from the chest strap to the shoulder mounted recorder. Missing data points were represented in the data set as empty cells.

5.3.3 GPS

The fire fighters wore a compact GPS receiver on their shoulder (Figure 5.1). The GPS receiver recorded location every 10 seconds in three axes; latitude, longitude and height above sea level and recorded time of data collection. At the end of the data collection period, the data file was downloaded to a computer and using an application within the GPS recorder software, could be displayed as a GPS trace on an aerial photograph (Figure 5.2).

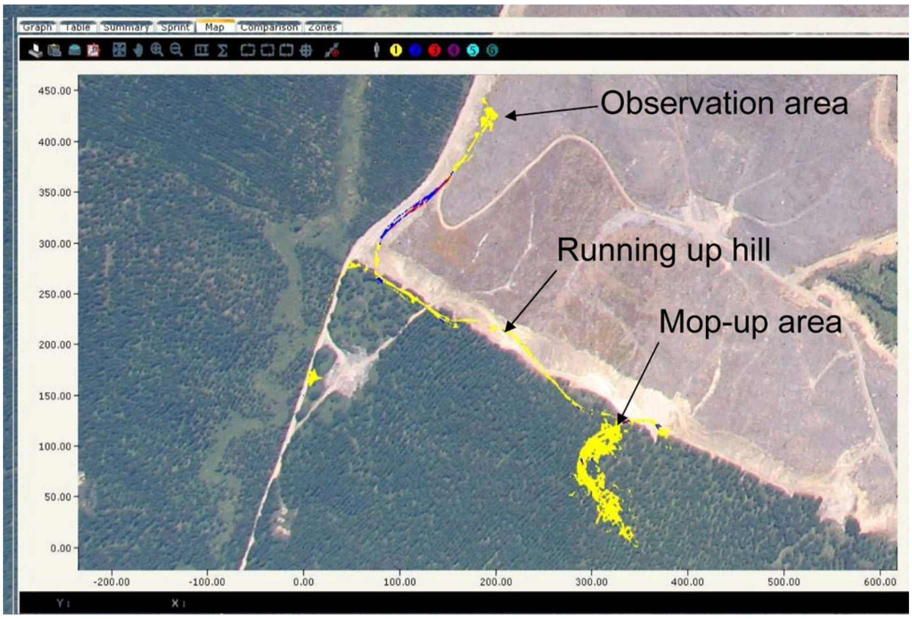

Figure 5.2 - GPS trace, derived from GPSports software, of the path of a fire fighter overlaid on an aerial photograph 'Mop-up area' is where the fire occurred.

However it was difficult to interpret the slope of the terrain traversed by the fire fighter. In an attempt to better portray fire fighter travel and the terrain in three dimensions the GPS file was saved in a generic GPS format (GPX file) and imported directly to *Google Earth*. The path of the fire fighter could then be displayed on three dimensional terrain using the three dimension function of *Google Earth* (Figure 5.3). However *Google Earth* imagery for the region where Fire 1 occurred was poor.

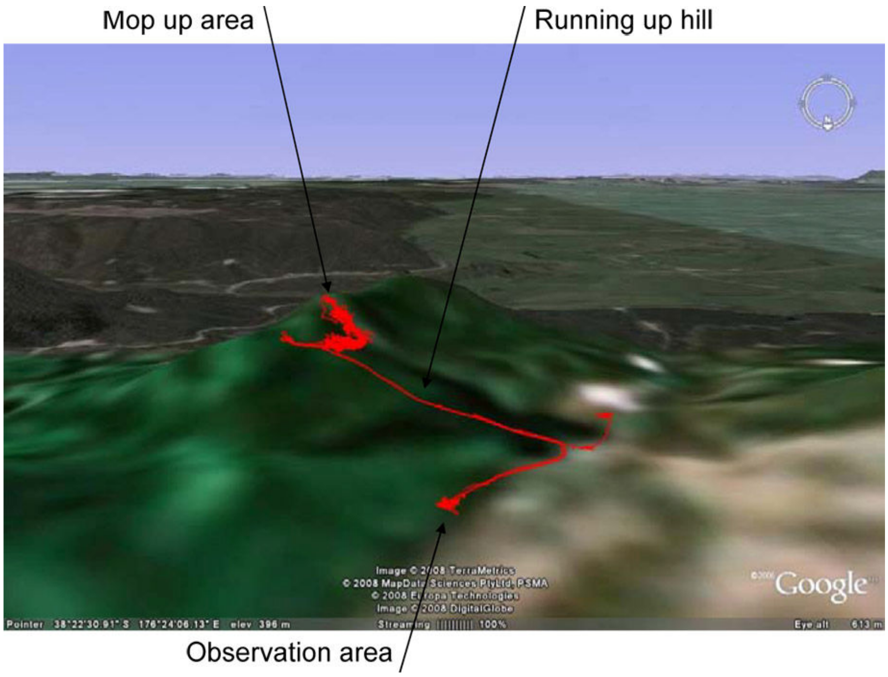

Figure 5.3 - Path of a fire fighter overlaid on a three dimension Google Earth map with very low resolution imagery.

Higher resolution imagery was subsequently acquired from an aerial photograph supplied by the Timberlands forest company. The aerial photograph was integrated with *Google Earth* to provide a much higher resolution image of the terrain. Additionally, to improve the understanding of the path travelled by the fire fighter an application, *Active GPX Route Player* (http://hybridgeotools.com/html/active_gpx_route_player.html) was used to display the path of the fire fighter as a moving icon (Figure 5.4). The GPX file was created in the *GPSports Analysis* package downloaded to *Active GPX Route Player* which allowed control of the speed of the fire fighter icon across the terrain. I am not aware of other fire fighter studies, or indeed any work studies that have reported using commercial-off-the-shelf (COTS) technologies in this way.

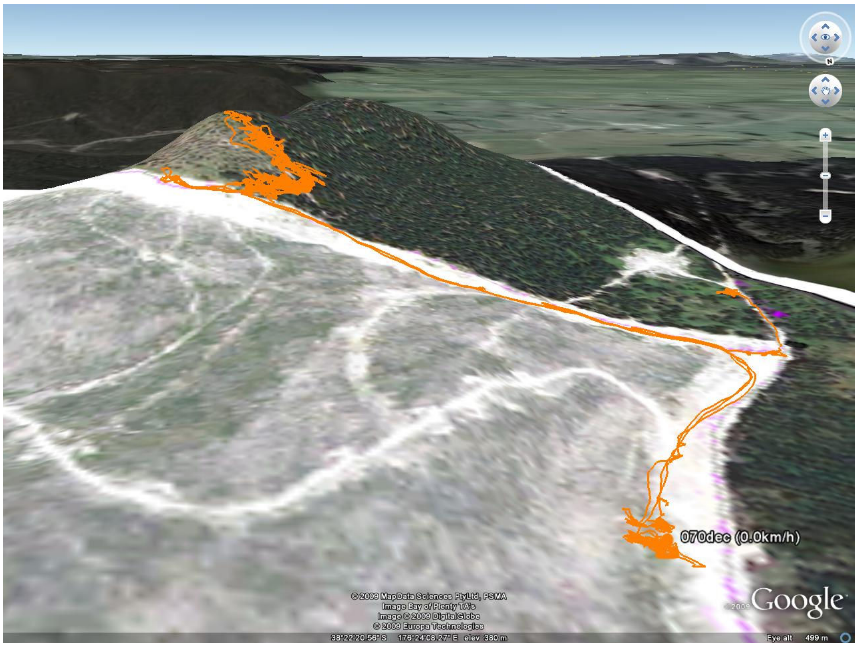

Figure 5.4 - Image of the path of the fire fighter displayed on an aerial photograph overlaid on a three dimension Google Earth terrain model. The viewer can 'fly' through terrain and view the path of the fire fighter. The fire was on the hill at the top left of the image.

5.3.4 Integration of data

Multiple streams of data were collected from sensors worn by the fire fighters. In the laboratory a coding scheme was created in the behaviour observation software package *Observer XT* using the elements described in Table 5.1. The elements were derived from discussion with experienced fire fighters and observation of the video of fire fighting. The video file was imported to the *Observer XT* software and viewed and coded (Figure 5.5). During coding, the video file could be rewound to view scenes a second time to ensure coding was accurate. This enabled me to synchronise video files with GPS data files for analysis. Also, the video footage was synchronised with the heart rate data to build up a picture of activities, work rates and movements of each fire fighter.

Table 5.1 - Elements used to describe fire fighter activities.

Element	Description
Walk	Walk through the terrain
Run	Run through the terrain
Stop	Stop
Radio	Talking on the radio (may be walking at same time)
Hand tool	Using a hand tool such as a McCloud Tool or shovel to expose burning material
Conversation	Talking with other people
Pull hose	Moving an unrolled hose
Nozzle	At nozzle end of hose applying water

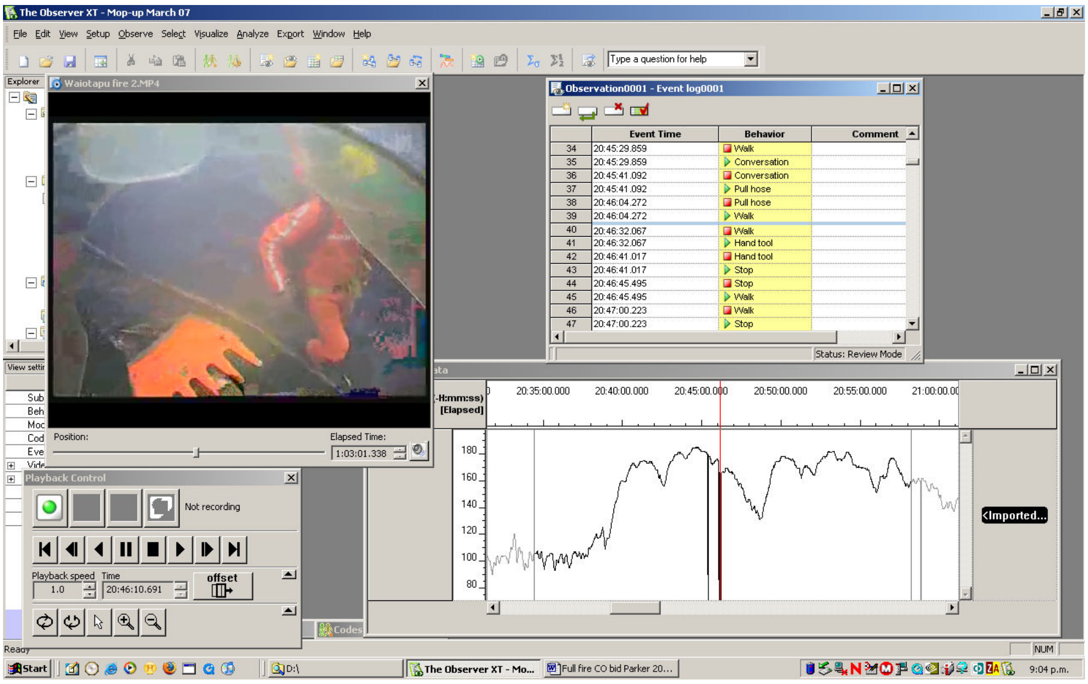

Figure 5.5 - Observer XT observation window used to code activities. The video image is from a helmet mounted camera, tasks are displayed in the top right window and heart rate displayed in the bottom right window.

5.4 Results

Data were collected at two fires in the Bay of Plenty region of the North Island of New Zealand. Fire 1 was in young pine trees (*Pinus radiata*) on steep terrain in Kaingaroa Forest and Fire 2 was in gorse, broom, black berry and eucalyptus undergrowth on flat terrain in Rotorua City (Table 5.2).

One of the reasons it is very difficult to collect data on fire fighters at real fires is because it is an emergency situation, and the fire fighters' priority is to suppress the fire. Clearly, the data collection had to be opportunistic because I could never be sure where a fire would break out. Fire 1 was an unexpected escape of a planned, large scale, burn to remove logging debris. The wind changed direction after ignition and the fire escaped into young standing trees. A fire fighter had been instrumented before ignition and was expected to engage in some light suppression activity such as patrolling the fire boundary and putting out 'hot spots'. He was then called on to fight the fire.

Fire 2 was the result of arson in a forested reserve on a walking track beside Lake Rotorua in the city of Rotorua. It was a Sunday afternoon and I observed smoke from the fire from my home on the opposite side of Lake Rotorua. I went into town, collected an ensemble of instruments and went to the fire. After explaining the reasons for the study and gaining his written consent, a fire fighter wore an ensemble of data collection equipment.

Table 5.2 - Summary information on the data sets from Fire 1 and Fire 2.

	Fire 1	Fire 2
Date	20 March 2007	23 March 2008
Activity	Water mop up Laying hose Communication	Water mop up
Terrain	Steep	Flat
Location	Kaingaroa Forest	Lake Rotorua

5.4.1 Task analysis

The tasks were determined from examination of video images from a helmet mounted video camera, however this was somewhat restrictive as the field of view of the cameras was narrower than that of the human eye (Figure 5.6). Sound was collected with shoulder mounted microphones which allowed conversations to be heard. At times ambient sound levels were high from fire fighting helicopters flying overhead (Fire 1) and from the sound of high pressure water being applied to vegetation (Fire 2).

Figure 5.6 - Screen capture of a scene at Fire 1 from the helmet mounted video camera showing two fire fighters, one in conversation with the instrumented fire fighter. Frequently the fire fighters were working in smoke.

When fighting a fire, the fire fighters do tasks which vary depending on the type of fire (subsurface fire, surface fire, crown fire), the fire suppression method (water from hose, water from backpack sprayer, beater, hand tools digging earth) and their role in the fire crew (crew boss, crew member, pump operator).

Table 5.3 - Example of tasks performed over 8-10 minutes for the fire fighters at Fire 1 (crew boss) and Fire 2 (crew member) show the different range of activities.

Fire 1		Fire 2	
Time (hh:mm:ss)	Task	Time (hh:mm:ss)	Task
01:04:35	Run	00:22:02	Nozzle
01:05:18	Conversation	00:26:36	Walk
01:05:25	Walk	00:26:54	Pull hose
01:05:43	Stop	00:27:16	Nozzle
01:05:49	Tender hose	00:34:08	Pull hose
01:06:17	Stop		
01:06:29	Conversation		
01:06:56	Run		
01:07:05	Conversation		
01:07:33	Stop		
01:07:43	Walk		
01:08:16	Tender hose		
01:08:57	Stop		
01:09:12	Tender hose		
01:09:25	Stop		
01:09:56	Pull hose		
01:10:04	Stop		
01:10:26	Pull hose		
01:10:38	Stop		
01:10:52	Pull hose		
01:11:06	Conversation		
01:11:47	Pull hose		
01:11:53	Conversation		
01:11:59	Stop		
01:12:05	Walk		
01:12:15	Pull hose		
01:12:20	Walk		
01:12:34	Conversation		

The tasks the fire fighter is engaged in can be rapidly changing (Table 5.3). At Fire 1, the fire fighter was a crew boss and was engaged in face to face communication with other fire fighters, radio communication with other crew bosses and fire fighters and hose handling and hand tool fire suppression tasks. At Fire 2, the fire fighter was a crew member who tending the hose or applied water to the fire. He had no supervisory tasks and did not use a radio.

Table 5.4 - Time engaged in fire fighting tasks for Fire 1 (crew boss, steep terrain) and Fire 2 (crew member, flat terrain).

Element	Fire 1		Fire 2	
	Time (mm:ss)	Proportion (%)	Time (mm:ss)	Proportion (%)
Walk	20:13	18	2:49	6
Instrumentation	-	0	1:54	4
Run	5:15	5	-	0
Stop	30:58	28	2:34	5
Tender hose	1:27	1	13:53	27
Radio	3:18	3	-	0
Hand tool	9:14	8	-	0
Conversation	38:52	35	2:53	6
Pull hose	1:30	1	3:23	7
Nozzle	-	0	23:26	46
SUM	110:47	100	50:52	100

The fire fighter at Fire 1 was observed for a total of 110 minutes and 47 seconds. He spent 35% of the study period engaged in face to face conversation with other fire fighters. Almost all conversations were related to obtaining and relaying information related to fire suppression and the welfare of fire fighters in his crew. He was stopped, not talking or engaged in other activity for 28% of the observation period. This comprised mostly watching the fire and periods where he appeared to be resting after physical exertion. He engaged in physical fire fighting tasks for only a small portion of the observation period. He tended hose, pulled hose and used hand tools (McCloud tool or shovel) for fire suppression for only 1%, 1% and 8% of the observation period respectively.

In contrast, the fire fighter at Fire 2 applied water for 46% of the observation period and tended the hose for 27% of the observation period. He engaged in little conversation; only 6% of the observation period. This reflects the difference in the roles of the two fire fighters and the detailed information that can be gathered about their work from a helmet mounted camera.

5.4.2 Heart rate

Fire fighting is a physically demanding job. At Fire 1, on steep terrain, the fire fighter had a maximum heart rate of 185 beats per minute. At Fire 2, on flat terrain the fire fighter had a maximum heart rate of 144 beats per minute. Expressed as a proportion of their estimated maximum heart rate (220 beats per minutes – age) they were operating at peaks reaching 96% and 79% of their maximum heart rate which is extremely high. Heart rate data was collected for a longer period than video data because the heart rate monitor had a greater battery capacity than the video recorder.

