Fire Research Report

Rural Firefighter Exposure to Fireground Gases with Relevance to Physiological Workload & Fire Suppression Productivity

SCION

October 2010

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This report will only describe the two complete data sets collected which comprised video, heart rate, gps location and CO. Data collection will continue in coming fire seasons and subsequent data sets will be added for analysis.

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EXECUTIVE SUMMARY

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This report will only describe the two complete data sets collected which comprised video, heart rate, gps location and CO. Data collection will continue in coming fire seasons and subsequent data sets will be added for analysis.

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Location	National

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INTRODUCTION

Many tasks in rural firefighting are physically demanding (Budd, 2001; Gaskill, 2002; Heil, 2002) and result in high levels of fatigue. Research has been published from workload and fatigue studies in Australia and North America (Ruby et al., 1999, 2000, 2001) but there are no published reports measuring New Zealand rural firefighter workload other than the work by Parker et al. (2008) and Parker (2010). Fire behaviour, work practices, climate and equipment in New Zealand differ from those in Australia, the United States and Canada.

The firefighter's heat load and level of fatigue (Brotherhood et al., 1997; Budd, 2001; Budd et al., 1997a; Gaskill, 2002) are influenced by complex interactions among work practices, work behaviour and clothing. The measurement of physiological workload is necessary to understand the factors that contribute to fatigue and so the subsequent success of fatigue management programmes can be measured. Physiological workload also provides a quantitative measure of the physical requirements of a task. New work techniques, items of equipment and work organisation can then be measured to determine if they alter the physiological workload of the firefighter. If a new technique, item of equipment or way or organising work imposes a greater physiological load further modifications and developments would be necessary for successful introduction (Budd et al., 1997b).

The presence of carbon monoxide (CO) will have a significant influence on physiological workload and must be taken into account in any reliable measures of physiological workload and associated productivity on the fireground. CO is a colourless and odourless gas which when inhaled binds to haemoglobin in the blood producing carboxyhaemoglobin (COHb), resulting in more difficult tissue oxygen extraction (Pandolf, 1988). Continuous exposure to high levels of CO may cause a build-up of COHb levels and could lead to reduced work capacity. Elevated levels of CO have been shown, in laboratory studies, to result in significant decrements in human physical performance (ability to do work) (Raven et al., 1974).

Productivity of initial attack crews and more specifically of fireline construction has been of interest for many years and has been the subject of numerous studies, although few studies have actually measured productivity under real fire conditions. Little material has been produced in terms of new data, since the commonly cited studies of Schmidt and Rinehart (1982), and Barney et al. (1992), and most of the studies have produced either limited or extremely variable data, restricting the validity and applicability of the resulting guidelines. Most of the current guidelines are adapted from these early studies, although their validity is enhanced through application of local conditions and of expert knowledge and information.

There is ongoing need for information specific to New Zealand conditions. With the availability of new technology, in particular for monitoring the effects and importance of human factors, significant advances and improvements can (and should) be made to existing data and guidelines through research on productivity of fire suppression resource types mobilised in New Zealand.

Project Objectives

This project sought to establish more detail about physiological workload demands of rural firefighters in New Zealand, and aimed to:

1. Measure the concentration of CO within the breathing zone of rural firefighters at real fires.
2. Combine CO measures with the actual physiological workload and productivity associated with rural firefighting tasks under New Zealand conditions at real fires.
3. Relate measured workload and productivity for firefighting tasks to fitness and productivity requirements.
4. Contribute to guidelines for fatigue and shift length recommendations and real productivity standards.

Overview of methodology

The methodology for this study involved a range of tools to provide data that supported the stated objectives:

- A literature search was undertaken to identify relevant overseas and New Zealand studies on outdoor smoke products inhalation and associated effects on physiological workload.
- Firefighting tasks during wildfires were observed and videoed (using helmet-mounted cameras).

Ambient CO concentration, heart rate and task data were collected. Physiological workload and terrain were measured by GPS linked heart rate monitors.

BACKGROUND

The published literature on firefighter exposure to CO is most comprehensive in the areas of exposure measurement, urban firefighting, fatalities in domestic fires, and the long term health risks of occupational smoke inhalation.

Brotherhood, et al. (1990) examined whether CO poisoning could have contributed to fatal entrapments of Australian bush firefighters by impairing their judgement. They assessed carboxyhemoglobin saturation (COHb%) levels in 24 firefighters working with handtools and in 12 accompanying scientific observers, before and after firefighting (duration 37-187 min) on 15 experimental bushfires. Increases in carboxyhemoglobin levels were higher in the firefighters than in the observers. They also found that smokers were exposed to as much CO from their cigarettes as from bushfire smoke and concluded that bush firefighters are generally unlikely to experience hazardous levels of CO exposure. CO has a half-life of four to five hours and will return to background levels once CO exposure is eliminated (Reisen et al., 2007). No more recent work has been published on the issue of smoking and the immediate on long tem effects for rural firefighter performance.

