Fighting fatigue whilst fighting bushfire: an overview of factors contributing to firefighter fatigue during bushfire suppression

Aisbett and Nichols explore the physiological factors contributing to firefighter fatigue while fighting bushfires

Abstract

Aching muscles and joints, lethargy, and sleepiness are all signs of firefighter fatigue during bushfire suppression (Figure 1). If not managed, fatigue may lead to injury or illness for the individual, which may also compromise the safety and productivity of their crew. Understanding the many sources of firefighter fatigue is, therefore, fundamental for all Australian fire agencies. This article will briefly address several factors thought to contribute to firefighter fatigue including; sleep loss, firefighter's work activity, their hydration, and nutrition, the hot and smoky working environment, firefighter's physical fitness and their experience. This brief overview draws on findings from firefighting research and the broader scientific literature.

Figure 1: Fatigued Australian firefighters following a bushfire suppression shift.

Introduction

Fatigue can be defined as a reduction in physical and mental work capacity, resulting from physical or mental load(s), that is reversible with rest. On the fireground, obvious symptoms of firefighter fatigue include aching muscles and joints, lethargy, reduced work output, sleepiness, and trouble concentrating (MTDC, 2003). These symptoms are often the first clear indication that the firefighter is suffering escalating strain in response to fireground stress (Figure 2). Stress is defined as the physical, mental, or environmental load imposed on the firefighter (Budd et al., 1997a). Common sources of stress on the fireground include smoke, the intensity and duration of the work, and heat from firefighter's exertion, the weather, and the fire (Budd et al., 1997a). The strain experienced by firefighters can include physiological responses such as elevated heart rate and sweating and subjective responses such as increases in perceived exertion and thermal discomfort (Budd et al., 1997a). Under sustained or increasing stress, fatigue may quickly lead to impaired work performance and judgment, unsafe behaviour, accidents (i.e., injury), and in very rare cases death [Figure 2 (Budd et al., 1997a)]. Sustained fatigue on the fireground can also increase firefighter's risk of illness (Ruby et al., 2002b). Injured or ill firefighters compromise the wellbeing of their crew, their crew's fire suppression objectives, and potentially, the protection of people and property by the affected crew. Understanding and managing fatigue on the fireground is, therefore, a critically important issue confronting fire authorities and land management agencies across Australia.

Figure 2: A model of stress and strain during bushfire suppression. Adapted from Budd et al. International Journal of Wildland Fire, 7, 69-76. Reproduced with permission from CSIRO PUBLISHING, Melbourne Australia.

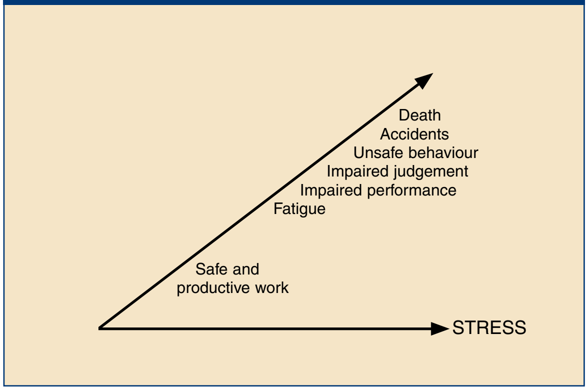
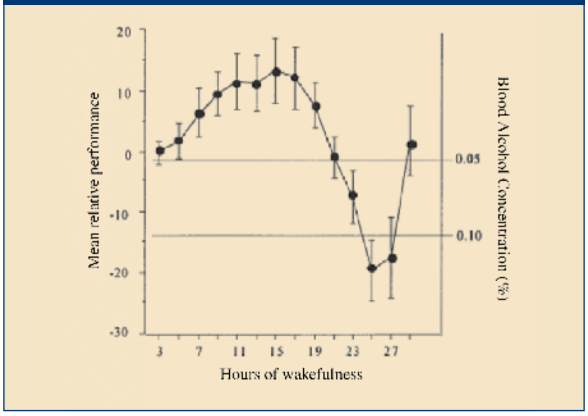


Figure 3: Mean relative mental performance with sustained wakefulness compared to different blood alcohol concentrations. Adapted from Lamond and Dawson. Journal of Sleep Research, 8, 255-262. Reproduced with permission from BLACKWELL PUBLISHING, Oxford, United Kingdom.