Table 5.5 - Summary of physiological data from Fire 1 and Fire 2.

	Fire 1	Fire 2
Sample period (hh:mm)	1:59	0:52
Resting heart rate (bpm)	64	68
Average heart rate (bpm)	145	109
Maximum heart rate (bpm)	185	144
Minimum heart rate (bpm)	107	85
Age (years)	28	38
Terrain	Steep	Flat

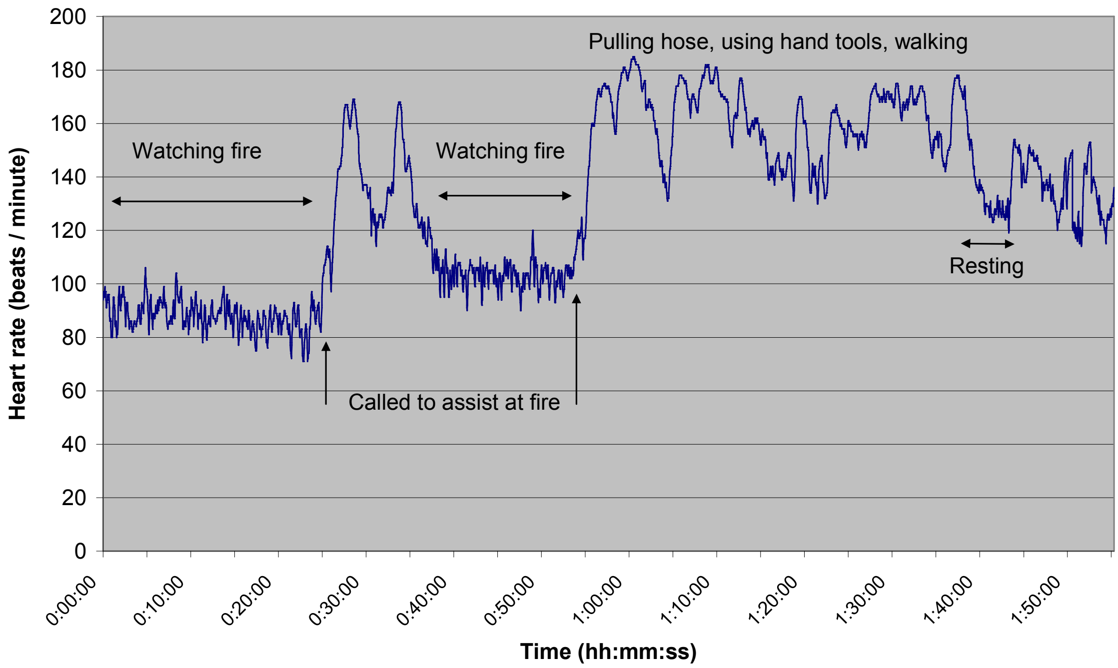

Figure 5.7 - Heart rate of fire fighter on steep terrain (Fire 1) over a period of one hour and 55 minutes.

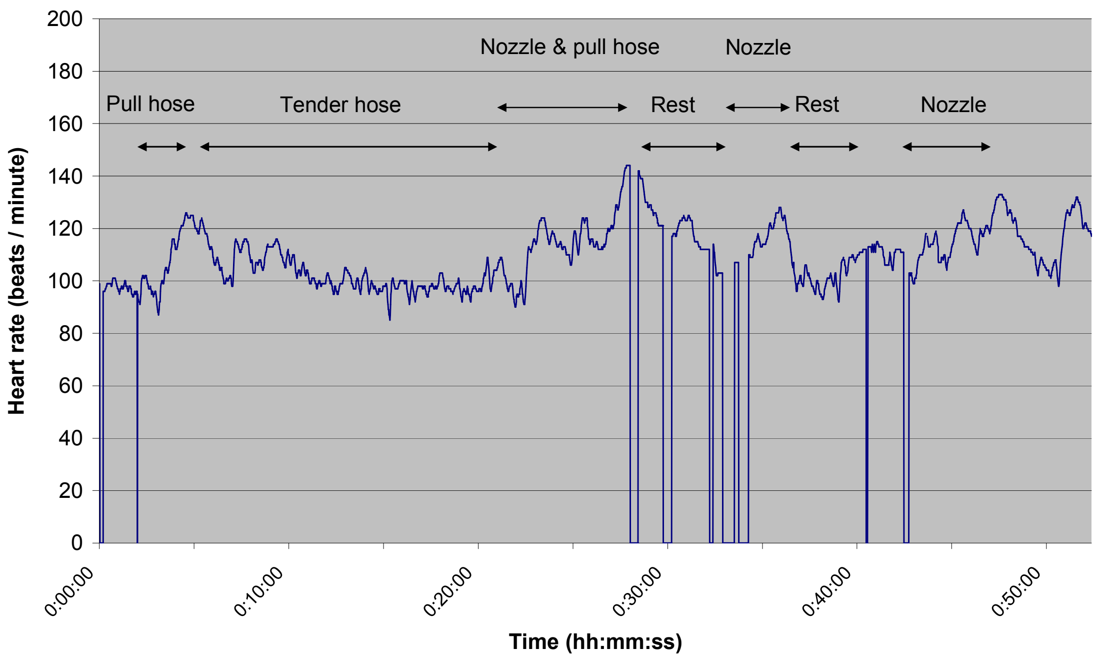

Figure 5.8 - Heart rate of fire fighter on flat terrain (Fire 2) over a period of 52 minutes.

At Fire 1 (Figure 5.7) the fire fighter's heart rate was low while he was watching the fire being ignited by a helicopter. He was standing still watching the progression of the fire and ensuring flames did not spill over the firebreak he was protecting. At 25 minutes he got a radio call that one of his team members was overcome with smoke and he walked and ran up the hill to assist her. He then returned to the road and watched the fire burn and continued to monitor the fire break. At 55 minutes he was called on the radio for assistance at the site where the fire had spilled over into standing trees. He ran up hill to the fire and worked with a hose crew and monitored his crew members.

At Fire 2 (Figure 5.8) the fire fighter was engaged in two main tasks – tending the fire hose or holding on to the hose nozzle directing water at the fire. Occasionally he would pull the hose along the ground to reposition it. His heart rate would climb rapidly when repositioning the hose, would remain constant when tending the hose and climb gradually when on the nozzle. Holding the nozzle and directing the flow of water is physically demanding because the fire fighter has to hold the nozzle against the reactive force of the water.

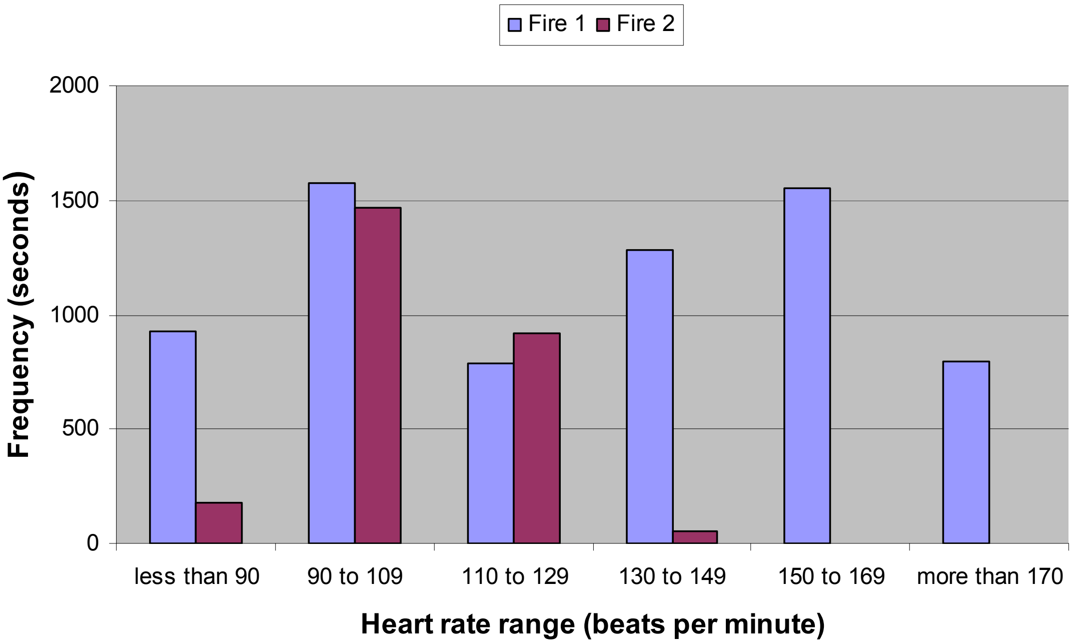

Figure 5.9 - Distribution of heart rates for fire fighters at Fire 1 and Fire 2.

The fire fighter at Fire 1 was engaged in a broad range of activities during the observation period which are reflected in the range of his heart rate readings. There were periods of inactivity, watching the planned burn and considerable periods of high heart rate while running during fire suppression. The fire fighter at Fire 2 had a more stable work environment. He was either tending a hose or holding on to a hose at the fire. The terrain was flat and distances traversed were short. The highest heart rate occurred while pulling a charged (filled with water) hose to reposition it.

5.4.3 GPS

The position of the fire fighters was logged at 10 second intervals with an accuracy of 0.5 % (Coutts & Duffield, 2010; Hampson & McGowan, 2007). The GPS records revealed that the fire fighter at Fire 1 traversed 3160 metres in two hours of data recording and the fire fighter at Fire 2 traversed 1560 metres in one hour and 40 minutes of recording.

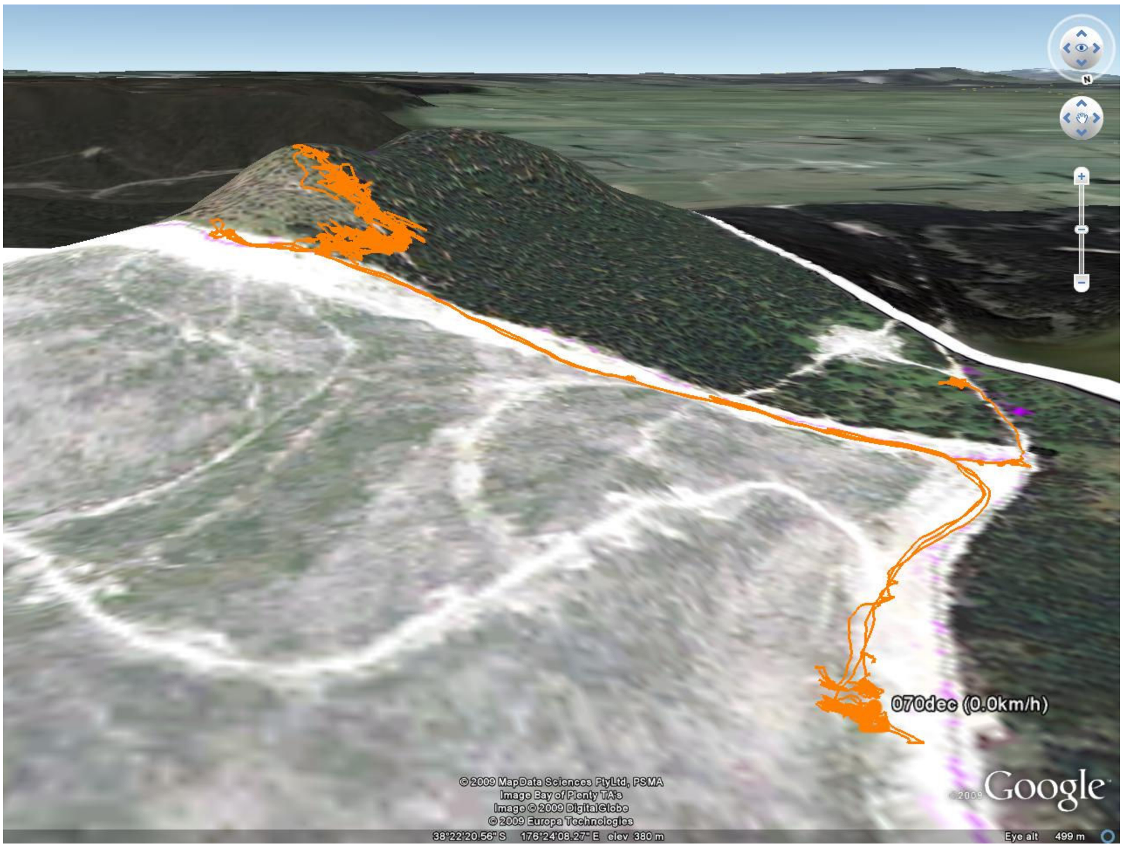

Figure 5.10 - Fire 1: Oblique view from the North of the fire area with the path of the fire fighter indexed to a Google Earth terrain model with an aerial photograph overlay. The fire was at the top left hand corner of the image.

Figure 5.11 - Fire 2: Oblique view from the South of fire area with the path of the fire fighter indexed to a Google Earth terrain model.

The track of the fire fighters can be seen in relation to the terrain by overlaying the track GPS coordinates on a *Google Earth* terrain model (Figures 5.10 & 5.11). However the terrain model does not provide detailed information on the steepness of the ground. A second software package, *Active GPX Player* was used to convert the GPS coordinates into a display of elevation which provides a greater understanding of the terrain being traversed by the fire fighter (Figure 5.12).

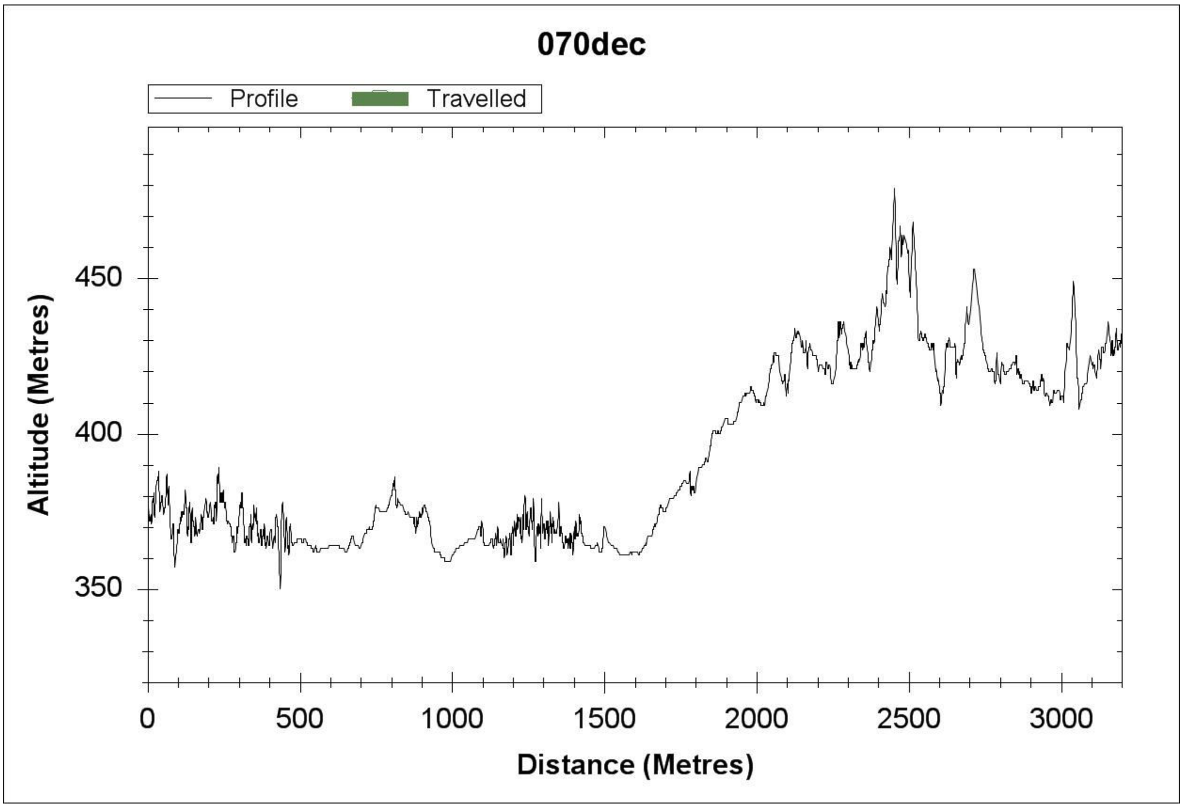

Figure 5.12 - Depiction of elevation of the terrain traversed by the fire fighter provided by Active GPX.

The fire fighter at Fire 1 traversed 3100 metres and climbed from 360 metres above sea level to 480 metres in the two hour recording period. He had numerous journeys up and down hill as can be seen in Figure 5.12. The fire fighter at Fire 2 was walking on flat terrain and his elevation diagram has not been presented.

5.4.4 Integration of data

The results presented so far have shown discrete items of data from the fires without any linking of the data to provide a greater depth of understanding. Using appropriate software these discrete data sets can be presented in a more integrated form.

The behavioural observation software *Observer XT* allows the synchronisation of some of the data streams generated in the fire studies. These data streams can then be presented in ways that allow more informed interpretation. For example fire fighter task analysis (from video) and heart rate can presented together as an *Observer XT* ‘visual analysis’ (Figure 5.13). The figure indicates the dynamic nature of the fire fighting task for fire fighter. He has numerous bouts of walking interspersed with conversation, pulling fire hose and using hand tools. His heart rate during that time varies from 80 to 180 beats/minute.