Self-pacing of firefighters is also probably a highly significant factor when examining workload and heart rate in the presence of respiratory pollutants. An Australian study on occupational fitness and work strain (the adopted level of individual 'effort') in bushfire firefighting (Budd, 2001) found that firefighters paced themselves at similar levels of strain (relative to their own abilities) regardless of the wide range of levels of fitness in the crews. Performance/productivity therefore differed widely but 'effort' did not. In the earlier studies on which the 2001 paper was based, Brotherhood et al. (1997) concluded that 'perceived exertion and ventilatory threshold (the upper limit of comfortable breathing) provided the cues by which firefighters pace themselves at sustainable work rates that balance their fireline productivity against its physiological cost'. Heart rate increased linearly with productivity, whereas perceived exertion and ventilatory threshold increased curvilinearly, rising steeply at fast work rates.

Milhevic et al. (1983) studied motor performance in the presence of CO, finding that task difficulty appeared to be a significant factor in mediating behavioural affects of exposure. No studies were found that specifically studied the ability of rural firefighters, or other similar occupation groups, to carry out decision-making relevant to their tasks, in the presence of elevated CO levels; nor were any found on levels of productivity in varying smoke conditions.

The implication of the reviewed literature for the current studies is that the measurement of CO in the environment and expiration of the firefighters will indicate where reduced lung function is to be anticipated. If firefighters in New Zealand show a similar pattern to those studied in South Australia, and self-pace to maintain a consistent workload based on rate of perceived exertion and upper levels of comfortable breathing, then their heart rate data sets may be unchanged, but there will be reduced productivity profiles – with firefighters working as hard but achieving less. This may or may not be compounded by a drop in quality of decision making as COHb levels rise in the body. Poor decision making may result in greater physiological demands, to recover lost time, and/or degrade technique directly, increasing effort required to achieve the same ends.

According to the literature for recording methods, datalogging of CO via dosimeter in the field (OSHA 1993) is a reasonable method of estimating respiratory irritant exposures – until better methods for data collection are developed (Reinhard et al., 1999).

Video exposure monitoring

The data collected in this study used an elaborated form of 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). In the current study CO was recorded with a data-logging dosimeter. Heart rate was recorded with a data-logging heart rate monitor.

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 United States National Institute of Occupational Safety & Health (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 differed in technical details but generally provided a video signal synchronised with the output of sensors which could be analysed and presented to participants. The greatest difficulty encountered with video exposure monitoring systems was the synchronisation of video with sensor output. Some gas, vapour and aerosol sensors had 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.”

When this work began, there was no published research available that provided work information or physiological data from rural firefighters engaged in suppression tasks at active fires. Studies had estimated workload (e.g. Heil et al., 2004) and productivity (e.g. Murphy & Quintilio, 1978; Murphy, Quintilio & Woodard, 1989) from simulated rural fires and some had asked the firefighters to estimate workload and/or productivity from memory (e.g. Schmidt & Rinehart, 1982; McCarthy, Tolhurst & Wouters, 2003).

The wearable camera and sensor technology developed for 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.

In addition to video data collection, geographical position was also recorded. A GPS recorder was used to track the movements of the firefighters in the field. The GPS device receives signals from satellites stationed above the Earth and calculates the location of the device to within 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 schistosomiasis.

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). We are 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). She reported measurement error in GPS units can make a path of travel appear overly tortuous and show changes in direction which did not actually occur.

METHODS

Data collection was opportunistic. Data collection ensembles were distributed to five fire crews around New Zealand. A crew member would wear the ensemble to a fire and return the ensemble for downloading of the data. Some data sets were incomplete and some data were lost. Some fire crews attended no fires while in possession of a data collection ensemble.

The fieldwork for this study occurred over the years 2008 to 2010. Primary data sources for the study were miniature body worn video cameras, heart-rate monitoring, CO and GPS tracking – enabling more comprehensive monitoring of participants' activities in work conditions that required them to be highly reactive to events, and, due to the nature of firefighting, often highly mobile. Rural firefighters 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.

In previous studies (Parker et al., 2008; Parker, 2010) the authors found firefighters had great difficulty donning and activating all the data collection sensors in an emergency situation. After considerable consultation with firefighters we moved all sensors, other than the heart rate monitor which had to remain in contact with the chest, onto the helmet (Figure 1). The video, gps and CO data loggers were secured in pockets mounted on rural fire helmets (Pacific Helmets, Model BR1T) by the manufacturer. All modifications ensure the helmets continued to conform to the relevant fire helmet standard (AS/NZS 1801 Type 3).

Figure 1 - Data collection helmet worn by firefighters. From the left are the CO monitor, GPS monitor and video recorder. Video camera is mounted on the right side of the helmet in the enclosure designed for a flash light.