Sources of Fatigue for Australian Bushfire Fighters

Firefighter fatigue during bushfire suppression can arise from a number of sources. The current overview will outline the relationship between fatigue and sleep, before focusing on the impact of firefighter's work activity, hydration, and nutrition before, during, and after their fireground shift has on firefighter fatigue. The influences that heat (from the weather, fire, and physical work), smoke, fitness, and experience each have on firefighter fatigue will also be briefly addressed. A detailed reference list is provided for readers interested in pursuing specific issues in greater depth.

Sleep

Sleep loss is a major cause of fatigue and is thoroughly reviewed elsewhere (Dawson & McCulloch, 2005). Briefly, the specific symptoms include forgetfulness, poor concentration and mood swings, and lethargy (MTDC, 2003). Sleep loss is, accordingly, more related to psychological and emotional fatigue rather than a reduction in work capacity (MTDC, 2003). Indeed, United States Forest Service (USFS) seasonal firefighters work output was not strongly related to the number of hours they slept the night before (Ruby & Gaskill, 2002). Extended sleep loss can, however, impair decision making to the same extent as blood alcohol concentrations that exceed 0.05% [Figure 3; (Lamond & Dawson 1999)]. Australian volunteer firefighters who perform a full fireground shift after completing their normal employment may be especially vulnerable to the negative effects of 'sleep loss fatigue'. Fire agencies may consider implementing shorter shifts for first responders at incidents that will require multiple shifts and crews. Restricting the shift length for volunteers who may have already completed a half or full days' employment may limit the time they have to stay awake and reduce the likelihood of bad decisions induced by sleep loss fatigue. Dedicated research into the interplay between firefighter's sleep patterns, their work output, physiological, and subjective responses during bushfire suppression is, however, required before changes to shift lengths can be implemented.

Work Activity

The intensity and duration of fireground work is a major source of stress for bushfire fighters (Budd et al., 1997a) and, hence, is a key factor in firefighter fatigue. For the Australian volunteer firefighter, this fatigue may be compounded by the work they do in their normal employment before turnout. The effect that their outside work has on the fatigue they experience during bushfire suppression has not been directly evaluated. Research using USFS seasonal firefighters indicates that firefighter's daily work output was strongly associated with the incidence of physical fatigue during their next day's shift (Ruby et al., 2002a). Though yet to be investigated, it is likely that Australian volunteers with more physically demanding jobs will experience more physical fatigue (i.e., reduced work output) during bushfire suppression. Alternatively, those firefighters with more mentally demanding employment may be prone to tiredness and trouble concentrating during their bushfire suppression shift. Crew leaders may need to consider firefighters' pre-shift activities before assigning specific duties on and off the fireground. Individual firefighters also need to recognize their own fatigue levels before turning out or volunteering for particular roles at an incident. Research into the relationships between firefighters' outside employment and their work output, physiological, and subjective responses during subsequent bushfire suppression shifts is, however, required before firm conclusions on this issue can be made.

No one has evaluated the physical demands of suppressing bushfires using water and other liquid suppressants delivered by fire hoses connected to fire trucks (i.e., tankers). The study of work activity is difficult for researchers due to limited access to firefighters prior to their shift and problems collecting valid work and physiological data in remote locations without interfering with the firefighter's work. Our laboratory has employed portable global positioning units, heart rate, and physical activity monitors to measure the work patterns and energy expenditure associated with individual firefighters undertaking tanker-based suppression of Australian bushfires. The units can be worn under firefighter's clothing (Figure 4) and collect data throughout a fireground shift without disrupting their suppression duties.

Figure 4: Portable global positioning system (inside blue pouch), heart rate, and activity monitors (connected to black horizontal strap) enable measurements of work patterns and energy expenditure during bushfire suppression without disrupting firefighter's work.