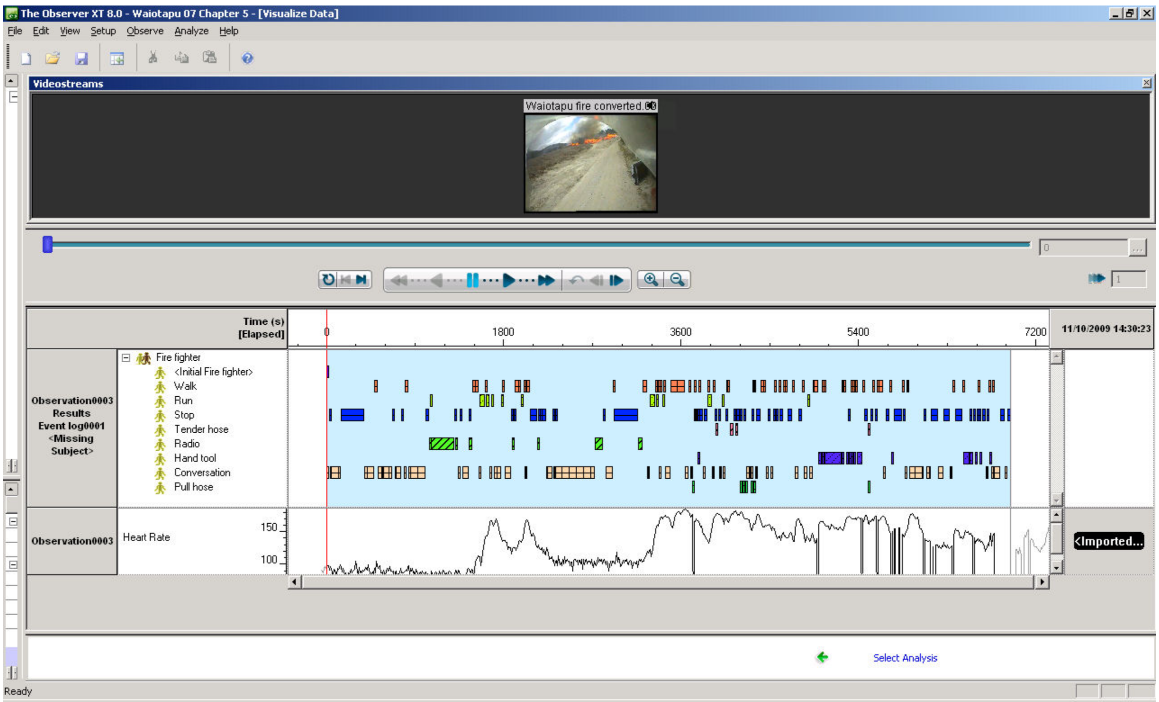

Figure 5.13 - Task analysis and corresponding heart rate of the fire fighter at Fire 1 presented as a ‘visual analysis’ in Observer XT.

Using the coded task data generated from *Observer XT* and combining it with synchronised heart rate data, an analysis of heart rate by tasks was generated for the fire fighters at Fire 1 and Fire 2 (Figure 5.14). The fire fighter at Fire 1 was engaged in a greater variety of tasks than the fire fighter at Fire 2 and at Fire 1 the fire fighter had a much greater average heart rate for each task.

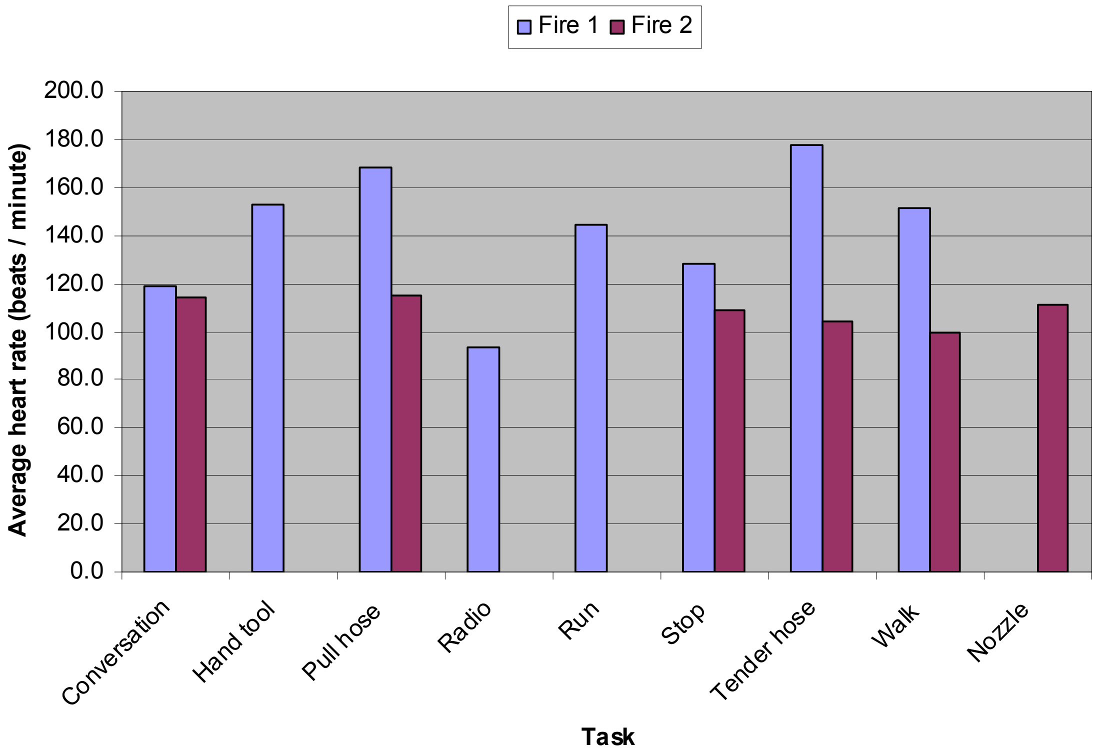

Figure 5.14 – Average heart rate by task for fire fighters at Fire 1 and Fire 2.

Using the integrated system I have been able to develop a high level of understanding of the fire fighters' work environment and responses to that environment. In Figure 5.15 the fire fighter is walking while carrying a McCloud hand tool. His heart rate is 170 beats / minute, he has been talking to another fire fighter about hoses. The air is thick with smoke and there is noise from helicopters flying overhead. He is walking up hill on a slope of approximately 30° at a speed of approximately 2 km/hour. In the past 5 minutes he has traversed 60m of ground. From the video images the terrain is loose dirt and burnt vegetation. In Chapter Six the level of integration and understanding of the work environment will be extended further by post event interview of the fire fighter.

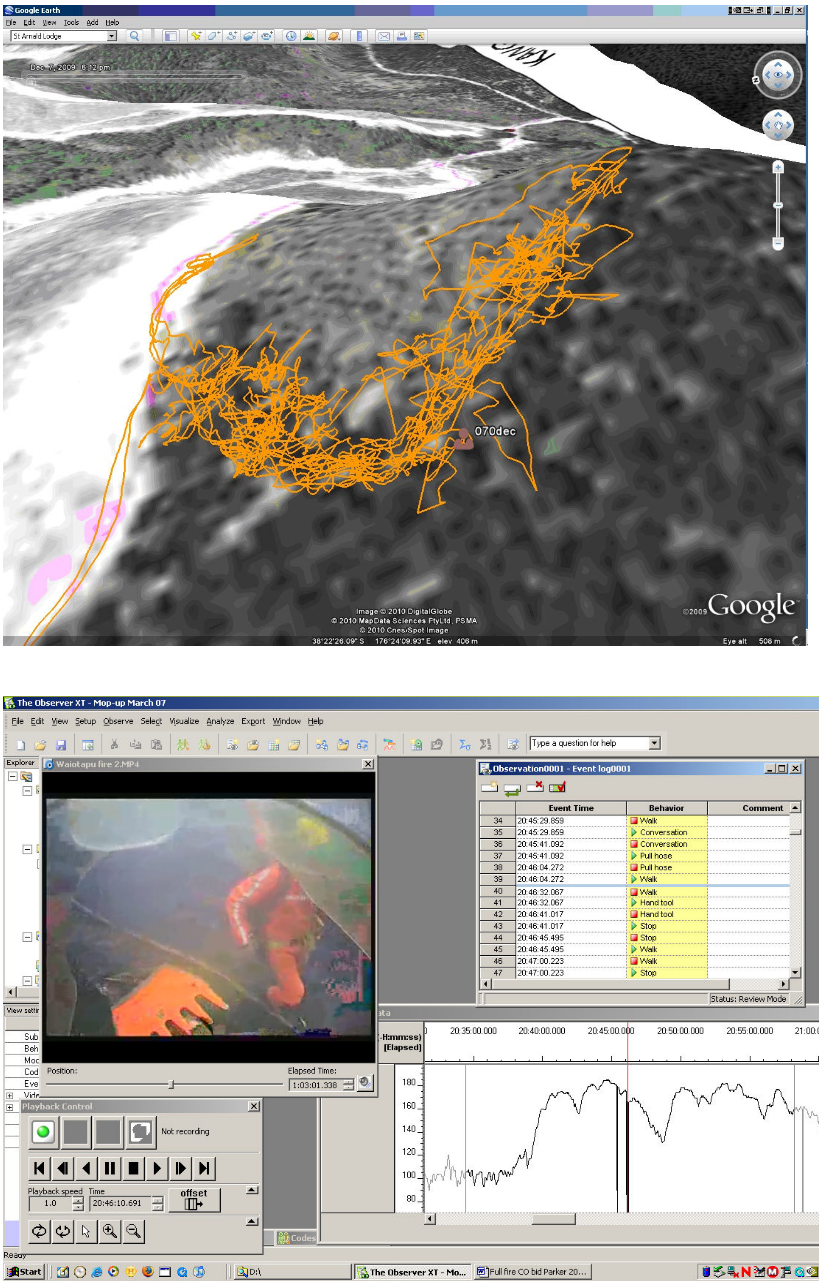

Figure 5.15 –View seen on two computer screens of the synchronised and animated integration of data from Fire 1. On the top screen is the moving position (icon) of the fire fighter's path using Google Earth and Active GPX Player. On the bottom screen is his helmet video image, audio, his heart rate and task analysis displayed on Observer XT. The icon on the top screen moves across the terrain in synchrony with the video and heart rate on the bottom screen.

5.5 Discussion

The data collected at the two fires have provided a comprehensive understanding of the work environment of the fire fighters at real fires. The aims of the study were to measure the workload and productivity of the fire fighters under real fire conditions.

5.5.1 Task analysis

The two fire fighters were working in quite different terrain and had different roles at their fires. The fire fighter at Fire 1 was on steep terrain and was a crew boss. He was assessing the developing situation, speaking regularly with his crew members and maintaining communication with those interacting with his crew. He spent 35% of his time in face to face conversation with other fire fighters, 28% resting or watching the situation, 18% of his time walking between fire crews and 9% of his time engaged in fire suppression activity, exposing 'hot spots' in the soil to burn out.

In contrast, the fire fighter at Fire 2 was a crew member and engaged almost completely with tending the fire hose (27%) and applying water on the fire (46%).

The only other rural fire fighter task analysis I have found reported in the literature was at an experimental burn where the fire fighters, presumably, knew they had additional fire suppression support if needed (Budd et al., 1997a). All the fire fighters in the Budd et al. (1997a) study were crew members using hand tools and no crew leadership tasks were reported. Those fire fighters engaged in their hand tool tasks for almost all of the recording period with very little (1 to 2%) rest recorded.

5.5.2 Heart rate

The following scale has been proposed by Rodahl (1989) to give estimates of workload from heart rate:

Heart rate (beats / minute)	Physiological workload
Less than 90	Light
90 – 110	Moderate
110 – 130	Heavy
130 – 150	Very heavy
150 -170	Extremely heavy

According to this, all tasks except observation of fire can be classified as "Heavy" resulting in average heart rates between 110 and 130 beats/minute. These results are similar to New Zealand forestry tasks where average heart rates between 115 and 130 beats/minute are common. Examination of detailed heart rate traces (Figures 5.8 and 5.9) indicated the intermittent nature of fire suppression tasks. To maintain a high average work rate the fire fighters take brief rests by changing tasks or slowing down – 'self pacing'. This self pacing is also reported by Budd (2001) for Australian rural fire fighters.

Workload of the two fire fighters in this study was measured by heart rate recording. It is difficult to directly compare the two fire fighters in the studies presented here because they were of different ages, working in different terrain and undertaking completely different tasks. But this series of studies was to determine if physiologically useful data could be collected in the field at real fires under normal operational conditions and not to compare fire fighters or fire fighting on flat and steep terrain.

Average heart rate for the two fire fighters during the observation period was 145 and 109 beats/minute respectively for steep country (Fire 1) and flat land (Fire 2). This compares with (Budd, 2001) who reported that Australian rural fire fighters, at ‘realistic’ experimental bush fires, exhibited average heart rates of 152 beats/minute.

Budd (2001, p. 381) also went on to highlight the limitations of laboratory experiments and stated that: “Contrary to the findings of laboratory studies heart rate (and rectal temperature) were not changed by variations of 36-217 min in work duration; 406-630 W in energy expenditure; 15-34 degrees C in wet-bulb globe temperature (WBGT), 7-27% in body fat content; or 31-63 ml min(-1) kg(-1) body mass in maximum oxygen uptake (VO2max)”. Average heart rate in Budd’s study was 152 beats/minute. He concluded that the stability of the fire fighter’s heart rate is explained by the self pacing of work and by the wearing of clothing that allows unrestricted evaporation of sweat. However the higher heart rates found by Budd did not include rest periods and conversation which I report in this study.

5.5.3 GPS

The fire fighters covered remarkably long distances during the observation periods. None of the fire fighters, on questioning, realised they covered so much terrain in the normal course of their work. In this respect fire fighting differs from forestry tasks which remains more localised. Seto, Knapp, Zhong and Yang (2007) used GPS vests to track the occurrence of water contact of villagers in schistosomasis prone regions in China. They too reported that the villagers did not realise they travelled such great distances each day.

There are no published reports of the movements of rural fire fighters at fires. The data in this study has been used, primarily, in a qualitative way to understand where on the terrain the fire fighter was positioned when they were at the fire.

5.5.4 Integration

All of the streams of data have been integrated together in the form of a multimedia ‘playback’ with video, heart rate, task analysis and GPS location on a moving map (Figure 5.15). Informally this presentation has been viewed by fire fighting trainers and fire coordinators who can see value in the multimedia playback for ‘debriefing’ situations where aspects of the fire can be ‘relived’ and in training to show novice fire fighters the noise, poor visibility and apparent chaos of a real fire.

5.6 Limitations of the study

There are two main limitations to be noted when considering the value of this study. The first is the small sample size, which is largely an artefact of the nature of the work and the difficulty of ensuring researcher presence, obtaining consent, and kitting workers up under these emergency conditions. The two fire fighters involved in the situations reported in this chapter, did, however, exhibit work patterns that reflected different terrain and fire conditions.

The second limitation that should be considered is that I did not measure the work capacity of individuals taking part in the study but rather provided a simple presentation of heart rate. This again reflects the complexities of the field situation of participants and researcher and also the part that heart rate measurement played in a much more comprehensive array of data collection methods. Nonetheless, the possibility of measuring the work load and productivity of rural fire fighters has been established.

5.7 Conclusions

The methodology used in this study has provided for the collection of robust and original data. Additionally, two of the most significant barriers – those of gaining acceptance, and being usable by workers in the field without scientific backup – have been overcome.

Further, the study has demonstrated that physiological workload data and productivity data can be effectively collected at real fires, without compromising fire fighter safety in a complex and unpredictable environment. This is the first time, to my knowledge, such detailed rural fire fighter data has been collected. Whilst only two fires and two fire fighters were investigated, the results show that useful data can be successfully obtained under extreme work conditions.

Finally, the collection of objective workload data during execution of the task in combination with task descriptive data provides an unparalleled opportunity to begin to explore the decision-making processes during rural fires. The important contribution of this work is not in the particular measurements collected in the field but the integration of the field data into a meaningful aggregation of data. The examination of this aggregation of data enables the researcher to not only journey with the fire fighter through his work, but be armed with objective measures of distance, speed, heart rate, time on task, altitude and subjective measures of air conditions, visibility and acoustic environment and be able to hear verbal communication.

This research provides a solid advance in the knowledge needed to understand rural fire fighting, and is further explored in Chapter Six.

6 Reflective Phase

6.1 Introduction

In the previous two chapters, I discussed the activities of loggers and fire fighters as recorded whilst carrying out their work. It was established that both tree felling and rural fire fighting are occupational tasks that can be considered dangerous and demanding, and they both require skills that are developed over time and ‘on the job’. People can be taught components of tree felling and rural fire fighting under controlled conditions, but under real work conditions there are many aspects of the physical environment that are not under the control of the worker. Further, the particular circumstances of each event cannot necessarily be foreseen.

The aim of this phase of the wider study was to explore reflective interview as a tool to establish ways decisions about possible courses of action are made, in these two cases, under extreme work circumstances. The use of reflective interview also enabled me to gain deeper understanding into data collected from earlier stages, and provided rich qualitative insights into work activity. Reflective interview was used to collect the thoughts of the participant after fire fighting and a trainer after tree felling, based on their responses to video collected while performing those tasks. The interviews were used to gain a greater depth of understanding of the workers’ work strategies and decision making in relation to their tree felling or fire fighting activities. I was interested in gaining insight into what was actually happening in the process of tree falling and fire fighting, the subjects awareness of the physical demands of the work being done and the reasoning and cognitive activity of them as workers.