Video

The actions of the firefighters were recorded with a miniature 65 mm by 20 mm colour PAL video camera (www.xtremerecall.com) mounted on the firefighter's helmet (Figure 1). Video was recorded using a specialist *Lawmate PV500* portable solid state MP4 video recorder with an internal battery. Video was recorded to an 8 Gb 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.

Heart rate

The heart rates of firefighters were collected with the *Zephyr BioHarness* http://www.zephyr-technology.com/ heart rate monitor. Cardiac electrical activity on the firefighters 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. The chest strap was worn, under clothing, for the duration of the investigation period. At the end of the data collection period, the chest mounted recorders were retrieved from the firefighters 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 electrical interference or body position causing the sensor strap to lose contact with the skin surface. Missing data points were represented in the data set as empty cells.

GPS

The firefighters wore a compact GPS receiver *Qstarz BT-Q1000XT* http://www.qstarz.com. 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.

However it was difficult to interpret the slope of the terrain traversed by the firefighter. In an attempt to better portray firefighter 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 firefighter could then be displayed on three dimensional terrain using the three dimension function of *Google Earth*.

Additionally, to improve the understanding of the path travelled by the firefighter an application, *Active GPX Route Player* (http://hybridgeotools.com/html/active_gpx_route_player.html) was used to display the path of the firefighter as a moving icon. The GPX file was created in the *Qstarz Travel Recorder* software downloaded to *Active GPX Route Player* which allowed control of the speed of the firefighter icon across the terrain. We are not aware of other firefighter studies, or indeed any work studies that have reported using commercial-off-the-shelf (COTS) technologies in this way.

Integration of data

Multiple streams of data were collected from sensors worn by the firefighters. In the laboratory a coding scheme was created in the behaviour observation software package *Observer XT* using the elements described in Table 1. The elements were derived from discussion with experienced firefighters and observation of the video of firefighting. The video file was imported to the *Observer XT* software and viewed and coded (Figure 2). During coding, the video file could be rewound to view scenes a second time to ensure coding was accurate. This enabled us to synchronise video files with GPS data files for analysis. The video footage was also synchronised with the heart rate and CO data to build up a picture of activities, work rates and movements of each firefighter.

Table 1 - Elements used to describe firefighter 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
Pump	Operate pump

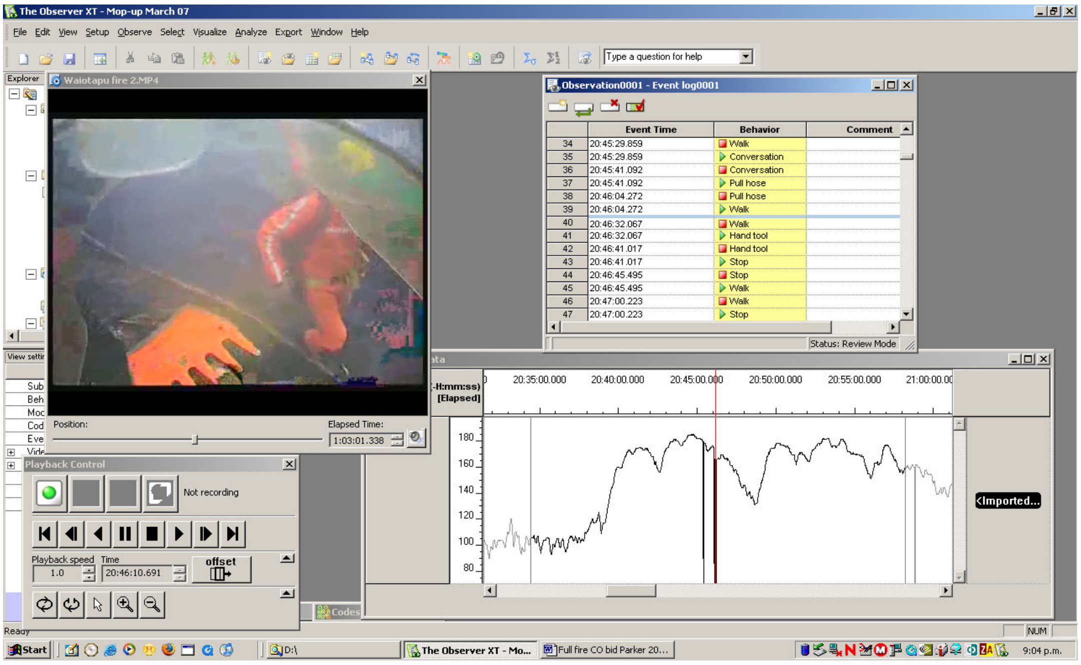

Figure 2 - Observer XT observation window used to code activities. The video image is from a helmet mounted camera, tasks are displayed in the top right window and heart rate displayed in the bottom right window.