Preliminary data from the 2006-2007 fire season indicates that tanker-based bushfire fighting is an intermittent activity with brief periods of intense work separated by lower levels of activity. During a typical (10.2 ± 2.1 hr) shift, firefighters (n = 42) spent 21.7 ± 18.4% of their time traveling in the tanker. On the fireground, they covered 15.6 ± 5.5 km on foot at an average speed of 1.7 ± 1.0 $km{\cdot}hr^{-1}$. During their shift, the firefighters' average heart rate was 101.2 ± 12.6 $beats{\cdot}min^{-1}$ [54.4 ± 5.0% of age-predicted maximum heart rate (HRmax)], whilst their peak HR was 169.0 ± 17.8 $beats{\cdot}min^{-1}$ (92.0 ± 9.2%HRmax). The average and peak heart rates are considered 'moderate' and 'very hard' respectively by the American College of Sports Medicine (ACSM). The peak heart rates are consistent with the demands experienced during periods of charged hose advance (Bennett et al., 1994, Gledhill & Jamnik, 1992) and 'normal' to 'fast' rake hoeing (Brotherhood et al., 1997a). Such intense bursts of effort can lead to the accumulation of chemical compounds (including potassium, lactate, and hydrogen ions) in the muscles and blood which are thought to impair physical performance (Westerblad et al., 2002) and contribute to subjective perceptions of fatigue (Noble & Robertson, 1996). A rapid acceleration of blood pressure and heart rate accompanying a brief, intense exercise session may also put some firefighters at increased risk of cardiovascular distress (Balady et al., 1998). Firefighter fatigue may not only arise from intense, intermittent work bouts but also from the long duration of their fireground shift. Unpublished data from our laboratory has shown that, in 95% of cases, Australian rural firefighters work for between 8.5 to 12 hours. The energy expended during this time is yet to be determined. During typical 12 – 18 hour shifts, USFS firefighters expend a similar amount of energy as elite marine units and US swimmers during training camps (Ruby et al., 2002c). Firefighters with the USFS primarily use handtools (e.g., rakes, chainsaws) to clear combustible fuel (e.g., small shrubs, plant litter) to create fire breaks of bare earth to curtail the spread of the fire. Fundamental differences in movement patterns between this type of suppression work and that performed by tanker-based fire crews (Figure 5) limit the application of findings from the USFS to the Australian volunteer tanker-based firefighter. There are also considerable differences between Australian volunteer firefighters and the seasonal firefighters employed by the USFS with respect to age, demographics, and physical condition (i.e., health and fitness). Further investigation is required before the energy expended by tanker-based fire crews can be quantified. Without this knowledge, the hydration and nutritional requirements for Australia's volunteer bushfire firefighters cannot be determined.

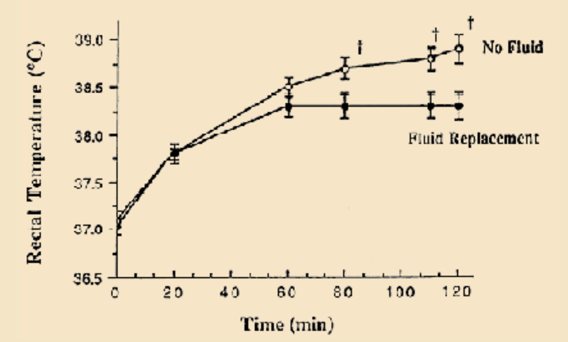
During campaign fires, fire crews frequently undertake multiple fireground shifts in consecutive days. Shift work schedules are likely to accelerate the fatigue that firefighters experience in a single shift and predispose the individual to fatigue-related injury and illness. Indeed, research from the USFS indicates that consecutive days of intense or prolonged fireground work suppress firefighters' immune systems, increasing their chance of illness (Ruby et al., 2002b). Alternating 'easy' (< 8 hr) followed by 'hard' (> 14 hours) work shifts preserved firefighters' immune response after consecutive fireground shifts (Ruby et al., 2002b). Fire agencies should consider investigating the effects that flexible work scheduling has on the fatigue that Australian volunteer firefighters experience during consecutive days of bushfire suppression. Recovery between shifts may also be improved by firefighters engaging in low intensity activity (such as walking). Walking is a simple and practical way to reduce any fatigue from one shift to the next. Periods of 'active recovery' have been consistently shown to augment athletes' recovery from vigorous and / or prolonged sporting activities (Reilly & Ekblom, 2005). Whether active recovery produces a meaningful benefit for fatigued bushfire fighters is currently unknown.