In this chapter I report on what emerged when subjects were presented with the recordings of their work activities (fire fighting) or others work (tree felling) and asked to reflect on them.

6.2 Theoretical background

Reflective activity in a work context is defined as the “activity by which subjects (or a group of subjects) take work itself as an object of reflection” (Mollo &

Falzon, 2004, p. 531). Reflective activity is central to the construction and evolution of technical knowledge (Mollo & Falzon, 2004). It thus makes sense to use the reflections of tree fallers and fire fighters observing their own work, or others, to gain a greater understanding of their mental processes and use of operational knowledge. This is particularly so because fallers and fire fighters engage in 'performance self-monitoring' – the delegation of responsibility to the operator to decide whether or not the output conforms to its predefined specifications. There is no one looking over their shoulders, as they work, monitoring their actions, and success often depends on routine responses under non-routine circumstances. Prior training in appropriate responses enables fire fighters to work together under extreme circumstances, as they can reasonably predict what others' responses might be to the changing conditions they are faced with. Effective and safe practice requires constant reference back to accepted protocols, providing at least some predictability of response, even under conditions where 'commonsense' would tell one to act in a way that is ultimately less safe (e.g. Weick, 1993).

It has been asserted that "Encouraging reflective thinking and critical evaluation is particularly challenging in disciplines that focus on learning by doing" (Cherry, Fourier & Stevens, 2003, p. 1). Cherry et al.'s claim was made in relation to the teaching of dance composition, but similar challenges are encountered when trying to improve occupational safety and health or productivity of tree fallers or rural fire fighters. Fallers and fire fighters are engaged in tasks that are best learnt by actually felling trees or fighting fires and not by learning facts in a classroom.

Reflective thinking in these situations can be aided by a range of recording mechanisms. Video is one means by which to provide a "concrete representation" (Cherry et al., 2003) of the student's work which both the student and instructor can later refer to. This provides a common reference point, without which: "…conversation relies on the possibly faulty assumption that the participants in the conversation have a shared mental model of the [performance]" (Cherry et al., 2003, p. 2). In my study, the 'performances' to be recorded are those of tree felling or rural fire fighting.

Without particular reference to reflective interview, Cherrett, Wills, Price, Maynard and Dror accept that video has a place in training to improve health and safety and improve productivity. They state that:

> “Traditional lecture-based courses often fail to recreate the dynamic realities of managing H&S on site and therefore do not sufficiently create deeper cognitive learning (which results in remembering and using what was learned). The use of videos is a move forward, but passively observing a video is not cognitively engaging and challenging, and therefore learning is not as effective as it can be” (2009, p. 1124).

By reflecting on the video, and by viewing one’s own work or the work of others, a greater depth of understanding of the work and one’s own performance is achieved.

6.2.1 Verbal protocol

Verbal protocol methods have been developed that are well-suited to collecting workers' verbal reflections. Kirwin and Ainsworth (1992, p. 71) state that the main aim of verbal protocols "is to obtain (or infer) information on the covert psychological processes which underlie performance, which are not directly observable, such as knowledge requirements or mental processes involved." However, whilst verbal protocol methods have been used to investigate cognitive tasks, they have only recently been used to investigate workers' thoughts during manual handling tasks (see Ryan & Haslegrave, 2007a & b; Ericsson & Simon, 1993). Ryan and Haslegrave admit to difficulties applying these methods, pointing out that:

> "Concurrent verbal protocol reports can be affected by the difficulty of putting thoughts into words and problems verbalising each thought which comes to mind within the time constraints of the task, and with the potential for some interference with the execution of the task during verbalisation" (Ryan & Haslegrave, 2007a, p. 178 citing Ericsson & Simon, 1993).

Further, Omodei and McLennan (1994, p. 1415) suggest that "… there is evidence that verbalisation during the performance of a complex cognitive task which does not normally involve verbalisation usually disrupts the cognitive processes involved (Ericsson & Simon, 1980; Genest & Turk, 1981) …".

These limitations are particularly germane when considering applying verbal protocols within potentially dangerous work environments, like fire fighting and logging. The methods are not practical, since tree felling and rural fire fighting are complex dynamic tasks where concurrent verbal reports from the participants cannot be used without drastically compromising both effectiveness on the job, and worker safety. Hence, post event methods must be used to elicit information from the participants, through the use of retrospective verbal protocols. Usual research techniques to elicit information after the event are 'thought listing', where the subject is asked to list whatever thoughts they can recall having had, and detailed closed-ended questionnaires (Martin, 1992). However, both of these approaches are subject to reliability issues due to varying literacy levels of the subjects and their accessibility. Moreover, “the complexity of the event streams involved in dynamic decision-making environments is such that large gaps and distortions occur in such past-task reports” (Omodei & McLennan 1994, p. 1412). Retrospective verbal protocol reports can also be affected by problems with recall of the range of thoughts during the task, and such retrospective reports can be biased by retrospective reasoning or rationalisation of the thoughts (Ericsson & Simon, 1993; Ryan & Haslegrave, 2007a).

Yet there are some clear advantages associated with retrospective verbal protocols, especially given claims that they are useful for collecting different types of information from concurrent protocols. For example, in a study of computer monitor use, Bowers and Snyder (1990) reported that concurrent verbal protocol collected procedural information from subjects whereas subjects using the heavily cued video retrospective verbal protocol gave explanations and design statements. Another study using interview while viewing video of self-performance sought to understand the temporal dynamics of acrobatic sport (Hauw & Durand, 2008). Yet another, this time an occupational study, was reported by the French ergonomists Mollo and Falzon (2004) who used reflective interviews of saffron farmers watching video of others harvesting saffron. Their objective was to “propose concrete helpful tools of reflective activity allowing saffron farmers to accelerate the construction, the explanation and the spreading of technical knowledge based on practice” (Mollo & Falzon, 2004, p. 531). They report that if the video recording of work is used a long time after the observations, it does not act as a recall but as an aid for rebuilding the activity.

This is in contrast to Ryan and Haslegrave (2007a) who state that reports from retrospective video appear to be simple commentaries using hindsight about the events the subject were watching. They suggest that “these (video assisted) reports may therefore be more susceptible to the effects of bias during reconstruction … but it is difficult to either prove or disprove this” (Ryan & Haslegrave, 2007a, p. 187). Ryan and Haslegrave (2007a, p. 187) reach the conclusion that:

> “On the basis of the findings on the potential for bias during reconstruction and problems identifying task demands in this type of report, self-observation of video material will have limited practical use as a general method for the collection of information on the range of things that workers actually pay attention to during a task.”

It is worth noting, that the authors reach this conclusion as a consequence of an investigation of verbal references by participants to postural and biomechanical loadings – yet perhaps their participants never actually thought about their own postures.

6.2.2 Event recall of head mounted video

There is evidence that audio and video-stimulated event-recall (Lyle, 2003) has been successful in assisting subjects to recall thoughts and feelings which they experienced in a recent event. Video recordings have been used in psychotherapy and sport performance (e.g. Blanksby, 1986; Ivey, 1974). This technique has most commonly been used from the ‘outsider’ perspective where the subjects view themselves and their actions from the perspective of a third party: they appear as actors in the scene. Omodei and McLennan (1994) describe an alternative approach where the video record serves as a stimulus to assist the subject recall important mental events (thoughts, choices, conflicts, uncertainties, positive and negative feelings, decisions) which determined the observable behaviours. This ‘insider’ approach has not been commonly used to study work in natural settings due to the difficulty of recording events without the recording itself disrupting the tasks being studied. Overcoming this barrier might ameliorate some of the problems referred to by Ryan and Haslegrave (2007a). Using verbal protocol analysis of point-of-view retrospective video allows the participant to potentially ‘relive’ the event from the same perspective as when they participated in the event (Omodei, McLennan & Whitford, 1998).

Some of the obstacles to using retrospective accounts based on video footage emerge because conventional video recording of work utilises fixed or hand held cameras. Omodei and McLennan (1994, p. 1413) identify four limitations of such camera systems in the work or sport environment: the camera or recording personnel are likely to be intrusive and disrupt the processes being studied; many complex decision making activities in natural settings involve subjects moving rapidly over considerable distances, as at emergency, accident and disaster sites and at sporting events; many real world settings result in the camera’s line of sight being frequently blocked; and, lastly, the camera’s perspective provides information which differs in important details from that available to the subject such as broadcast camera versus the umpire’s perspective on a potential sports-rule violation.

All of these limitations can be addressed or even overcome by the use of head mounted video cameras. Video images that move through the environment, in the same way as the human visual system, have been demonstrated to be more informative and impressive for a viewer, than conventional hand held or fixed video which follows a subject moving through the environment (Kipper, 1986).

6.3 Methods

6.3.1 Data collection

The video and audio recording methods have been presented earlier in the thesis, but I will briefly review them here to provide context for the ensuing discussion, and to point out the ways in which limitations of former reflective studies of hard physical work were addressed in this phase of the research. In particular, it is useful to recall that different configurations of recording equipment were used for tree fallers and rural fire fighters because of operational limitations and different requirements for information. In tree felling I required information about the direction the tree faller looked and this was provided by a helmet mounted video camera. I also needed to know what task the tree faller was engaged in. This was provided by a shoulder mounted video camera which focussed on the tree faller's hands and chainsaw. In fire fighting a single helmet mounted camera was used. A second camera on the fire fighter's shoulder would have provided additional information but required the carrying of an additional video recorder. As fire fighters often wear a backpack with shoulder straps an additional shoulder mounted camera would have hampered this while also adding more weight and wiring to the fire fighters ensemble. In short, while it was impossible to eliminate negative impact on the work situation, every attempt was made to minimise any impediment to the worker in carrying out their work. Details of the recording equipment used to capture the actions and sounds of tree fallers and fire fighters are set out earlier in Chapters Four and Five.

6.3.2 Task analysis

As detailed in Chapters Four and Five the tree fallers and fire fighters under observation engaged in a limited range of tasks (Tables 6.1 & 6.2). The video files were imported into *Observer XT*. Coding of the video file into an event log was performed using the *Observer XT* observation window.

Table 6.1 – Tree felling task elements

Element	Description
Assess	Look at the tree – to assess tree weight distribution and wind direction and look at surrounding environment
Clear scrub	Cut undergrowth for access to tree and to place felling cuts
Top scarf	Insert top cut of scarf
Bottom scarf	Insert bottom cut of scarf
Wing cuts	Insert cuts either side of scarf
Backcut	Insert cut which cases the tree to fall
Wedge	Inset wedge into backcut and hit with hammer
Walk	Walk between trees and into and out of felling area
Waiting	No obvious activity
Look up	Looking at canopy of trees

Table 6.2 – Fire fighting task elements

Element	Description
Walk	Walk through the terrain
Run	Run through the terrain
Stop	Stop
Radio	Talking on the radio (may be walking at same time)
Hand tool	Using a hand tool such as a McCloud tool or shovel to expose burning material
Conversation	Talking with other people
Pull hose	Moving an unrolled hose

6.3.3 Auto and allo-confrontation reflective interviews

Having gathered the rich video data for the previous phases of this study, I used individual auto-confrontation interview (Mollo & Falzon, 2004) applied to one fire fighter and allo-confrontation interview applied to one tree faller. With auto-confrontation interview, the participant verbalises about the (video and audio) recording of their own activity. Individual auto-confrontation is used to better understand the processes underlying the execution of a work task. According to Mollo and Falzon, (2004, p. 533), the method aims to induce participants:

> "To become aware of the procedures they use to fulfil their tasks, thanks to the description of their work activity and;
>
> To clarify these procedures in order to decipher the cognitive processes involved in the work activity, which are not necessarily conscious, but which can become so, thanks to the process of externalisation of knowledge."

Unlike Mollo and Falzon, I am not using the method to "decipher the cognitive processes" of the individuals involved in the work activity, but rather, to gain a greater depth of understanding of the context of the work. I wanted to gain underlying information, which is not obvious from examining video or audio alone, about how the work is organised, why particular events occurred and why particular work methods were used.

With allo-confrontation interviews, the participant is asked to verbalise about an activity they practice while viewing a video of someone else doing that activity (Mollo & Falzon, 2004). Some of the expected benefits of this method are: "an awareness of other forms of knowledge which leads participants to become aware of their own activity with regard to that of others; [and] the evaluation and the justification of their procedures compared to those of others" (Mollo & Falzon, 2004, p. 533). Both of these benefits are valuable to my study. Tree fallers do not get the opportunity to view the work of other tree fallers by actually 'looking over their shoulder' because the work is too dangerous. The participant viewing the video has the opportunity to be removed from danger and concentrate on, explaining to me, the work methods of the tree faller who has been videoed.

The tree felling interview was performed 18 months after the field data was collected and the fire fighting interview was performed 20 months after the field data was collected. The large time lag was because an interview component was not included in the original research plan. This did not prove a difficulty because the purpose of the interview was to understand the knowledge used in performing the work rather than “to analyse the specific cognitive processes peculiar to a task carried out at a particular time” (Mollo & Falzon, 2004, p. 536).

The interviews were conducted in a private office. The objectives of the study were explained to participants and they were asked to provide as much detail as they could recall about the video clips being displayed. Participants were asked to provide informed consent to be audio-recorded during the interview.

Each participant was first shown a video clip of a full work cycle. For tree felling the video clip consisted of images from the two cameras synchronised in *Observer XT*, providing data for the tasks tabulated in Table 6.1. For fire-fighting, where is there was a greater range of activities; a fairly discrete set of activities (the task of running out a hose) was selected as a focus for the interview. This particular task was selected because the fire fighter was running the hose away from the fire which appeared unusual. I hoped that interview would provide the fire fighter with an opportunity to more fully explain his actions.

The video clip was controlled by the participant who provided an explanation of what was happening in the scene. At various points, the interviewer prompted the participant to give more detailed or accurate comments about their work activity with questions such as: “What are you doing now?”, “Why are you doing that?”, “Who is that person?”.

The interviews were recorded with the software package *Camtasia*. In this way the anonymity of the participant was ensured and vocal responses were synchronised with recorded task activity. Also the participant could point at events occurring on the recorded video clip with a cursor and stop and start the video to clarify explanations. All these actions were recorded by *Camtasia* as a video file.

6.4 Results

6.4.1 Fire fighting event

A 10 minute 45 second video clip from a real forest fire was used as stimulus for the reflective interview. The video clip comprised conversation, walking, running and interaction with other fire fighters.

Understanding from naïve viewing

Viewing the video without post event commentary by the fire fighter has allowed the following understanding of events.

> The fire fighter and colleagues are pulling a hose up the hill. The water flow has reduced and the fire fighter is asked to get another hose. He retrieves another hose, at speed, but then runs the hose down hill, presumably away from the fire. As hose fills with water he takes the kinks out of it. He then has a conversation with other fire fighter about water pumps and water dams (small portable water reservoirs).

The task analysis provides information on when an event happened and some information on the task, but there is no 'who', 'why' or 'where' information. Who? - from the original video we only know the fire fighter wearing the camera: he is a Department of Conservation (DOC) fire fighter. The external observer does not know who the other participants are, but it is reasonable to assume that the fire fighters in orange with 'DOC' on their backs work for the Department of Conservation too. The external observer does not know who the fire fighters wearing yellow overalls work for. Table 6.3 documents the activity and sound evident from close analysis of the video and sound data.

Table 6.3 - Transcript of voices heard on the 10 minute 45 second video clip partitioned into 15 second segments. The contents of the 'Who', 'What', 'Why' and 'Where' cells were created by interpretation of the video and audio by me. "FF" refers to fire fighter talking and colour of their clothing.

Time	Voice	Who	What	Why	Where
1:02:00			Walking along hose line		Somewhere on hill but don't know where fire is
1:02:15			Getting his breath back		
1:02:30	FF: "That's all we've got mate"		Helping to pull hose		
1:02:45	FF yellow: "We're not getting any water out"		Walking along hose line		
1:03:00	FF yellow1: "We've got no water" FF orange: Unintelligible. FF "Yeah"		Standing looking at other fire fighters on hose line. Helicopters overhead		
1:03:15			Expose hot embers		
1:03:30			Walk up hill along hose line, FF yellow2 with hose pack behind him		Too much smoke to see fire
1:03:45	FF yellow1: "Hey guys it's just that the pump won't push any higher than that there OK. Can you just relay back that to push any higher we need another Wajax … another pump or something eh"				
1:04:00	FFyellow1: "If we want to push higher than that" FFunseen: "I'll just follow this contour a bit" FFyellow1: "Alright mate, beauty".				

Time	Voice	Who	What	Why	Where
1:04:15	FF: "You want me to get in and break up some of that shit or not?" FFyellow1: "Ah, at this stage just…" FF: "Dampen it" FFyellow1 : "Yeah" FF: "All right"		Heavy breathing and talking to FFyellow1		
1:04:30	FF?: "Hey Graham" FFyellow1: "Yeah" FF?: "It's just that we have reached the height that the Wajax will push it up to Ok. When we drop down a couple of metres from there it will pump again"		Standing, breathing hard		
1:04:45	FFyellow: "Hey, are you getting good flow again?" FFhose: "I've dropped down a bit though"		Spits. Standing still with McCloud tool		
1:05:00	FFyellow1: "I'd go up to that same height again. Because if its gonna work we could put another hose on the end. Do you reckon it will still go" FFhose: "Yeah" FFyellow1: "Can we have another hose" FF: :Yeah, I'll grab that pack" FF: "Have you got a hose pack there Bry"		Starts running back down hill to get another hose pack	To get another hose pack … no one has told him to.	
1:05:15	FFBry: "Sorry" FF: "Is there a hose pack there"		Running fast down hill		
1:05:30			Collects hose pack from FForange and runs back up hill with pack.		