RESULTS

Complete data sets were collected at only two fires. Fire A was mopping-up with water and Fire B was a hay barn which had caught fire and subsequently collapsed when the rural fire crew arrived.

One of the reasons it was very difficult to collect data on firefighters at real fires is because it is an emergency situation, and the firefighters' priority is to suppress the fire. Clearly, the data collection had to be opportunistic because we could never be sure where a fire would occur.

Table 2 - Summary information on the data sets from Fire A and Fire B.

	Fire A	Fire B
Activity	Water mop-up	Hand tools to rake
	Laying hose	Removing roofing iron to expose burning hay
	Communication	
Terrain	Undulating	Flat
Fire type	Vegetation	Burning hay bales

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 (Figures 3 & 4). Sound was collected with helmet mounted microphones which allowed conversations to be heard. At times ambient sound levels were high from a Wajax water pump (Fire A) and from strong wind (Fire B).

When fighting a fire, the firefighters 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). These tasks were determined from the video record.

The firefighters were engaged in incompletely different tasks at the two fires. At Fire A the firefighter was engaged in walking to the mop-up area, carrying hoses, applying water to the smouldering vegetation, rolling up hoses, making adjustments to the Wajax water pump and communicating with other firefighters. At Fire B the firefighter was predominantly removing roofing iron and using a hand tool to rake out the burning hay.

Figure 3 – Screen capture of a scene from Fire A. The firefighter is applying water to vegetation.

Figure 4 – Screen capture of a scene from Fire B. The firefighter is pulling roofing iron to expose burning hay.

Carbon monoxide

At both fires the firefighters were exposed to smoke and CO. At Fire A, in mopping up among burning roots and logs there were a total of 9.3 minutes over 3 hours where the CO concentration exceeded 5 parts per million (ppm). There were only 1.5 minutes where the CO concentration exceeded 50 ppm. The highest CO concentration recorded was a 10 second peak of 350 ppm. All occasions when the CO concentration exceeded 50 ppm were when the firefighter was making adjustments to a petrol powered Wajax pump (Figure 5). The firefighter was exposed to lower CO concentrations when applying high pressure water to smouldering tree stumps and roots.

At Fire B the firefighter was exposed to much higher concentrations of CO. He was removing corrugated roofing iron and exposing burning hay. There were a total of 23 minutes over a recording period of 28 minutes where the CO concentration exceeded 5 ppm. There were 14.3 minutes where the CO concentration exceeded 50 ppm. Most importantly there were 3.8 minutes when the CO concentration exceeded 400 ppm and reached a 10 second peak in excess of 900 ppm. He was probably exposed to more CO than was recorded because the CO monitor was removed from the helmet on occasions as can be seen from gaps in the record in Figure 6.

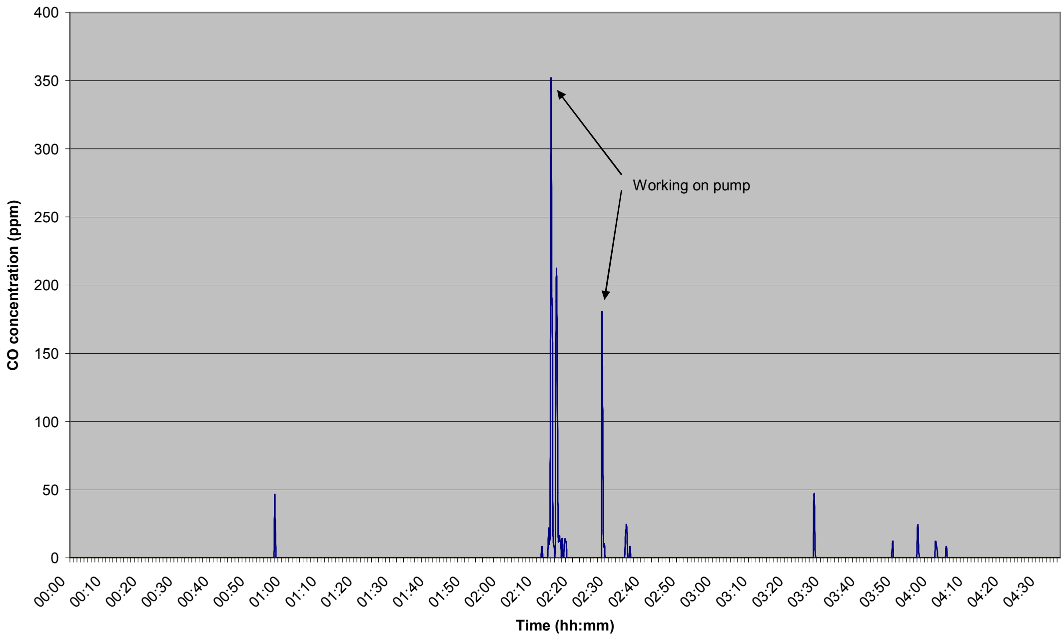

Figure 5 – CO concentration exposure of the firefighter at Fire A making adjustments to a Wajax pump and applying water to shouldering stumps and roots.