Figure 5: Differences in core work tasks for fire authority personnel (left) and land management crews (right). Reproduced with permission from Country Fire Authority, Victoria, Australia.

Hydration

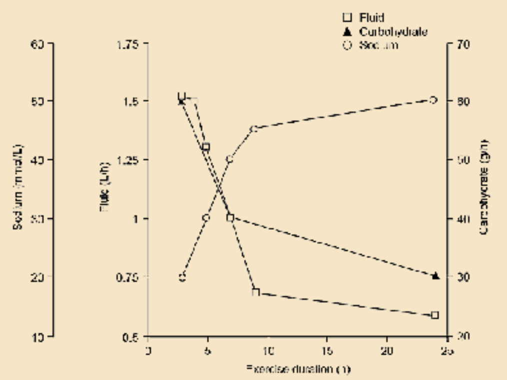
The loss of body water (i.e., dehydration) is a classic source of fatigue (Sawka & Pandolf, 1990). Dehydration causes fatigue by exaggerating physiological strain, and impairing physical, and mental performance (Kay & Marino, 2000). Each of these factors can compromise the health and safety of the individual (Sawka & Pandolf, 1990). The fatigue experienced as a result of dehydration may be related to a rise in core temperature (Febbraio, 2003). Fluid loss reduces blood volume, which in turn reduces the volume of blood that that can be sent to the skin surface to cool the body through sweat and evaporation (Coyle & Gonzalez-Alonso, 2001). When fluid is not replaced during an exercise session, core temperature rises steadily until exhaustion [Figure 6; (Hamilton et al., 1991]. Modest increases in core temperature have been associated with muscle weakness and a loss of balance (Wilmore & Costill, 1994). These symptoms present a serious risk to the health and safety of Australian bushfire fighters who are performing repetitive manual handling tasks over an 8.5 – 12 hour shift. If core temperature continues to rise, the individual will stop sweating and lose consciousness (Wilmore & Costill, 1994). The reduction in blood volume without fluid replacement also causes heart rate to increase rapidly, as the heart must beat faster to deliver the same amount of blood (Hamilton et al., 1991). The accelerated heart rate associated with dehydration may be particularly harmful for older individuals or those with pre-existing heart conditions. Dehydration also impairs cognitive function (e.g. decision making) in proportion to the volume of fluid loss (Cian et al., 2000; Gopinathan et al., 1988) which may compromise the health, safety, and productivity of the individual and their fire crew. The negative effects of progressive dehydration during physical work may be amplified in the volunteer firefighter who may report to the fireground in a dehydrated state having already completed their normal employment before turning out. Simple measures of hydration status such as urine colour could be used by firefighters before their shift to ensure they are well hydrated before turn out. Investigating the accuracy and acceptance of such measures will be valuable to Australia's fire agencies, as the hydration status of Australian tanker-based volunteer firefighters has not been directly assessed.