Time	Voice	Who	What	Why	Where
1:05:45	FF: "Want me to tell them the Wajax is on the way?" FFBry: "And the dam" FF: "Yeah". FFyellow1: "Great stuff" FF:"She said they are setting up a Wajax and a dam mate, as soon as they can"		FFyellow? runs down to meet FF to collect hose pack	Passes on message to FFyellow?"	
1:06:00			Walks up the hose line, breathing very heavily		
1:06:15	FFyellow?: "Run this back down eh" FF: "Yeah"		Is given fresh hose to run out down hill		
1:06:30			Laying hose out down hill. Breathing very heavily.		
1:06:45	FF: "That's it mate drop it" FFBry: "Sorry" FF: "That's sweet as"		Run hose down as far as FFBry. Spits	Don't know why hose is being run downhill away from the fire	
1:07:00	FFBry: "unintelligable … won't burn" FF: "Yeah I know"				
1:07:15	FF: "Within 5 minutes mate it jumped" FFyellow1: "Has someone got a radio there?" FF: "What do you want us to convey?" FFyellow1: "We just want them to switch the water off for a while while we connect XXXX"				
1:07:30	FF: "You've got a radio to the pump eh. Tell them we want water off just to change a coupling"		Runs back down hill to person with radio	Running down to pass on message to someone with a radio	
1:07:45	FForange: "Ian from Joe. We want water off over" FF: "To change a coupling"				

Time	Voice	Who	What	Why	Where
1:08:00	FForange: "We are going to change a coupling up here once we get water off over" FForange: "Can you let us know when it's off please over"			Need the water off so they can change a coupling on the hose	
1:08:15	FF: "You fellas have got your gloves, you should chuck them on ok" FForange: "Waters off" FF: "Yeah"		Talking then runs back up hill		
1:08:30			Runs up to new hose and FF up hill. Then signals with hand. Noise from helicopters overhead	Tells guys up the hill on end of hose that the message has been passed to turn off water. Then signals to start water again to FF with radio down hill	
1:08:45			Handling fresh hose and moving up hill	Don't know why he is handling new hose	
1:09:00			Handling hose still		
1:09:15	FFyellow1: "You right?" FF: "Yeah"		Hose filling with water, FF handling it		
1:09:30	FFyellow1: "Good one guys, excellent"		Standing looking up and down hill		
1:09:45			Walks up hill a bit and looking at full hose		
1:10:00			Spits and unhooks hose from branches	Still looking up and down with hose and handling hose	
1:10:15			Handling hose and screen goes blank		
1:10:30			Standing looking at hose		
1:10:45	FF: "That it"			Apparently doing nothing … just standing around.	

Time	Voice	Who	What	Why	Where
1:11:00			Moving hose … heavy breathing		
1:11:15			Moving hose … heavy breathing		
1:11:30	FF: "You can't ask for better training than this man" FForange: "xxxx send someone down … set it up…				
1:11:45	FForange: "I'll take Bry out and a couple of shovels and we will wait for further instructions" FF: "Are you happy to do that" FForange:"Yeah … have you still got the radio?" FF: "No I left it with Zoe down the bottom"				
1:12:00	FForange: "So we've got Ian anyway" FF: "He's our pump man" FForgange: "Water on just above it xx" FF: "We are going to have to get them to jump up one if we can. Bring on up to that other dam are we?".				
1:12:15	FForange: "The other dam is going to come in just above the vehicle here" FF: "WHAT DO YOU WANT? WHAT DO YOU WANT?" FFyellow1: "Yeah yeah keep coming" FF:" You fellas go and do that and me and Bridgie will keep on this line"			People up hill want more slack in the hose	

Time	Voice	Who	What	Why	Where
1:12:30	FF:"That's it mate, that it" FFyellow1:"Is that it?" FF:"There's no more" FForange:"Alright if I take Bridgie?" FF:"Yeah"		Dragging hose	No more slack in hose	

Understanding from reflection of fire fighting

The participant sat in front of a computer monitor which was showing the 15 minute video clip. He controlled the viewing to the extent that he could start, stop and rewind the clip and point to features of interest in the clip with the mouse cursor. A microphone was fitted so that the explanation of what was happening in the video clip could be more accurately captured on audiotape. Reflections were transcribed verbatim in 15 second blocks and reported as “Fire Fighter reflective transcript” in Table 6.4. Upper case denotes researcher prompts

Table 6.4 - Transcript of voices in the original 10 minute 45 second video clip and transcript of the participating fire fighter viewing the clip and explaining events unfolding. The contents of the 'Who', 'What', 'Why' and 'Where' cells were created by interpretation of the video and audio by me. My questions in uppercase.

Time	Voice	Fire Fighter Reflective Transcript	Who	What	Why	Where
1:02:00				Walking along hose line		
1:02:15		I've got a three person crew, two ladies with me. We are at the end of a 'dozer line. You can sorta see that fresh earth where the dozer has got to.	DOC	Getting his breath back		At the end of the line created by a bulldozer
1:02:30	FF: "That's all we've got mate"	We are just assisting these guys with their hose line. Just trying to get any slack that we can so they can continue up along that right hand flank, up along the edge and pinch it off at the top. You can see the bulldozer. That's where it got to.	Others	Helping to pull hose	Getting the slack out of the hose so they can continue up the right flank of the fire	Right flank of fire
1:02:45	FFyellow: "We're not getting any water out"	We are just checking the integrity of that hose line, making sure it's not sitting on anything hot and and just trying to get as much slack for these guys as we can up at the top of the line.		Walking along hose line	Checking the hose keeping it off hot spots and giving slack for the fire fighters further up the hill	
1:03:00	FFyellow1: "We've got no water" FForange: Unintelligible. FF "Yeah"	We are also assessing hot spots along the edges here. HOW HOT IS THE GROUND UNDER YOUR FEET? It's not overly hot because we are not lingering on any of the burning stuff. It got through quite quickly. It's done the top layer, what we call the duff layer		Standing looking at other fire fighters on hose line. Helicopters overhead	Checking for hot areas The hot spots might flare up again	
1:03:15		Not really burning any heavy materials, not really generating that heat down below. See a bit of a hotspot in there. Trying to break that up. Really we wanna get some water in there. I think I go and ask this guy next.		Expose hot embers		
1:03:30		SO WHO IS IN CHARGE HERE? What we have got is we have got a bit of an interesting situation. I'm crew boss of our crew with these two ladies and we have got these two guys up here who aren't operating as a crew but they are sort of on the end of the hose.		Walk up hill along hose line, FF yellow2 with hose pack behind him		

Time	Voice	Fire Fighter Reflective Transcript	Who	What	Why	Where
1:03:45	FFyellow1: "Hey guys it's just that the pump won't push any higher than that there OK. Can you just relay back that to push any higher we need another Wajax … another pump or something eh"	They have got no communications back to the pump which is quite important so I've taken on the role of you know because I've got a radio just to act as an intermediary between these two		Pass messages to person down hill with radio communication with pump	Two fire fighters on hose have no communication back to pump	
1:04:00	FF yellow1: "If we want to push higher than that" FF unseen: "I'll just follow this contour a bit" FFyellow1: "Alright mate, beauty".	So this is when we get a message to go back to set up another dam with some more altitude and another pump so we can pump out because what's happening is we've got a Wajax pump way back down the hill and it gets to a point where it can't pump any higher			set up another dam and pump higher because current pump too low	
1:04:15	FF: "You want me to get in and break up some of that shit or not?" FFyellow1: "Ah, at this stage just…" FF: "Dampen it" FFyellow1 : "Yeah" FF: "All right"	And these guys are thinking that they can't they can't pump any higher. We've also got the helicopters working right up the top there trying to stop anything getting over the top of the hill.		Heavy breathing and talking to FFyellow1		
1:04:30	FF?: "Hey Graham" FFyellow1: "Yeah" FF?: "It's just that we have reached the height that the Wajax will push it up to Ok. When we drop down a couple of metres from there it will pump again"	ARE YOU FEELING PRETTY KNACKERED THERE? ARE YOU BREATHING HARD? Yeah, I'm breathing heavy because I am running up and down the hill quite a lot and probably a little bit tired but still got the adrenaline pumping for sure.		Standing, breathing hard		
1:04:45	FFyellow: "Hey, are you getting good flow again?" FFhose: "I've dropped down a bit though"	HOW STEEP IS THAT HILL? Be about 35 degrees I think, from memory, that's going back a couple of years, but probably 30 35 degress from memory, reasonably steep		Spits. Standing still with McCloud tool		

Time	Voice	Fire Fighter Reflective Transcript	Who	What	Why	Where
1:05:00	FFyellow1: "I'd go up to that same height again. Because if its gonna work we could put another hose on the end. Do you reckon it will still go" FFhose: "Yeah" FFyellow1: "Can we have another hose" FF: :Yeah, I'll grab that pack" FF: "Have you got a hose pack there Bry"	IS IT HOT. IS THERE A LOT OF HEAT RADIATING? There is not a lot of radient heat, it is warm. More an encumberance with the gear having the helmet on, all your overalls and things like that, breathing mask		Starts running back down hill to get another hose pack	Hot with all the gear on	
1:05:15	FFBry: "Sorry" FF: "Is there a hose pack there"	WHAT'S GOING ON NOW? Getting an additional hose pack to put on the end of this line. These guys have sort of figured out that it might actually work, it's not the Wajax pump that is the problem but it might have been a bit of a block in the line. SO YOU ARE GETTING ANOTHER...? Running down to get another hose pack to put on the end.		Running fast down hill	Getting an additional hose pack to put on the end of this line because the pump might be able to pump this far	
1:05:30		Here it come now. ARE YOU REPLACING THE HOSE THAT WAS THERE? No just tacking another one on the end. Just to give us another 30 or 40 metres. IS THIS REALLY HARD WORK?		Collects hose pack from FForange and runs back up hill with pack.	Attaching another hose to get more length	
1:05:45	FF: "Want me to tell them the Wajax is on the way?" FFBry: "And the dam" FF: "Yeah". FFyellow1: "Great stuff" FF:"She said they are setting up a Wajax and a dam mate, as soon as they can"	The only thing hard about this is just the running up and down. Looks like I'm moving quite slow but from memory I was running as fast as I could, kind of up and down		FFyellow? runs down to meet FF to collect hose pack		

Time	Voice	Fire Fighter Reflective Transcript	Who	What	Why	Where
1:06:00		We are really just assisting these guys at the moment. The best thing that we could do. There is no point having any more of us at the end of the hose … is breaking up some stuff back here and providing a radio link between them and the pump.		Walks up the hose line, breathing very heavily	Not at end of hose, more useful down hill linking lines of communicat ion	
1:06:15	FFyellow?: "Run this back down eh" FF: "Yeah"	If something goes wrong up here and they need the pump shut off there is no one who can relay that message except for us so …		Is given fresh hose to run out down hill	Something could go wrong and may need pump turned off quickly	
1:06:30		SO THIS HOSE IS COMING BACK DOWN THE HILL. WHAT IS GOING ON HERE? Yeah, that was a bit of a strange one. I think what they wanted to do was not progress forward at that particular stage but get some water through. Maybe it's a percolating hose so it allows a little bit of water out. To establish that and then they pull it back up as well.		Laying hose out down hill – away from fire. Breathing very heavily.	Wanted to get water into hose so it is wet (perculating) before it is pulled across hot ground	
1:06:45	FF: "That's it mate drop it" FFBry: "Sorry" FF: "That's sweet as"	They didn't want to be unravelling the hose on the really hot ground I think. I think that's what it was.		Run hose down as far as FFBry. Spits		
1:07:00	FFBry: "unintelligible … won't burn" FF: "Yeah I know"	(Spits) HA HA HA Unbecoming of a gentleman. SO DID YOU HAVE A MASK … JUST PULLING THE MASK OUT OF THE WAY? Yeah yeah. Because you know you get quite a lot of … you get sweat in behind it and things like that. It's not particularly comfortable.			Mask uncomforta ble	
1:07:15	FF: "Within 5 minutes mate it jumped" FFyellow1: "Has someone got a radio there?" FF: "What do you want us to convey?" FFyellow1: "We just want them to switch the water off for a while while we connect XXXX"	SO YOU ARE NOW WAITING. WHAT ARE YOU WAITING FOR NOW? We are just relaying a message back		Running	Relaying message	

Time	Voice	Fire Fighter Reflective Transcript	Who	What	Why	Where
1:07:30	FF: "You've got a radio to the pump eh. Tell them we want water off just to change a coupling"	YOU ARE MOVING PRETTY QUICKLY ACROSS THE TERRAIN. Yeah yeah definitely, that's back downhill. I'm talking to the other crew boss here Jim.		Runs back down hill to person with radio		
1:07:45	FForange: "Ian from Jim. We want water off over" FF: "To change a coupling"	He is waiting for the other pump and dam to come up. He's got a link back to the pump. So we are shutting it down so we can change a coupling. SO THAT GUY THERE, THAT'S JIM. It is.				
1:08:00	FForgane: "We are going to change a coupling up here once we get water off over" FForange: "Can you let us know when it's off please over"	I know what we are doing now. What we are doing is putting a coupling in the end of that hose so we have one line that can go that way and one slightly up. I think that's what it was.			Fitting coupling	
1:08:15	FF: "You fellas have got your gloves, you should chuck them on ok" FForange: "Waters off" FF: "Yeah"	SO WHERE IS THE BULLDOZER IN RELATION TO YOU? It's right …we will come up a little bit and sort of get to the end of that track. It would have just over to the side here. The other thing I'm thinking about the whole time is … you would have heard me tell Jim to put on his gloves.		Talking then runs back up hill		Near bulldozer which is on the track it made
1:08:30		Because you are a crew boss so your principal concern is looking after your crew. Making sure they've got water, making sure they have got all their protective clothing on, those sorts of things. That's your paramount sort of job.		Runs up to new hose and FF up hill. Then signals with hand. Noise from helicopters overhead	Thinking about the safety of the crew	
1:08:45		WHAT'S THIS HAND SIGNAL? That's water on and increase the pressure. Because at the pump they have got a sort of accelerator I suppose that you can dribble water through right to having it go full noise.		Handling fresh hose and moving up hill. Hand signal	Signalling to increase water flow	
1:09:00		With all this carry on with the helicopters overhead it is easier to use hand signals. AND THEN WITH THE HOSE … ARE YOU GETTING THE KINKS OUT OF THE HOSE? Yeah yeah if you let a lot of water through at high speed and it's got a kink in it you can blow it very easily. And we want good flow at the hose-head.		Handling hose still	Hand signals because of noise from helicopters	

Time	Voice	Fire Fighter Reflective Transcript	Who	What	Why	Where
1:09:15	FFyellow1: "You right?" FF: "Yeah"	It's great of kinking up … especially at the couplings there … the joins		Hose filling with water, FF handling it	Getting kinks out of hose because a coupling could burst	
1:09:30	FFyellow1: "Good one guys, excellent"	IS THAT HOSE HEAVY? It's not overly heavy … it is it is after it has water running through it and collected a lot of soot from the ground. A hose pack has three lengths of hose in it, so three 30 metre lengths would be about 10 - 15 kgs		Standing looking up and down hill	Hose is heavy when wet	
1:09:45		So if you are hauling around a whole pack with those crappy old leather straps then yeah it is quite heavy and it is uncomfortable		Walks up hill a bit and looking at full hose	Hose packs uncomforta ble	
1:10:00		SO NOW THE WATER IS ACTUALLY FLOWING? Yep. You can see it is all nice and ah fat I suppose is the word. Again trying to get them as much line as we can by taking it over branches and things so they can continue working up that flank		Spits and unhooks hose from branches	Taking slack out of hose	Continue up flank of fire
1:10:15		and pinch it off. We've got the machines coming down through there and these guys coming up. SOMETIMES THE CABLE UNPLUGS.		Handling hose and screen goes blank		
1:10:30		Yeah ah it is probably. Yeah it is remarkable you have got this footage. I forgot all about it and probably had my helmet in the way and all sorts of things. Thinking about what these guys are doing up here and what my crew's doing behind me		Standing looking at hose	Forgot about video camera	
1:10:45	FF: "That it"	What's happening over at the pump and of course the fire, you know. SO IS THE FIRE STILL BURNING? It's trickling out ahead of these guys. It's had a bit of water dumped on it, on the flank you are right.			Fire still burning	
1:11:00		We are just really dampening it down to make sure its got no where to go so it can't continue to eek out into the green as we call it. WHAT ABOUT UNDER YOUR FEET? IS IT HARD FOOTING YOU KNOW, TO STAY ON YOUR FEET? Certainly something you have got to be aware of ... a lot of slash, twigs and little holes and things like that.		Moving hose … heavy breathing		