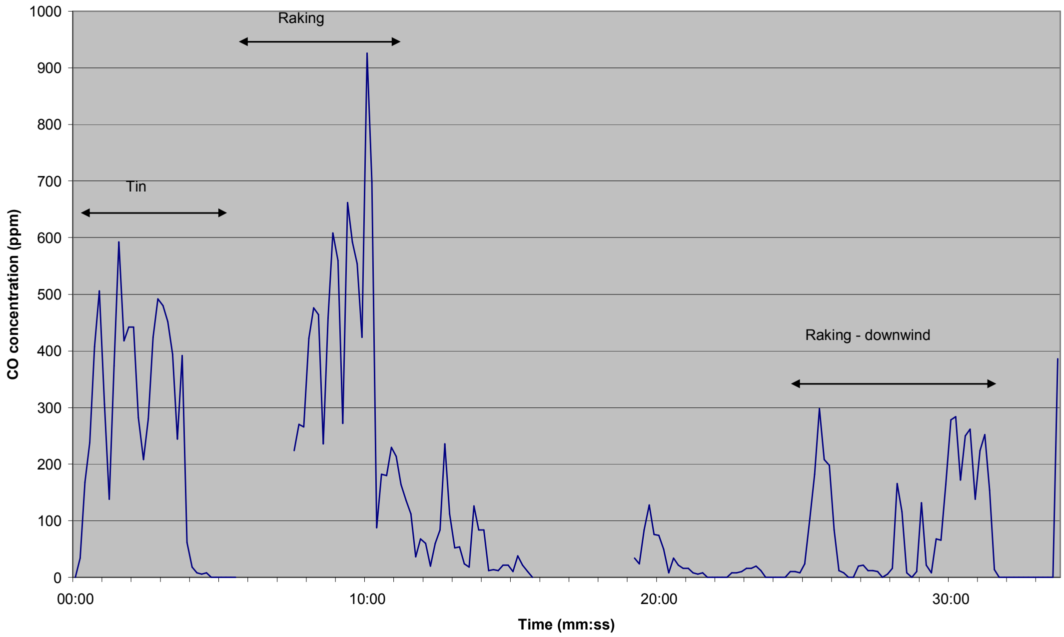

Figure 6 - CO concentration exposure of the firefighter at Fire B. Peaks in CO concentration occurred when removing roofing iron lying over burning hay and raking burning hay while working in smoke.

Heart rate

Firefighting is a physically demanding job. At Fire A the firefighter had a maximum heart rate of 168 beats per minute. At Fire B the firefighter had a maximum heart rate of 138 beats per minute. Expressed as a proportion of their estimated maximum heart rate (220 beats per minutes – age) they were operating at peaks reaching 83% and 68% of their maximum heart rate. People can only sustain such high levels of work for short periods. The firefighter at Fire A was working hard when pulling hoses (Figure 7). The firefighter at Fire B was working more steadily (Figure 8).

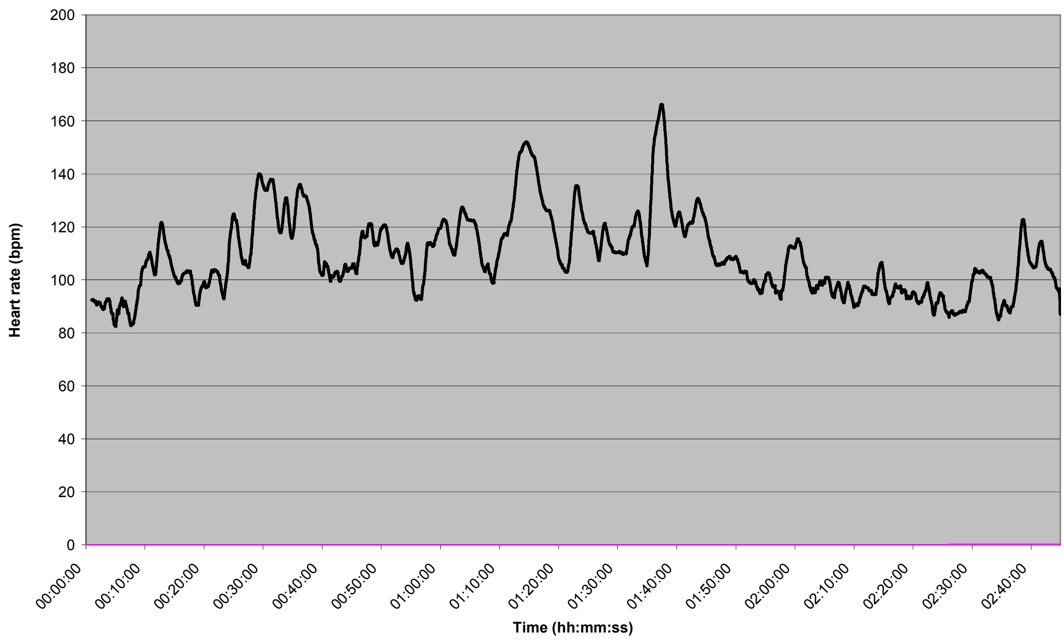

Figure 7 – Heart rate of firefighter at Fire A mopping-up with water.