**Figure 6: Rectal (core) temperature during endurance exercise with and without fluid replacement.
† indicates meaningful difference in rectal temperature between the fluid replacement and no fluid trials. Adapted from Hamilton et al. Journal of Applied Physiology 71(3): 871-877. Reproduced with permission from the AMERICAN PHYSIOLOGICAL SOCIETY, Maryland, United States of America.**



Research into the hydration status of Australian firefighters constructing fireline using handtools found these workers did not adequately replace their fluid loss even when under instruction to drink frequently (Hendrie et al., 1997). Whether this is reflects the type of drink that was available or is a part of the firefighting culture is not clear. The type of drink (or combination of drinks) required to maintain firefighter's fluid levels remains to be determined. Exercise science literature advocates a carbohydrate and electrolyte (i.e., salt) beverage is optimal for working in the heat (Rehrer, 2001). The carbohydrate provides energy, which is critical for sustaining work rate (von Duvillard et al., 2004) over the long working hours undertaken by bushfire fighters. During work in hot conditions, the body burns carbohydrates more quickly, reducing the sustainable energy supply (Febbraio, 2001). Provided the carbohydrate content is less than 10 per cent such as in many commercially available sports drinks, the fluid passes through the digestive system and reaches the muscles as fast as water (Convertino et al., 1996). The inclusion of electrolytes, particularly sodium, helps maintain the "drive" to continue drinking, minimizing urinary fluid losses post-shift, and therefore maintains body fluid volumes, more effectively than water (Rehrer, 2001). The increased fluid retention limits rises in core temperature (Hamilton et al., 1991), either creating a 'heat sink' in the gut (Kay & Marino 2000) or by sustaining sweat rates to continue evaporative cooling (Cheuvront et al., 2003). The concentrations of carbohydrate and electrolytes and the volume of fluid advised for exercise of different durations has been modeled in the broader exercise science literature (Figure 7). The exact make-up of a drink that firefighters are willing to drink frequently and will adequately maintain their fluid levels remains to be investigated. In the interim, firefighters should drink both commercially available electrolyte replacement drinks and water during their shift to stay hydrated.

Figure 7: Suggested rates of fluid, sodium, and carbohydrate levels during exercise of varying duration. Adapted from Rehrer (2001) Sports Medicine 31(10): 701-715. Reproduced with permission from WOLTERS KLUWER, Chester, United Kingdom.



Firefighters are likely to return from their shift highly dehydrated (Hendrie et al., 1997). Performing physical activity or work whilst dehydrated impairs cognitive functioning, reduces work output, and exaggerates physiological strain (Kay & Marino, 2000). Therefore, restoring fluid levels should be a fundamental part of firefighter's post-shift behaviour. If fluid levels are not replenished, firefighters will turn out to the next shift dehydrated, increasing their risk of fatigue, heat stress, and compromise the health, safety, and wellbeing of themselves and their crew. Formal research into the optimal re-hydration strategy for Australian bushfire fighters during and after their shift should be a priority health and safety research area for Australia's fire agencies.

Nutrition

Falling carbohydrate levels during exercise has been classically associated with fatigue (Coyle 1995). Without adequate carbohydrate stores, there is not enough energy to sustain their current work-rate (ACSM, 2000). Low carbohydrate stores have also been associated with reductions in decision making and mental awareness during physical work (Lieberman et al., 2002). The negative effects of falling energy levels during physical work may be amplified in the volunteer firefighter who may report to the fireground with low energy levels having already completed their normal employment before turning out. Firefighters should consume carbohydrate-rich foods with a slow release of energy (e.g., whole grain breads, pasta) before arriving at the staging area. Formal investigation into the energy levels of Australian volunteer firefighters is, however, required before fire agencies can develop practical pre-shift nutritional guidelines to preserve the wellbeing of their firefighters during bushfire suppression.

Research using USFS firefighters indicates that consuming small serves of carbohydrate-rich food regularly during a fireground shift increases productivity (Figure 8), especially late in the shift when the energy they obtained during the pre-shift or lunch meal has been already used up (Ruby et al., 2003). Regular consumption of carbohydrates during physical labour has also been shown to prolong alertness and delay the onset of lethargy and poor decision making (Lieberman et al., 2002). The frequency and type of carbohydrate (i.e., liquid, solid, or in combination) that Australian volunteer bushfire firefighters should consume to delay fatigue on the fireground should be a priority research area for Australia's fire agencies. In the interim, firefighters should ensure they snack frequently on convenient, carbohydrate-rich foods such as muesli bars and fruit to sustain their energy levels throughout a shift.