Time	Voice	Fire Fighter Reflective Transcript	Who	What	Why	Where
1:11:15		Isolated hot spots. IS THERE ANY RISK LIKE GOING THROUGH A BURNT ROOT LIKE HOLES IN THE GROUND? That's something that you've always gotta be aware of and that comes back to your PPE.		Moving hose … heavy breathing		
1:11:30	FF: "You can't ask for better training than this man" FForange: "xxxx send someone down … set it up…	Like looking at my crew and making sure they've got their overalls and their socks done properly. SO THESE GUYS … IS THIS THEIR FIRST FIRE? Yeah yeah yeah, those two ladies that are with me, that's their first fire so it was a golden opportunity for them.			First fire for other two in crew	
1:11:45	FForange: "I'll take Bry out and a couple of shovels and we will wait for further instructions" FF: "Are you happy to do that" FForange:"Yeah … have you still got the radio?" FF: "No I left it with Zoe down the bottom"	There Jim and I, the two bosses. We're um just dividing up some resources to get a dam established over there.	Two bosses			
1:12:00	FForange: "So we've got Ian anyway" FF: "He's our pump man" FForange: "Water on just above it xx" FF: "We are going to have to get them to jump up one if we can. Bring on up to that other dam are we?".	Bridgie is gonna stay with me and help these guys at the hose end and provide some communication back				

Time	Voice	Fire Fighter Reflective Transcript	Who	What	Why	Where
1:12:15	FForange: "The other dam is going to come in just above the vehicle here" FF: "WHAT DO YOU WANT? WHAT DO YOU WANT?" FFyellow1: "Yeah yeah keep coming" FF:" You fellas go and do that and me and Bridgie will keep on this line"	WHAT ARE YOU TALKING ABOUT NOW? We are talking about our water supply. We are pumping from quite low. We can't go any higher. Probably not a hellava good flow because the dams … the pump's way down here.				
1:12:30	FF:"That's it mate, that it" FFyellow1:"Is that it?" FF:"There's no more" FForange:"Alright if I take Bridgie?" FF:"Yeah"	We are wanting one on the road … higher. We are pretty happy with this area here. So we want to get a dam in higher bring in another hose line and continue up along that flank. You can see the line of the green right there.		Dragging hose		
1:12:45		YEAH, YEAH. The other thing is we want our crew always to stay in the black, just in case you know. It's already burnt … it's not going to burn again hopefully.			Crew stay in the black	

Comparison of task analysis and reflective interview

It is evident from the material presented in Table 6.4, that the reflective interview provides an investigator with the potential for greater depth of understanding of the task. The participant did not describe the execution of physical activity, such as walking, carrying a hose or talking, probably because these activities were self evident from the video record. Rather, the participant described the higher level organisational issues such as who was at the fire, the chain of command, why particular communications were taking place and his feelings at the time. The richness added by the reflective data is apparent in Table 6.5.

Table 6.5 - Comparison of the information collected from task analysis only and when combined with reflective interview.

	Task analysis only	Reflective interview
When	Time line	Time line
Who	Only know the camera wearer	Three person crew, two are women All work for DOC Two other people handling the hose, they are with the forest company Other DOC Boss is working with them controlling another crew
What	Pulling on hose Digging hot earth Running out a new hose	Getting slack in hose Removing kinks in hose Ensuring hose not on hot ground Looking for and putting out burning material at edge of fire Relaying messages to pump operator
Why	No understanding why events occur	Getting slack in hose so it can be pulled further up hill Removing kinks in hose so water flows well Ensuring hose not on hot ground where it could burn Forest company people have no radio but DOC people do Breathing hard because of exertion and adrenaline May need a second dam and pump to get water higher up the hill But first trying putting another hose on line to get water higher – may have had hose blockage from kink
Where	With GPS know it is on a hillside but don't know where fire is located	Along flank (side) of fire At the end of a bulldozer line On steep hill, approximately 35º

6.4.2 Tree felling

A 15 minute video clip comprising images and sound from two body worn cameras from tree felling was used as stimulus for the allo-confrontation interview. The video clip showed the felling of seven trees. There was no conversation recorded because the tree faller worked alone, which is usual in felling operations. A helmet mounted camera provided images of the direction the tree faller gazed and the shoulder mounted camera provided images of the tree faller's hands, chainsaw and the base of the tree being felled.

Understanding from naïve viewing

Viewing the video without post event commentary has allowed the following understanding of events:

> The tree faller is felling trees in a plantation pine forest. He appears to be using the correct technique – looking up at the standing tree to identify hazards and the lean of the tree. He inserts, with the chainsaw, felling cuts in the correct order. He then retreats from the tree once it starts to fall. This is a highly repetitive task and he fells a total of seven trees during the filmed sequence.

Table 6.6 - Activity of the tree faller partitioned into 15 second segments. The contents of the 'What' and 'Why' cells were created by interpretation of the video by me. Tree felling is a repetitive occupation and the cycle of actions is repeated for each tree.

Time	Tree	Apparent actions	What	Why
0:30	1	Look up	Looking at tree	To determine lean and presence of hazards
0:45	1	Look up		
1:00	1	Top scarf	First cut in tree	Cut location and size specified by guidelines to ensure tree falls in the intended direction
1:15	1	Bottom scarf	Second cut in tree	Cut location and size specified by guidelines to ensure tree falls in the intended direction
1:30	1	Wing cuts	Third and forth cuts in tree	Cut location and size specified by guidelines to ensure the fibres at the sides of the tree are severed so they do not split the tree when it falls
1:45	1			
2:00	1	Backcut	Fifth cut in tree	Cut location and size specified by guidelines to ensure the tree falls in a predicable direction
2:15		Retreat	Tree falls and faller moves away from the base of the tree	Keeping a safe distance from the base of the tree as it falls. The tree may bounce backward striking the faller, dislodge material above which may fall on the faller or the tree may twist off the stump and strike the faller
2:30		Look up		
2:45		Look up		
3:00	2	Look up		
3:15	2	Look up		
3:30	2	Scarf		
3:45	2	Backcut		
4:00	2	Backcut		
4:15	2	Backcut	Tree falls	

Time	Tree	Apparent actions	What	Why
4:30	2	Clear scrub		
4:45	3	Clear scrub		
5:00	3	Top scarf		
5:15	3	Bottom scarf		
5:30	3	Wing cuts		
5:45	3	Backcut		
6:00	3	Backcut		
6:15	3	Waiting	Watching tree fall	
6:30		Walk		
6:45		Cutting scrub		
7:00	4	Top scarf		
7:15	4	Top scarf		
7:30	4	Bottom scarf		
7:45	4	Wing cuts		
8:00	4	Backcut		
8:15	4	Backcut		
8:30	4	Backcut	Tree falls	
8:45		Look up		
9:00		Walking and clearing scrub		
9:15		Walking		
9:30	5	Top scarf		
9:45	5	Wing cuts		
10:00	5	Backcut		
10:15	5	Backcut	Tree falls	
10:30		Look up	Looking at canopy	
10:45		Look up	Looking at canopy	
11:00		Look up	Walking and looking at canopy	

Time	Tree	Apparent actions	What	Why
11:15		Walk		
11:30	6	Top scarf		
11:45	6	Backcut	Tree falls	
12:00		Look up	Walk and look at canopy	
12:15		Clearing scrub		
12:30		Look up		
12:45		Look up		
13:00	7	Top scarf		
13:15	7	Top scarf		
13:30	7	Bottom scarf		
13:45	7	Wing cuts		
14:00	7	Backcut		
14:15	7	Backcut		
14:30	7	Look up	Tree falls	

Understanding from reflection of tree felling

The tree felling trainer/examiner viewed the activities which were shown in a 15 minute video clip. He controlled the viewing to the extent that he could start, stop and rewind the clip and point to features of interest in the clip with the mouse cursor. A microphone was fitted so that the explanation of what was happening in the video clip could be captured on an audio file. Reflections were transcribed verbatim in 15 second blocks and reported as "Trainer reflective transcript" in Table 6.7. Upper case text denotes prompts by me.

Table 6.7 - Apparent activity of the tree faller from video and transcript of an experienced felling trainer viewing the video clip. The contents of the 'What 'and 'Why' cells were created by interpretation of the video and audio by me.

Time	Tree	Apparent actions	Trainer reflective transcript	What	Why
0:30	1	Look up	Ok well the faller at this stage appears to be assessing the tree, he's looking where his escape route might be, um obviously the vision of the top of the tree is a little restricted so he's got to do a bit of clearing around the base of the tree, in preparation to fall it.	Determining the lean of the tree and an escape route	So he can fell the tree in the direction he wants. The escape route is needed so he can get to a safe distance from the tree when it falls
0:45	1	Look up	He's looking up at the top of the tree again, and you can see there's um a bit of crown weight out it looks as though he is going to fall it in the direction that the lean is,	Looking at the tree crown	Determining the distribution of weight on the tree
1:00	1	Top scarf	So now it appears that he's putting the scarf in so he's obviously decided that he's assessed the direction correctly and he's now putting the scarf in, doing the top cut first.	Correct cuts	Guide the direction of fall of the tree

Time	Tree	Apparent actions	Trainer reflective transcript	What	Why
1:15	1	Bottom scarf	He's now putting the bottom cut of the scarf in and you can see he's using his thumb on the throttle of the chainsaw	Correct cuts and holding saw in a diffrent way	Easier to hold thumb rather than idex finger on throttle when saw is tilted
1:30	1	Wing cuts	IS THAT ALRIGHT? Yep, yeah thats fine thats quite acceptable. Now I think he's putting in wing cuts at this stage and that the idea of the wing cuts is to minimise the slabbing	Correct cuts	To stop the tree splitting up the sides
1:45	1		I'm not quite sure what he's doing now he may actually be just tidying the scarf up a wee bit DOES THE SAW SOUND LIKE ITS TUNED RIGHT?		
2:00	1	Backcut	Yeah a bit hard to see the um actually, in fact he might of been doing a quarter cut there just looking at it, cause it looks as though he's doing the back cut now yes and the trees falling, yes so in fact that first cut he was doing a quarter cut.	Correct back cut for tree with a heavy lean	Stops the tree from dangerously splitting up the back and potentially hitting the faller
2:15	1	Retreat	And then he retreated from the tree as it was falling you see, now he's moving on to look for the next tree, um there's this reasonable amount of undergrowth there.	Moving away from the tree	Getting a safe distance from the tree – it could fall or bounce backward

Time	Tree	Apparent actions	Trainer reflective transcript	What	Why
2:30		Look up	I'd say that um he possibly didn't clear much of an escape route prior to to cutting that tree but without sort of seeing the surrounding areas a bit hard to judge,	Scrub clearance was poor	Could have difficulty escaping from tree when it falls
2:45		Look up	So he's now looking up at a another tree, and you can see the undergrowth there he's just cut that one out of the way, its part of the requirements when you're tree falling to have a clear unobstructed view of the top of the tree	Looking up at tree canopy	Needs an unobscured view of the tree canopy to see when tree moves and hazards
3:00	2	Look up	So that you can see any obstacles that may fall out of the tree, so that you can detect any movement of the tree when it does start to fall, so he's doing a bit of clearing around the tree at this point.		
3:15	2	Assess	Looking around the other side of the tree, making sure that he's got room to perform his cuts and now he's started the scarf of the second tree.	Looking around base of tree	To ensure he has space to move and put in cuts
3:30	2	Scarf	He's done his top cut first and I can't quite see at what stage he's at IT JUMPS AROUND A BIT Yes he's, put the scarf on that one from both sides although its not a big tree.	Correct cuts	

Time	Tree	Apparent actions	Trainer reflective transcript	What	Why
3:45	2	Backcut	So I'd be surprised if he did. Not quite sure what he's doing at this stage. That now looks like a back cut doesn't it that he's doing, yeah. He's looking up you can see him looking up		
4:00	2	Backcut	as he's inserting the back cut watching for movement of the tree and the trees on its way.	Looking up and cutting	Watching for movement of the tree
4:15	2	Backcut	Yes its a bit a bit disconcerting looking at both the both pictures at the same time. Ok so he's moved around he's looking for a third tree. Clearing a little bit around the tree		
4:30	3	Clear scrub	My general impression is that he's perhaps not clearing quite enough undergrowth to give a good escape route and he does not appear to move a great distance away from the tree once it starts falling.	Cutting scrub	Poor escape route cut
4:45	3	Clear scrub	So if he's impeded by undergrowth then then thats certainly a risk that you will be taking in the falling process. He's doing a bit of clearing there,	Cutting scrub	

Time	Tree	Apparent actions	Trainer reflective transcript	What	Why
5:00	3	Top scarf	looking up at the top of the tree so his, tree assessment is fairly thorough and you can see him looking up several times. He's not just looking at the tree that he's falling but he's also looking at surrounding trees that might impede the fall of the tree and he's on the left hand side of the tree now.	Looking up and cutting	Good tree assessment
5:15	3	Bottom scarf	Putting the scarf in I think the other two trees we looked at he was on the right hand side of the tree. He's using the top of the bar, this time around he's using his finger on the throttle not his thumb.	Cutting tree	
5:30	3	Wing cuts	What He's Doing Now? I'm not sure, he might be putting wing cuts in. I can't quite see the scarf.		
5:45	3	Backcut	What's he doing now?I THINK THERE'S TWO WING CUTS. Two wing cuts was it? Yeah ok, sort of around the back of the tree now so it looks like he's putting in his back cut.	Cutting correctly	
6:00	3	Backcut	and I think he might be using his finger on the throttle again there, so has a bit of a look up and continues on with the cut.	Cutting	

Time	Tree	Apparent actions	Trainer reflective transcript	What	Why
6:15	3	Waiting	The hazard there you can see a dead spar out to the right hand side of that tree and obviously that he's got to be wary of that. But if that tree that falls strikes that dead spar could in fact send debris back towards him.	Watching the tree fall	There was a hazard, a dead standing tree, which he has been watching carefully
6:30		Assess	So that tree's gone his direction looks like he was falling away from the spar so was quite safe and now he's walking around assessing the other trees to find his next tree to fall.	Walking and assessing trees	Planning which tree to fell next how it will conflict with other trees
6:45		Cutting scrub	You can see a bit of wind in the undergrowth which is a sign that the wind has come up a wee bit. Sometimes that's not noticeable on the ground but when you look up you can see it.	Cutting and looking around	Looking for hazards – wind in this case
7:00	4	Top scarf	You can see the undergrowth moving, which is wind can be quite a factor in the tree falling process IT LOOKS QUITE STEEP TOO Yes it does look fairly steep,		Steep terrain and windy

Time	Tree	Apparent actions	Trainer reflective transcript	What	Why
7:15	4	Top scarf	Ok so he's putting his scarf in the next tree and you can see again he's cutting from the left hand side of the tree. Ok and when they cut from the left hand side of the tree they've got more bar to use in putting the scarf cut in so they can put a bigger scarf in if the trees bigger.	Cutting the tree	Can make bigger cuts on the tree if cut from the left
7:30	4	Bottom scarf	If they cut from the right hand side of the tree there's less bar available to them cause the motor comes up against the side of the tree. Ok so he's flicked his scarf out there, he's having a bit of a look at it.	Cutting correct	
7:45	4	Wing cuts	Putting his wing cuts in now and the purpose of the wing cuts is to try and stop slabbing up the side of the tree. Bit of a fine art in putting wing cuts in cause you don't want to put them too deep cause they'll affect the strength of the hinge.	Wing cuts correct	
8:00	4	Backcut	WING CUTS LOOK ALRIGHT? They look alright yeah, bit hard to tell on the camera but ah they look on a reasonably steep angle, they don't want to be too flat. So now he's putting in his back cut.		

Time	Tree	Apparent actions	Trainer reflective transcript	What	Why
8:15	4	Backcut	He's not looked up on this tree so far so not quite sure what he's doing there, possible that he needs to put a wedge in.	Not looking up	Could be hit by falling material when the tree starts to move
8:30	4	Backcut	No he's continuing with his back cut and he's looking up now. So this is a double leader this tree and you have to be a little careful with double leaders.	Looks up while cutting	Tree has two stems which is more hazardous to fell
8:45		Look up	Because generally if they fork close to the ground they can be a risk to cut because they could split off. I haven't heard whether that trees gone down. Can you Richard?		
9:00		Walking and clearing scrub	NO I CAN'T SEE IF THE TREES GONE DOWN OR NOT. No a bit hard to tell, either the trees gone and we've missed it. HE'S CUTTING THE UNDERGROWTH. Yes, so I'd say that trees probably gone down.		Tree has not fallen down. It has sat back on the backcut.
9:15		Walking	If it hasn't he maybe looking at driving another tree onto it. In which case he should've put a wedge in so just not quite sure. I didn't see the tree fall so we're not quite sure where we stand with that one.		He should have put in a wedge to prevent it sitting back.

Time	Tree	Apparent actions	Trainer reflective transcript	What	Why
9:30	5	Top scarf	Hopefully we might see it. Ok so he's scarfing another tree so if that other tree has gone down we missed it. He's now scarfing another tree.	Scarf ok	Preparing a "driver" tree
9:45	5	Wing cuts	If the double leader that he was cutting before had not fallen over, then he should have put a wedge in to secure that tree from coming back towards him. Ah and the other thing about a tree drive is that you are supposed		
10:00	5	Backcut	to actually prepare both trees before you put a cut in them, in any tree, so we maybe unfairly criticising this person. Looks like he's putting a back cut in that second tree		
10:15	5	Backcut	It's gone down so I think that, yes I think that		
10:30		Look up	is that that double leader still there. It's frustrating which, yeah it is, looks like it is so.		Driver tree (5) missed the standing tree (4)
10:45		Look up	The faller is, if that double leader has sat back then he's obviously not been able to get a wedge in it, and we haven't seen any sign of him putting a wedge in.		