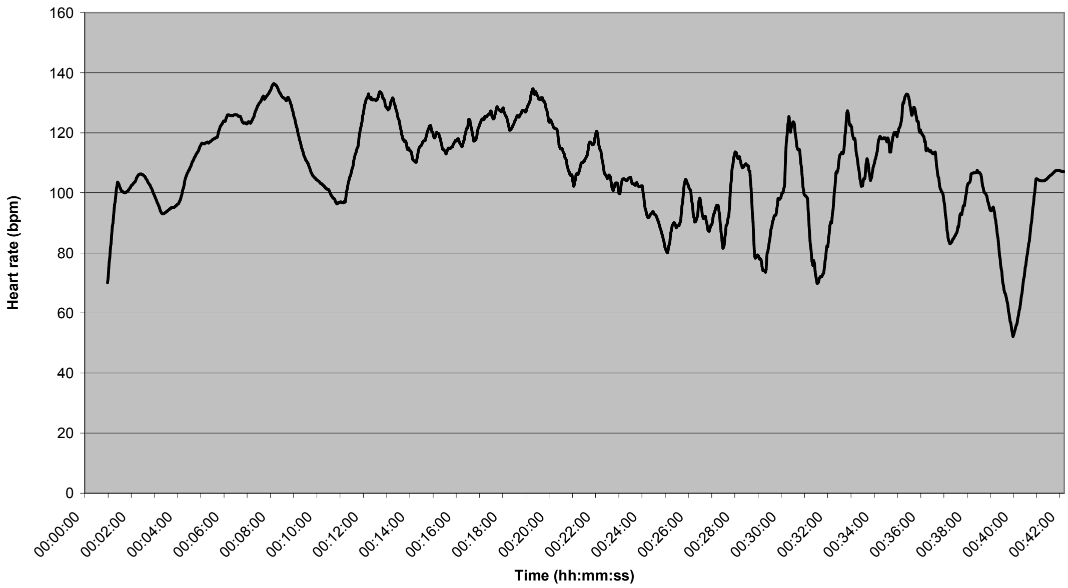

Figure 8 - Heart rate of firefighter on at Fire B using hand tools.

At Fire A the firefighter’s heart rate fluctuated between periods of rest interspersed with periods of intense activity such as pulling hose or walking rapidly with equipment and checking on crew members. At Fire B the firefighter was engaged in two tasks only. Pulling roofing iron, from a collapsed barn, off burning hay and raking burning hay. At times he rested in the fresh air by the fire appliance before returning to work on the fire.

GPS

The position of the firefighters was logged at 10 second intervals with an accuracy of 0.5 % (Coutts & Duffield, 2010; Hampson & McGowan, 2007). The GPS records revealed that the firefighter at Fire A traversed 8.6 km in 4 hours and 35 minutes of data recording and the firefighter at Fire B traversed 1.4 kilometres in 1 hour and 40 minutes of recording.

The track of the firefighters can be seen in relation to the terrain by overlaying the track GPS coordinates on a *Google Earth* terrain model (Figures 9 & 10).