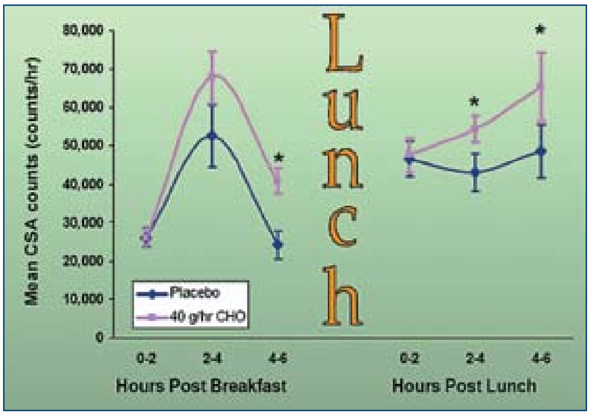


Figure 8: Work activity during work-shift with and without (placebo) intermittent carbohydrate feeding. Adapted from Ruby et al. Wildifre Lessons Learned, http://www.wildfirelessons.net/Home.aspx Retrieved February, 2006. Reproduced with permission from WILDFIRE LESSONS LEARNED CENTRE.

The restoration of firefighters' energy levels, primarily by eating carbohydrate-rich foods after their shift has been implicated in the preservation of immune function (Harger et al., 2004). Preliminary data from the USFS indicates that firefighters who maintain their carbohydrate levels show a lower incidence of upper respiratory tract infections (Harger et al., 2004). More research into the area of nutrition and immune function for firefighters and emergency service workers in general is required. Restoration of energy levels is vital for firefighters turning out for subsequent shifts where low energy levels will, most likely, be associated with the rapid onset of fatigue (ACSM, 2000), low productivity (Coyle, 1995), and poor decision making (Lieberman et al., 2002). Fire agencies need to continue working with nutrition experts to devise practical ways to deliver carbohydrate-rich foods to firefighters following their shift. Measuring the impact that post-shift nutrition has on the firefighter fatigue, especially during consecutive fireground shifts should be a fundamental part of the current and future nutrition practices employed by Australia's fire agencies.

Heat

Bushfires burn in hot, dry weather conditions (Cheney, 1976) and produce extreme radiant heat (Budd & Cheney, 1983). It is expected that Australian bushfire fighters face considerable thermal stress and risk heat-induced fatigue during their bushfires suppression duties (Black 1987). The only research into the heat loads imposed during bushfire suppression reports, however, that firefighter's physical labour actually exerts a greater heat stress than the fire and weather conditions combined (Budd et al., 1997b). The findings from Project Aquarius (Budd et al., 1997b) are directly applicable to land management agency fire crews during the preparation and containment of fuel-reduction burns. The relevance of their findings to fire crews working to suppress accidental summer bushfires may be less straightforward. The research in Project Aquarius was conducted using experimental fires burning in warm temperatures (17-33°C), with only medium relative humidity (14-81%) and moderate wind speeds (7-32 km·hr-1). Given that tanker-based bushfire suppression is usually carried out in hot (33-45°C), dry (relative humidity < 20%), and windy (25-72 km·hr-1) environments it is likely that the heat load and, hence, fatigue will be greater at wildfires than in experimental fire conditions. The actual heat load experienced by Australian tanker-based firefighters during bushfire suppression is unknown. The heat stress arises not only from the hot environment but also from the personal protective clothing worn to protect the firefighter from radiant heat and burning debris. Thought fundamental for the firefighter's safety, personal protective clothing often restricts evaporation of sweat and dissipation of metabolic heat, increasing heat storage, cardiovascular strain, discomfort, and fatigue (Budd et al., 1997c). The contribution of the current firefighting ensemble to firefighter heat strain is unclear. To measure firefighter's heat strain during bushfire suppression, our laboratory has started using an easily digestible tablet to measure core temperature and adhesive skin temperature patches. These devices collect data during tanker-based bushfire suppression without disrupting the firefighter from their duty (Figure 9). This research may lead to strategies to help firefighters cope more effectively with the heat loads they face during their bushfire suppression shift, delaying the onset of fatigue.