Time	Tree	Apparent actions	Trainer reflective transcript	What	Why
11:00		Look up	So it appears now he's clearing around another tree with a view to driving it onto the double leader. Lets just lets just wait and see.	Cutting scrub and looking	
11:15		Walk	If that double leader is cut and un-wedged then it is a potential hazard. You weren't there when this was filmed then Richard NO I DON'T KNOW WHAT IS HAPPENING. Ok		Working behind a tree which could fall on him
11:30	6	Top scarf	HE'S DOING A FAIR BIT OF WALKING AROUND. Yes he is and it does look quite steep in places there doesn't it? Gosh it's it's really quite hard looking at	Top scarf being cut	
11:45	6	Backcut	where his helmets looking all the time. So here he is now scarfing another tree actually he's scarfing this one from the right hand side. It looks like its a spar obviously a dead spar.		Cutting down dead standing tree (spar) which is a hazard. It could fall on him unexpectedly
12:00		Look up	He's got rid of that spar Yep he got rid of that dead spar		

Time	Tree	Apparent actions	Trainer reflective transcript	What	Why
12:15		Clearing scrub	And now it looks like he's approaching another tree. Oh I think that double leader must've gone down Richard we just missed it LIKE A SPORTS COMMENTATOR It is, I'll do a Murray Mexted comment now.		Double leader tree (4) actually still standing
12:30		Look up	Ok so he's clearing around another tree here, it looks like a bigger tree. We'll try and see when this tree falls. See if it makes contact with another tree and knocks it over - it is being driven.	Cutting scrub and looking	Preparing another driver tree
12:45		Look up	Ok so he's taking a bit of time assessing this tree, looking again for the lean. Looking for potential hazards up that tree like sailors, things that could fall down and strike him		Carefully preparing to fell tree
13:00	7	Top scarf	He's looking a lot longer at this tree. Hmm he's taking more time and often that's the case too Richard when the tree's a little bit more tricky they really do have to spend more time assessing it. Because you really only get one chance to get it right.		He must control the direction the tree falls so it strikes tree 4 and knocks it over

Time	Tree	Apparent actions	Trainer reflective transcript	What	Why
13:15	7	Top scarf	So he's started his scarf cut now and you can see he's on the right hand side of the tree, so either the trees not so big or its perhaps more accessible on the right hand side.		
13:30	7	Bottom scarf	So the scarfs been put in, he's now putting the bottom part of the scarf in. WHY HAS HE GOT ALL THIS RUBBING BEHIND THE TRIGGER? All the what sorry Richard?		
13:45	7	Wing cuts	ON THE SAW JUST BEHIND THE PETROL CAP? Ah possibly rubbing it against his thigh, not sure, need to I haven't noticed that.		
14:00	7	Backcut	Ok so he's finished his scarf, he's now putting his back cut in looking up. Looking at the tree itself, he's finishing off his back cut there.		
14:15	7	Backcut	He's moving away from the tree and that's probably why we missed that other one. Now he's looking back. IS HE TRYING TO DRIVE?		
14:30	7	Look up and cry of jubilation from faller	I think he's trying to drive that double leader. I think he might have.		Tree 7 successfully knocks over tree 4

Comparison of task analysis and allo-confrontation interview for tree felling

The task analysis (apparent actions) tells us that the faller is performing various tree felling tasks (looking, scarf cuts, back cut, etc) and performing those tasks in the same order on each tree. But the task analysis provides no information about whether the tasks were performed correctly or if tasks were omitted from the work cycle. Allo-confrontation interview provides the investigator with an expert's impression of the tree felling task. The expert is looking at the task from the perspective of the faller wearing the cameras and provides an additional layer of interpretation of the fallers' actions. The expert tells us what is professionally required of the faller and provided a critique of the faller's work methods.

Table 6.8 - Comparison of the information collected from task analysis only and when combined with reflective interview.

	Task analysis only	Allo-confrontation interview
When	Time line	Time line
Who	Only know the camera wearer	Only the camera wearer. No one else present.
What	Looking for hazards Clearing away undergrowth Inserting felling cuts	Used specialised tree felling method “Quarter-cut” Didn’t clear very good escape routes before felling the trees Tree faller doesn’t move very far away from the tree before it starts falling Assessment of tree lean is thorough A serious hazard was identified by the faller and dealt with correctly - a dead standing tree, A tree (No. 4) sat back and had no wedge inserted to prevent sit back An attempt was made to drive tree No. 4 over with tree No. 5 but it missed Tree 4 had to be driven over by another tree (No. 7).
Why	No explanation of why a particular task was performed	Some understanding of task performance derived from the experts view of the tasks For example quarter-cutting stops dangerous slabbing of the tree stem Cutting the undergrowth to see the top of the tree to locate hazards Not a big enough escape route cleared Cut the tree from the left side so more cutter bar can be used because the chainsaw motor is not in the way Double leader can split if it forks close to the ground
Where	Location available from records	Location available from records

6.5 Discussion

In the fire fighting task, ‘auto-confrontation’ reflective interview has been used to gain a greater depth of understanding: how the fire fighters are organised, why they are doing particular tasks and how they work together? Without the reflective interview component fire fighting appears chaotic and we have no understanding of the structure of the task. Auto-confrontation reflective interview gives us a window to see the underlying structure of the work and how it is organised. Without this window the fire fighting task cannot be studied with any insight.

Tree felling is a completely different type of task. Auto-confrontation was not used because I could not track down any of the fallers and I think that having an expert look at their work gave a greater understanding of skill (or lack of it). So I used allo-confrontation. In contrast to fire fighting, tree felling is apparently very orderly and repetitive. The same cycle of tasks are performed in the same order for each tree. However the work can descend into chaos but still appear orderly and repetitive. For example tree No. 4 sat back on its stump and expert knowledge was needed to identify the situation. The tree faller was at risk of fatal injury if tree No. 4 had fallen back on him. The actions of the tree faller while trying to rectify the situation appeared ‘normal’ – for example clearing scrub, inserting felling cuts, looking at tree canopy, but these tasks were undertaken in a very dangerous situation. There is a skill component in tree felling which doesn’t really exist in the fire fighting in this study. If the chainsaw cuts are not correct the tree will fall in the wrong direction which will cause problems later, when machines are used to take the tree out of the forest.

Using individual auto and allo-confrontation reflective interview as an exploratory tool, the precise nature and origin of technical knowledge embodied in tree felling and fire fighting can be explored at a level of detail and insight not possible without participant insight. Both tasks are so hazardous that error will result in severe injury or death. Detailed codes of work practice govern the training for such tasks and under steady-state (controlled, unrushed) work conditions, work practice should be predictable and exactly follow ‘best practice’ laid out in the Codes. Additionally, the organisation of work can become uncontrolled through time stress or dangerous situations and workers will exhibit departure from codified norms. In these situations the worker must use technical knowledge in ways not prescribed in Codes. For example, fire fighters take the fire hose back down the hill away from the fire, because experience has shown that unrolling the dry hose on very hot ground will allow it to burn. Once wet the percolating hose is fire resistant.

The task analysis identified only the visible component of each activity and did not account for “the rules of action underlying the various observed procedures” (Mollo & Falzon, 2004, p. 536). Individual auto-confrontation reflective interview was used in the fire fighting case to elicit what the participant was trying to achieve (what they were considering in the work environment and doing) when they were undertaking the tasks. Additionally, because a long time had elapsed between recording the original task and interview the whole process was ‘rebuilding’ the work experience.

The tasks of tree felling and fire fighting are quite different but the techniques developed in this research worked equally well. Tree felling is a solitary occupation characterised by a repetitive cycle of tasks which have to be performed in a specific order and with skill. The consequence of error can be death. Movement through the terrain is slow and a small geographical area is traversed. Rural fire fighting, in contrast, is a social activity with frequent communication and characterised by varied tasks, which have to be performed with skill and quick movement across the terrain over an often large geographical area.

A simple task analysis of the video of the fire fighter provides a very shallow understanding of the task. Task analysis only provided basic information about the visible actions performed by the fire fighter and no information about why those actions were performed. The audio record provided additional contextual information but not enough to gain a great depth of understanding. Reflective interview provided information on who the participants were, who was in charge and comments about the execution of the tasks. The reason for each task was explained, for example the hose was pulled away from the fire to keep it off hot ground, which could burn it. When filled with water the percolating hose was resistant to burning. The actual location of the fire front could not be seen in the video. While viewing the video the participant could indicate the location of the flame front. Also the location of the water dam and pump was not evident from simply viewing the video.

The participants had no difficulty viewing the moving video image captured by the helmet mounted camera. Both Omodei and McLennan (1994) and Kipper (1986) report that movement of the visual image actually improved experiential immersion of the viewer. Kipper's (1986) results indicated that moving-camera viewers better understood and remembered the physical properties of the scene. These findings indicate that the moving camera could benefit productions where knowledge of the environment is important. Sound was especially valuable in assisting perceptual stabilisation (Omodei & McLennan, 1994). The sound of heavy breathing brought back memories of the physical demands of fire fighting and the 'rush of adrenaline' in fighting a fire. Conversations and audible commands assisted in recall of the reasons particular activities were taking place.

The reflective interview was very easy to apply and record. The participant had full control of the video clip and could stop, start or rewind at will. The computer cursor was used to point at items of interest in the video scene and the participant spoke into a microphone. The video, audio from the video, audio from the participant commentary and cursor movements were recorded by the software package *Camtasia* as a second video file. The sound track of the original video (dialogue, bulldozer, helicopters, water pumps, etc) was audible alongside the participant's dialogue.

In addition to the obvious advantages in illustrating and enhancing observations in the field, individual auto-confrontation could be used to enhance learning and disseminate work-related knowledge. In the first instance, the purpose of carrying out the reflective interview (confrontation) was to explore its value as a tool to establish ways decisions about possible courses of action are made. Implicit in this study was the associated aim of gaining a greater understanding of the mechanisms and activities inherent in tree felling and fire fighting. Novices could be shown how situations evolve in real life, with associated expert dialogue. Tree fallers in particular could have their work, that was recorded on video, critiqued by a trainer and be provided with constructive criticism.

Of note, was the degree of interest that participants showed in the video material, and their own activities. During the formal viewing process, the fire fighter participant acknowledged that without the video prompt, he would have been unlikely to recall what had happened. He commented:

> "Yeah it is remarkable you have got this footage. I forgot all about it and probably had my helmet in the way and all sorts of things. Thinking about what these guys are doing up here and what my crew's doing behind me."

The reflective phase of the study had a number of limitations due chiefly to the small number of participants interviewed. Reflective interview was included in the study after reading literature (e.g. Omodei & and McLennan, 1994) which demonstrated the additional understanding of work that could be gained by reflective interview. As I interviewed only one tree faller and one fire fighter the results cannot be used to generalise or predict the actions, during work of tree fallers or fire fighters. However, the research in this chapter did show that a much greater depth of understanding of work could be gained from reflective interview, both auto-confrontation and allo-confrontation.

6.6 Conclusions

It has been established that it is a difficult task to be able to record work activity in dangerous real life occupations such as tree felling and rural fire fighting. But helmet mounted video technology has enabled the researcher to see this work, for the first time, from the perspective of the worker. Video collected from helmet mounted cameras also allows video assisted recall by the participant months after the event occurred. This chapter has provided a window into the enriched insights that can be provided when the participant sees events in a reasonable facsimile of how they originally saw them, and not merely as an actor within the scene. Reflection by the participant provided considerably more information about work than task analysis alone.

The techniques presented here should be easily transferred to other occupational situations where work is to be investigated. Forestry and fire fighting are physically demanding occupations in difficult environments yet the participants soon forgot about the presence of the recording equipment. Yet further applications of the material (the combination of video, audio and reflections of the worker) could serve a valuable educative function beyond the individual involved.

A further use of this technology and methods is for the development of training resources. The video images collected provide a unique perspective of work under real conditions, allowing trainees to see correct procedures from the perspective of the participant.

7 Conclusions

7.1 Introduction

The overarching purpose of this research was to investigate the use of new technologies in facilitating the field study of people engaged in dangerous work situations, without disrupting the work or adding to the danger. To this end, the aim was to explore the efficacy of new technologies to study work in dangerous environments.

This was achieved by focusing on four aspects of the work: the first was to record, measure and understand the work (including physiological workload) of people engaged in dangerous occupations; the second was to understand how hazards are identified and dealt with by individuals working in extreme conditions; the third was to gain insight into hazardous work environments for the purpose of enhancing training for personnel working in dangerous conditions; and finally, to explore the value of reflective interview as a tool to establish ways decisions about possible courses of action are made.

A case study approach was adopted using the logging and the rural fire sectors as paradigms.

7.2 Advances in technology

The previous chapters have reported on the development of equipment and it's application in successfully trialling new technologies to study fire fighters and tree fallers at work. The 'normal' work environments for people engaged in these occupations hold elements of hazard and unpredictability. Further, the worker is reliant on physical agility to optimise their own safety and traditional equipment for recording work both in the field and in the laboratory, is limited by its intrusiveness. Given that I wished to avoid the limitations of conducting a study under simulated conditions, and given the potential risks associated with using traditional technology under 'real' conditions, it was necessary to develop a novel response. Considerable attention was given to sourcing, building and trialling equipment that would continue to operate reliably in the very demanding fire fighting and tree felling environments. The ensemble of equipment used in this study comprised a unique assemblage of commercial-off-the-shelf technologies and custom made wiring harnesses. All participants in the study commented that they 'forgot' that they were wearing video cameras and other sensors.

Previous researchers who have studied work with video, and other sensors, have done so from the perspective of the worker as an actor in the scene (e.g. video exposure monitoring). In this study I have been able to capture work from the worker's perspective, using the head mounted video methods pioneered by Omodei and McLennan, and then I have combined that data with those from other sensors.

I have also taken the body mounted sensor ensemble and placed it on workers who are engaged in normally completely inaccessible occupations where error can result in death. In contrast, earlier researchers have collected data in simulations of work or in safe recreational pursuits such as orienteering or low risk occupations such as saffron harvesting.

By collecting data from a number of sensors and using reflective interview, I have been able to triangulate findings on a number of levels. The use of two body mounted video cameras on the tree fallers, has enabled me to measure the tree scanning activity of the fallers, from the helmet mounted camera and conduct a detailed task analysis from the shoulder mounted camera. These can be combined (Figure 4.7) to show what task the faller is engaged in while looking at the canopy of the trees. A further overlay was provided by video-cued recall recording an expert's interpretation of the tree felling technique. Such triangulation of information on tree falling has never been reported before.

Evidence collected for the fire fighting case indicates that fire fighters move across the terrain rapidly and GPS data provides information on the slope, distance travel, and speed. These insights, combined with video to show what is happening in the fire fighter's immediate physical environment, and with heart rate measures to show the body's response to occurrences and terrain, provides a detailed record of events. Again, this type of triangulation of information for rural fire fighting has never been reported.

Thus my study represents a step forward in our ability to unobtrusively carry out field studies in dangerous work environments and collect accurate and comprehensive data. Moreover, it opens the way for further opportunities to enhance the health and safety of workers in dangerous occupations.

7.3 Recording, measuring, and understanding work in dangerous environments

This is one of the few studies of work in dangerous environments actually undertaken in the field – a situation due largely to the difficulties detailed in Chapters Four and Five. Thus, in a general sense, its insights have enhanced our understanding of dangerous work in New Zealand, and made some advances in the measurement of work. More specifically, the study has added to our knowledge of both fire fighting and tree felling activities and their impact on individuals in those roles.

With respect to fire fighting, some other studies of rural fire fighting have taken place at real, uncontrolled fires, but the investigators have not collected detailed information about the individual fire fighters such as heart rate, detailed task analysis or detailed geographical position. Instead, they have focused on the productivity of the fire fighters as a group. Other investigators have collected detailed physiological and work data at real experimental fires but these fire fighters had back-up support if the fire got out of control or their lives were in danger. Work in Chile has demonstrated the value of collecting data in field studies under natural conditions. Indeed, studies such as Apud, Meyer and Maureira's (2002) are a valuable resource for the fire manager and fire fighter fraternity, and provide the intellectual stimulus for ongoing research under local conditions.

Building on this work, to increase our understanding of dangerous work settings in New Zealand, this study developed a methodology and instrumentation that enabled me to authentically capture work in the field. My research successfully recorded the work of, and collected comprehensive physiological and geographical data from, individual fire fighters performing under difficult physical conditions at uncontrolled fires. The study also captured the spontaneous social interactions that occurred between fire fighters at an actual fire, and which proved integral to our enhanced understanding of dangerous work.

The other dangerous occupation that this study has helped to demystify, is that of tree felling. New Zealand tree fallers, who work in relative isolation from their colleagues, continue to die or suffer serious injury on the job. Therefore the tree faller must almost inevitably be an important focus of ergonomists' attention. Again, through utilising instrumentation 'customised' for the tree felling situation, this research collected a range of technical and qualitative data that provided the basis for rich analysis of workers and work in hazardous situations.