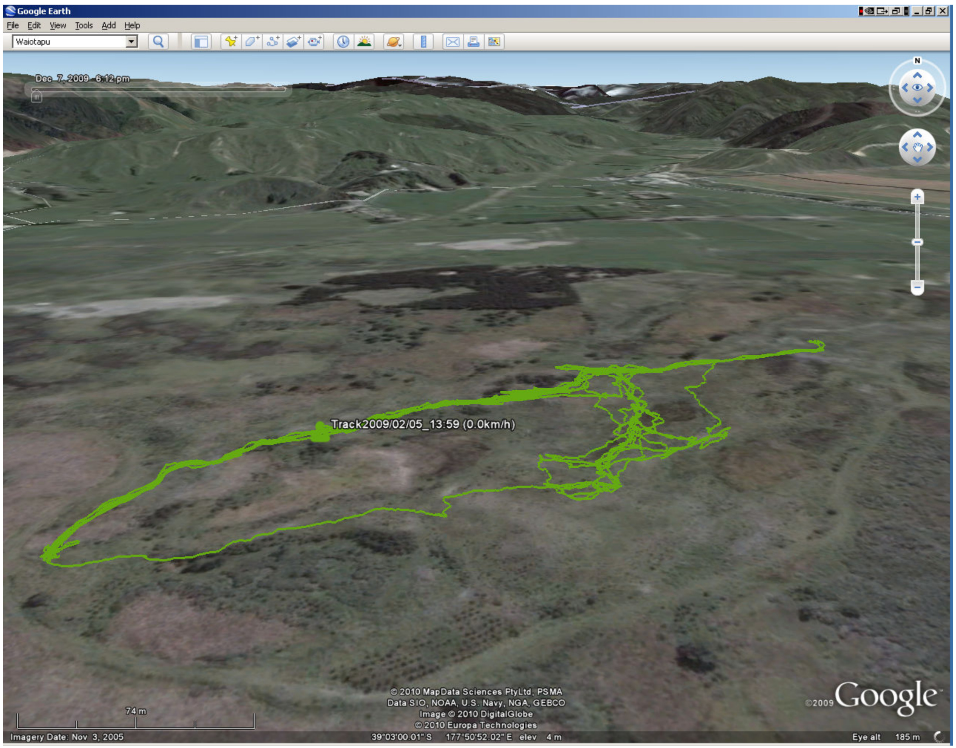

Figure 9 – Fire A. Oblique view, from the South, of the region where the firefighter worked. The green line is a trace of his path.

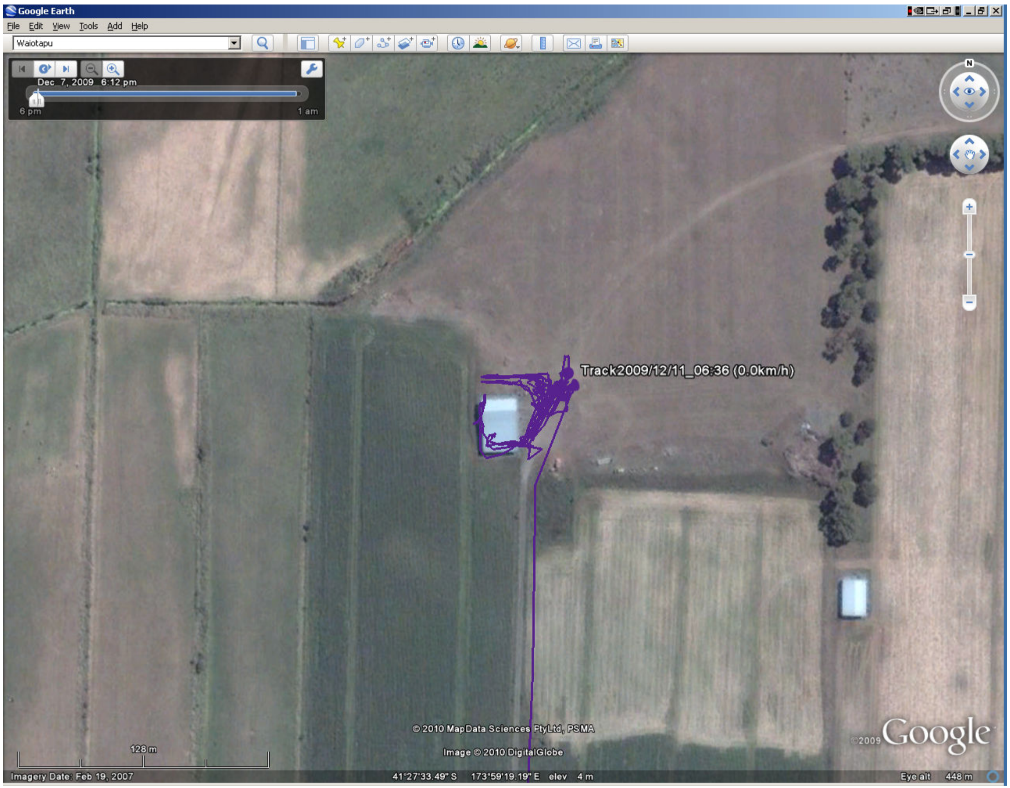

Figure 10 - Fire B. Plan view of the region where the firefighter worked. The purple line is a trace of his path.

DISCUSSION

The data collected at the two fires have provided a comprehensive understanding of the work environment of the firefighters at real fires. However more data needs to be collected at more fires.

Task analysis

The two firefighters were working at quite different fires and had different roles at their fires. The firefighter at Fire A was on undulating 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.

In contrast, the firefighter at Fire B was a crew member and engaged almost completely with removing roofing iron and raking burning hay under very smoky conditions.

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

Carbon monoxide

CO occupational exposure limits are 30 ppm for an 8 hour work day, 200 ppm for 15 minutes and a peak of 400 ppm should not be exceeded at any time (De Vos et al., 2009). Symptoms of exposure include mild headaches (at rest) at 200 ppm after two to three hours. Nausea, headache and dizziness can occur at 400 ppm after one to two hours. Confusion, ataxia, coma and seizures may develop at concentrations higher than 800 ppm.

In the current study under New Zealand conditions the firefighter mopping up with a hose was exposed to transient peaks of 30 to 50 ppm on occasions when applying water to smouldering tree stumps and roots. However, peaks of CO exposure of 350 ppm and 180 ppm occurred when the firefighter was working immediately beside or near a Wajax pump. This result is consistent with Materna et al. (1992) who reported the highest exposures to CO of Californian wildlands firefighters (instantaneous 300 ppm) was associated with operators of petrol powered water pumps.

The findings of Miranda et al. (2010) on the CO exposure of rural firefighters at controlled burns in Portugal are similar to those found in our New Zealand study with occasional peaks up to 400 ppm. They report that high CO concentrations were found outside the “flaming periods” during mop-up. CO is a smouldering-derived pollutant (Andreae & Merlot, 2001).

The firefighter engaged in mopping up after a hay barn fire was exposed to much higher concentrations of CO. In a 10 minute period he was exposed to a CO concentration in excess of 400 ppm for 4 minutes and 20 seconds. These are figures more likely to be found in structural fires (which this was). For example Treitman et al. (1980) report CO concentrations in excess of 200 ppm.

Reinhardt and Ottmar (2004) reported that with a reliable measure of CO from a calibrated dosimeter, the concentrations of other respiratory irritants could be estimated (Table 3). This could be useful in further studies to reconstruct the total pollutant load on the firefighter.

Table 3 -Linear regression coefficients of determination between carbon monoxide and other pollutants measured at prescribed burns in the United States. (From Reinhardt and Ottmar, 2004, p. 601).

Pollutant pair	Number of sample pairs	Coefficient of determination (r^2)
Carbon monoxide, acrolein	87	0.63
Carbon monoxide, benzene	125	0.74
Carbon monoxide, formaldehyde	240	0.82
Carbon monoxide, respiratory particulate	162	0.73

Reinhardt and Ottmar (2004, p. 604) recommend that "…further effort should be aimed at measuring peak smoke exposure at all types of fires – we believe that our measurements have not identified the upper range of smoke exposures."

Respiratory protection is available for aldehydes and particulate matter but not for CO. It is not practical for rural firefighters to be using self contained breathing apparatus as used by structural firefighters. Reinhardt and Ottmar (2004) recommend a CO dosimeter to provide immediate warnings about CO levels in smoky conditions. They conclude that smoke (and CO) exposure is a manageable hazard because high-exposure situations are predictable.

Among the smoke exposure recommendations of the United States National Wildfire Coordinating Group that are immediately relevant to the New Zealand rural firefighters situation:

1. Training firefighters on the hazards of smoke
2. Modifying firefighting planning and tactics to emphasise flank attack of wildfires, minimising mop-up efforts, let areas burn if resources not threatened and reduce the need for holding firelines and direct attack at prescribed burns
3. Use electronic CO dosimeters to regularly assess smoke exposure.

Reinhardt and Ottmar (2004, p. 605) "…recommend that our observed correlations among pollutants be used to predict exposure to several pollutants when resources allow only one (such as CO) to be monitored."

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 rest periods can be classified as “Heavy” resulting in 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 7 and 8) indicated the intermittent nature of fire suppression tasks. To maintain a high average work rate the firefighters take brief rests by changing tasks or slowing down – ‘self pacing’. This self pacing is also reported by Budd (2001) for Australian rural firefighters.

Workload of the two firefighters in this study was measured by heart rate recording. It is difficult to directly compare the two firefighters 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 has shown physiologically useful data can be collected in the field at real fires under normal operational conditions.

Budd (2001, p. 381) highlighted 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)”. He concluded that the stability of the firefighter’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 we captured in this study.

GPS

The firefighters covered remarkably long distances during the observation periods. None of the firefighters, on questioning, realised they covered so much terrain in the normal course of their work. In this respect firefighting differs from forestry tasks which remains more localised. Seto, et al. (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 firefighters at fires. The data in this study has been used, primarily, in a qualitative way to understand where on the terrain the firefighter was positioned when they were at the fire.

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 instrumenting firefighters under these emergency conditions. The two firefighters 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 we 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 firefighters has been established.

The objectives of the study were to measure the concentration of CO within the breathing zone of rural firefighters at real fires; combine CO measures with the actual physiological workload and productivity associated with rural firefighting tasks under New Zealand conditions at real fires; relate measured workload and productivity for firefighting tasks to fitness and productivity requirements and contribute to guidelines for fatigue and shift length recommendations and real productivity standards.

CO concentration has been measured at real fires. However, due to operational difficulties and the very steep learning curve encountered by the researchers only a small sample of data has been collected, so far. It is planned to continue data collection in coming fire seasons to expand the database. Then, with an adequate database meaningful results can be used to contribute to guidelines for fatigue and shift length.

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