Because, in contrast to fire fighting, tree felling is not an emergency occupation, all elements of that case study could occur in a more planned way. However, this was not without challenges and my novel application of a dual camera ensemble, has enabled some new insights that help to fill gaps in our understanding of tree felling. In this research the presence of the observer is eliminated thanks to the instrumentation carried by the tree faller that records detailed information about his work without disrupting his normal work activity. In that it is unobtrusive, my approach goes beyond other published studies, which have used observation techniques where the investigators shadowed the tree faller and watched and recorded his work. My research methodology has helped to address disadvantages such as investigator fatigue, altering the fallers work methods, having to be kept safe from danger by the faller and engaging in conversation with the faller, all of which are presented in Chapter Three.

Video-cued reflective interview data have provided me with another dimension for gaining an understanding of work. The fire fighter viewed video collected from a camera on his helmet so 'relived' the events in which he participated at the fire, auto-confrontation (Mollo & Falzon, 2004). He was able to recall the reasons why particular events occurred and his or others reactions to them. For example, he was also able to explain the apparent ad-hoc command structure which was established between fire fighters of two different organisations working on the same hose line.

A tree felling trainer reflected on events while watching video of a tree faller. The trainer viewed video from two cameras and could see what the tree faller looked at (helmet camera) and what the tree faller's hands and chainsaw were doing (shoulder mounted camera). In the reflective interview, the trainer was not reliving the events in the same way as the fire fighter but was able to comment on the strategies used by the tree faller and see how he coped with hazards.

Thus, the research approach used, resulted in my getting valuable insights of two occupations that are, by nature dangerous, but are quite distinct. Indeed, because tree felling and fire fighting differ in a number of dimensions ranging from the solitary to the social and from repetitive to the chaotic, and each has differing physical skills and physical demands, they have proven useful focal occupations for the research.

7.4 Identifying hazards

The second associated aim of the research was to understand how hazards are identified and dealt with by individuals working in extreme conditions. Visual and audio data collected provided evidence of moments when each of the fire fighters and tree fallers were confronted by hazards. Without the opportunity for post-hoc analysis by an informed observer (the fireman and the trainer of tree-fellers), some of the hazards would have remained unidentified. The expert commentary provided in the second phase of the research also allowed for a rich qualitative overlay to the recorded data. Evidence in Chapter Six demonstrates the value of the mixed methods approach adopted. Hazards were not only identified, but further explanations were provided. Further, the participants were themselves surprised at the value gained from the process.

In the tree felling videos, visible hazards were counted and the frequency of looking up at the tree canopy was also counted. These findings were complemented by the qualitative insights provided in phase two, leading to a more nuanced understanding of the workers response to potential risk. The felling trainer, by viewing the activities of the tree feller in the video, was able to identify and record the strategies used by the tree faller when faced with these hazards.

The reflective interview in the case of the rural fire provided an extra insight into the social and organisational dimensions of the work and highlighted the importance of communication as a key element of job safety. It further enabled the fire fighter to explain how he was ever-mindful of the safety of his fire crew, ensuring they wore their gloves, face masks, drank water frequently and kept out of smoke.

These combined insights serve to contextualise hazardous situations and to offer the researcher, policy-maker and practitioner a more detailed understanding of the complex challenges associated with certain dangerous occupations.

7.5 Training

Besides providing a unique and compelling viewpoint of dangerous work, the fire and tree felling videos and the use of reflective interviews provide valuable and practical training tools. The video recordings helped understand a number of issues that have puzzled previous researchers, thus providing trainers with evidence of where training might be better targeted. For example research into tree felling productivity had previously found that novice fellers had a lower productivity than experienced fellers, yet the cause was unknown. Detailed examination of the video records made for this study has revealed that the first felling cut was critical. If this cut is incorrect, time is wasted because additional cuts will need to be made to correct the initial mistake.

The recorded visual data can also be directly used in the training situation, as resources for analysis and discussion. Video of felling situations from the tree faller's point of view can provide a useful training aid with a skilled instructor explaining the events in the video. This has already been recognised by the New Zealand Accident Compensation Corporation who have incorporated this method into their training programme as a direct outcome of findings from this study. Also in response to my research findings, the New Zealand forest industry research company, Future Forests Research Limited, has funded the collection and formatting of video from ‘breaking out’ operations, another hazardous forestry task which results in several New Zealand fatalities every year. In addition, the events in the videos have been transcribed into a task analysis and visualisation software programme (*Observer XT*) so provide an indexed view of work. For example, if the instructor wants to show a particular aspect of work such as inserting the scarf cuts, he can go directly to them on the video file.

The training of trainers is frequently overlooked as we assume they bring expertise and will engage in ongoing professional development. However, phase two of my study served to highlight the potential training value of exposing industry trainers to the data. The reflective interviews revealed that trainers too learn about the work situation if asked to explain and critique what is happening.

7.6 Reflective interview

Overall, the reflective interview proved a valuable enhancement to the study. Moreover, the reflective interview phase of the research was a relatively straightforward progression from the typical use of such footage by the researcher-observer – the interviews were simple to arrange and record. My experience suggests that application in future studies would be a cost- efficient addition that is reasonably easy to implement. I was able to demonstrate, through the use of reflective interviews, an additional application of the technology developed, and thus the value of the technology to genuinely deepen our understanding of tasks being studied.

In summary it is clear from Chapter Six that the head-mounted video ensemble, capturing the events from the operator perspective, provided evocative, meaningful, information unlike that captured in either simulated environments or by external camera operators recording the activity. This approach also allowed us to extend the use of audio visual data beyond ‘scientific’ third party observation and analysis of recorded activity, to having practitioners from the selected occupational groups engage directly with the video of field activity after the event. Observer-participants, at their own pace, could scrutinise the footage, ‘relive’ the event and respond to what was on the screen. With respect to the fire fighter, this reliving was related to his own activity; with respect to tree falling, the trainer gained the unusual dual experience of objectivity twinned with a degree of empathy.

As discussed in Chapter Six, the commentaries provided by both participants led to a ‘thickening’ of understanding and thus a refined interpretation of events. The researcher’s initial analyses of the recordings were shown to be enhanced by the additional insight provided by practitioner accounts. But benefits were shown to be even more far-reaching in terms of future application for health and safety of workers.

Worker activities captured in the video footage were those of people engaged in high concentration, high stress tasks that required them to act ‘instinctively’ to unpredictable real-world events, drawing on their training and experience. The opportunity to view and reflect on activities led to sometimes surprising additional insights into how workers performed their roles, what factors were influencing their decisions and why certain activities were carried out. In short, this phase of the research demonstrated a further application of this technology that is likely to prove valuable for use in safety training, productivity improvement and even training of trainers.

7.7 Implications of the study

My work in this research study has contributed to the study of people working in dangerous environments by developing a novel ensemble of technologies and methods which can be used by ergonomists. I have been able to unobtrusively measure work in conditions which are too dangerous for the presence of a researcher. In the study of people at work it is important that normal working conditions and practices are not disrupted to get a true measure of how work is conducted. I have created a working ensemble of technologies which collect comprehensive data without interfering with the normal activity of the worker and been able to gain insights into work practices of fire fighters and tree fallers. Further, lessons from this research will add to the array of training resources to better equip workers to perform their jobs safely and productively.

7.7.1 Limitations of the study

In earlier sections I have detailed the limitations of the various approaches used in this investigation. The primary limitation was the small sample size for the fire fighting studies (Chapter Five) due the difficulty of planning for work in emergency conditions. Although I was only able to collect data from two fires and two fire fighters and on both occasions my early attendance at the fires was serendipitous, the material gathered proved a rich and varied source of information.

Another limitation of the study was the inability to measure work capacity of the fire fighters because of the constraints mentioned above. In the tree felling studies (Chapter Four) it was easier to organise data collection and I was interested in measuring the differences between experienced and novice tree fallers. A sample of eight tree fallers, three experienced, five novices, provided a sufficiently large sample to use statistical tests to explore differences between the two groups.

The video-cued reflective interviews (Chapter Six) were conducted with only one fire fighter and one felling trainer because the intention was to explore the usefulness of reflective interview and not to compare the reflective experiences of a number of individuals doing the same task. Fire fighting and tree felling are completely different types of tasks; fire fighting is a social task with little repetition, tree felling is a solitary task with considerable repetition and short cycle times. I did not interview a tree faller reflecting on his own work because I could not subsequently locate any of the tree fallers who had participated in the study. I then got one of New Zealand’s most highly experienced tree felling trainers to view the video of a novice tree faller. Both the fire fighter and trainer supplied a rich commentary on the tasks and work situations they viewed in the videos.

7.7.2 Strengths of the study

It should be noted that these apparent limitations are countered by the overall research design, which brought a number of elements together that lent strength and rigour to the study. Equipment design made it possible for me to get into the field, away from simulated environments found in the laboratory and overcome many of the barriers to recording and analysing workers in hazardous situations. This in turn enabled the evaluation of workers in their normal work environments, with typical pressures and normal social interactions.

To my knowledge, the use of auto and allo-confrontation reflective interviews with video material and other data from real work in dangerous occupations is a novel element in ergonomics research. This qualitative dimension favoured analytical depth and complexity rather than breadth and generalisation.

Comparing two sets of workers in different environments and work circumstances – one solitary, one social – helped demonstrate that dangerous occupations can have completely different social contexts. The type of data gathered as a consequence of the research design also potentially facilitates a greater understanding of dangerous work for decision makers in government or industry who might never experience such extreme situations. Yet these people may be making decisions that affect the fire fighters and tree fallers and will benefit from the opportunity to gain authentic insights to inform their decisions: video and audio data are accessible to most people, and are likely to be effective means of gaining such insight.

7.8 Concluding comment

This study, measuring dangerous work has incorporated a number of methodological innovations and led to new understandings of New Zealand fire fighting and tree felling occupations. My study has highlighted the value of, and need for, research that is situated in real work environments, and that captures the multidimensionality of workers' activities.

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Appendix 1: Glossary

ARS	Logging Accident Reporting Scheme maintained by the Logging Industry Research Association and the Centre for Human factors and Ergonomics from1984 to 2004.
Campaign fire	Large fire requiring may days to extinguish.
Codec	Software which compresses and decompresses video files.
COHFE	Centre for Human factors and Ergonomics. A Group within Scion created in 1999.
CF	Compact Flash – a solid state memory card.
CSV	Comma separated value data in Microsoft Excel.
Dam	Small portable reservoir for water and is used with a fire pump.
Delimb	Remove limbs (branches) from a tree. In this thesis all delimbing is done with a chainsaw.
Faller	Person who cuts down trees.
Fire line	The part of the fire where people are actively engaged in fire suppression.
Gb	Giga byte of data.
GPS	Global positioning system.
GPX	Generic GPS data file which can be used by other applications.

Haptic feedback	Using the sense of touch for feedback.
Hot spot	Small area still burning.
Initial attack	First fire fighters at the fire engaged in suppression.
LIRA	Logging Industry Research Association, existed from 1975 to 1991. A Research Association of the DSIR (Department of Scientific and Industrial Research).
LIRO	Logging Industry Research Organisation, existed from 1991 to 1999. Successor to LIRA.
LTI	Lost time injury – person cannot return to work the next day because of the seriousness of their injuries.
McCloud tool	A heavy rake used for scraping and grubbing into sub-surface fires.
Mechanisation	In logging – the felling and processing of trees with heavy tracked or wheeled hydraulic machinery, some machines are in excess of 50 tonnes.
MPEG4	Moving Picture Expert Group – 4 is a collection of methods to compress audio and visual data. Used in this study to collect video in the field.
MP4	The file extension of MPEG4 compressed video and audio.
Overcut	A potentially dangerous felling situation where one cut of the scarf is extended beyond the other.

PAL	Phase Alternate Line – the video system used in New Zealand. In contrast to North America which uses the NTSC system.
Pinus radiata	Radiata pine, the predominant plantation tree in New Zealand, originally from the Monterey Peninsula in California.
PPE	Personal protective equipment, e.g. helmet, gloves, goggles, boots.
Rural fire	Vegetation fire.
Scarf	Notch cut in the stem of a tree above the stump to control its direction of fall.
Scion	Trading name of the New Zealand Forest Research Institute Ltd.
SD	Secure digital memory card.
Stem	Trunk of the tree from the stump to the tip.
Structural fire	Fire consuming a house or built structure.
Urban fire	Another term for structural fire.
VEM	Video exposure monitoring.
Wajax	Portable internal combustion engine powered water pump used at rural fires. Used with a dam.

Appendix 2: Informed consent

INFORMATION SHEET

Researcher:
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Felling Productivity & Hazards Study

Study Objectives

This research project aims to measure work of tree fallers by determining, under New Zealand operational conditions, work methods and hazards of felling tasks.

At the same time, the research will measure felling productivity under real conditions.

Data collection equipment will be worn by the faller - video camera on helmet and video camera on shoulder.

If you agree to participate in the study we will ask you to:

- Undertake your felling duties in the normal way
- Follow any normal felling safety precautions
- Wear the video cameras while working.

PLEASE NOTE:

★ Your are free to ask questions regarding the study, at any stage
★ The information provided by you is confidential to the researchers
★ All information will remain anonymous
★ Video and audio material will only be made available to others with your permission
★ You may refuse to wear the equipment or withdraw from the study at any stage, without having to give an explanation, and without any disadvantage to yourself.

[1] Formerly known as the "New Zealand Forest Research Institute"

INFORMATION SHEET

Researcher:
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Cell phone: 027 290 6964

Firefighter Productivity & Workload Study

Study Objectives

This research project aims to improve the health and safety of rural firefighters by determining, under New Zealand operational conditions, the physiological workload of firefighting tasks.

At the same time, the research will measure fire suppression productivity under real fire conditions to provide real data for incorporation into fire management decision support systems.

Data collection equipment will be worn by the firefighter - video camera on helmet, gps unit on webbing and heart rate monitor on chest.

If you agree to participate in the study we will ask you to:

- Undertake your fire suppression duties in the normal way
- Follow any normal fire suppression safety precautions
- Wear the video camera, gps and heart rate equipment at fires

PLEASE NOTE:

★ Your are free to ask questions regarding the study, at any stage
★ The information provided by you is confidential to the researchers
★ All information will remain anonymous
★ Video and audio material will only be made available to others with your permission
★ You may refuse to wear the equipment or withdraw from the study at any stage, without having to give an explanation, and without any disadvantage to yourself.

[2] Formerly known as the "New Zealand Forest Research Institute"

COHFE
Centre for Human Factors and Ergonomics

Tree Felling Study

PARTICIPANT CONSENT FORM

This consent from will be held for a period of five (5) years

I have had the details of the study explained to me.

I have had time to consider whether to take part.

My questions have been answered to my satisfaction, and I understand that I may ask further questions at any time.

I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study at any time for any reason.

I agree to participate in this study.

Signature: .... **Date:** ....

Full Name - printed ....

Richard Parker, Researcher: 027 290 6964 richard.parker@cohfe.co.nz

COHFE
Centre for Human Factors and Ergonomics

Fire Study

PARTICIPANT CONSENT FORM

This consent from will be held for a period of five (5) years

I have had the details of the study explained to me.

I have had time to consider whether to take part.

My questions have been answered to my satisfaction, and I understand that I may ask further questions at any time.

I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study at any time for any reason.

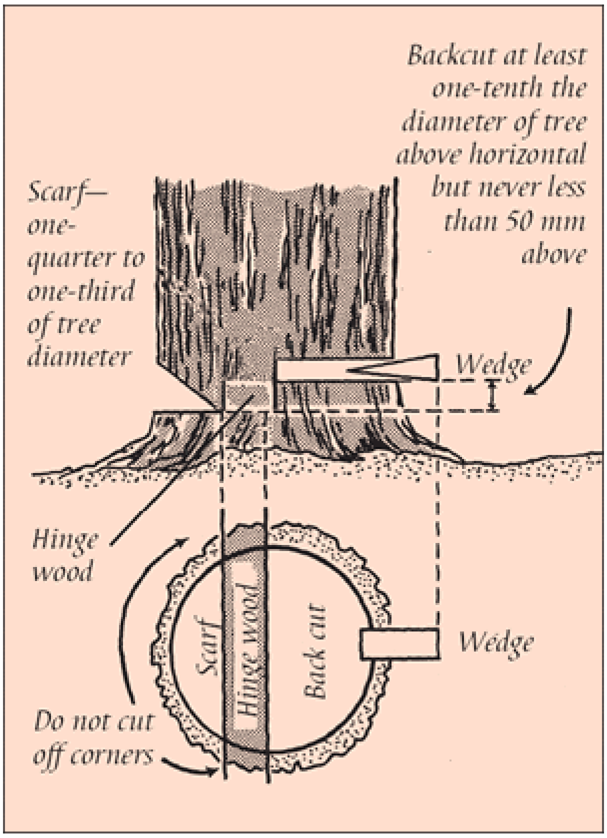
I agree to participate in this study.

Signature: .... **Date:** ....

Full Name - printed ....

Richard Parker, Researcher: 027 290 6964 richard.parker@cohfe.co.nz

Appendix 3: Felling cuts



From: “Chainsaws – a guide to safety”. New Zealand Department of Labour.
http://www.osh.dol.govt.nz/publications/booklets/chainsaws2007/pg2.html

Appendix 4: Video files

To view these video files you must install the TSCC.exe Codec file by copying it to your hard drive and double clicking on it.

You should then be able to view the video files.