Figure 9: Core temperature tablet (a), skin temperature patch (b), and portable data logger (c) for measuring heat strain during tanker-based bushfire suppression. Adapted from http://www.minimitter.com/Products/VitalSense/index.html Retrieved February, 2006. Reproduced with permission from, MINIMITTER INC., Oregon, United States of America.

Smoke

In the smoke filled environment of a bushfire, exposure to carbon monoxide and other smoke compounds may also lead to fatigue. For instance, carbon monoxide exposure can lead to headaches, dizziness, and confusion that increase with the level of exposure (Raub et al., 2000). Exposure to carbon monoxide before or during exercise also reduces work output whilst increasing heart rate (Carlisle & Sharp, 2001), exaggerating physiological strain – all symptoms of fatigue. Other smoke compounds such as particulate matter and volatile organic compounds may also impair lung function, reducing the value of air that can be inhaled and exhaled (Carlisle & Sharp, 2001) potentially limiting firefighter's work productivity. For a comprehensive discussion on the interactions between the compounds commonly found in air pollution (including smoke) and work activity, the reader is referred to Carlisle and Sharp (2001).

Fitness

Cardiorespiratory endurance or 'aerobic fitness' is considered fundamental to countering firefighter fatigue (Sharkey, 1997). High levels of aerobic fitness enable individuals to continue or persist in strenuous whole-body work tasks for long periods of time (Nieman, 2003). Preliminary research from the USFS indicates that aerobic fitness was strongly associated with daily work output over a nine day period (Gaskill et al., 2002). Australian research into handtool fireline construction also suggests that superior aerobic fitness becomes especially important in emergency situations when firefighters cannot afford to pace themselves during their shift (Brotherhood et al., 1997b). The importance of aerobic fitness to safe and productive handtool fireline construction has led to the routine assessment of fire crews' aerobic fitness levels in USFS (Sharkey 1999) and Australian land management agencies (Ellis & Gilbert, 1997). The highest 'fit for duty' standard for land management agency fire crews is achieved by walking 4.8-km, wearing a 20-kg pack in less than 45 minutes (Sharkey, 1999). The pack-hike test has been deemed to simulate the physiological demands of hand tool suppression of bushfires (Sharkey, 1999). The expectation upon passing this test is that the individual has the necessary fitness to complete similar work tasks on the fireground (Payne et al., 2005). Whether the pack hike test accurately simulates the physiological demands of tanker-based suppression is yet to be determined. Differences in core work tasks (i.e., raking fireline versus spraying fire hoses) between land management and fire authority crews [Figure 5 (AFAC, 2002)] may limit the applicability of the pack hike test to tanker-based fire crews. The physiological attributes necessary for safe and effective tanker-based bushfire suppression have not been identified. Tanker-based crews move, carry, and hold equipment (including fire hoses), and patrol firelines repeatedly over an 8.5 to 12.0 hour period. Tanker-based work is not only likely to challenge firefighter's aerobic fitness, but also their muscular strength, and muscular endurance. Investigating whether aerobic fitness, muscular strength, and / or muscular endurance are important for safe and productive tanker-based bushfire suppression is fundamental to preserving the wellbeing of Australia's rural firefighters. By identifying the fundamental fitness components for tanker-based bushfire suppression, fire agencies can advise their personnel on the physical activities they can undertake to prepare physically for the fire season, increasing their resistance to fireground fatigue. Research into the principal fitness components for safe and productive bushfire suppression is yet to be undertaken.

Experience

Skilled or experienced workers expend less energy during a set period of work (Sparrow & Newell, 1998). Experienced shearers, for instance, expended less energy whilst shearing the same amount of sheep as their inexperienced colleagues (Poole & Ross, 1983). Further, Salvendy and Pilitisis (1974) demonstrated that, with practice, performance increased and energy expenditure decreased in a repetitive manual handling task. Experienced firefighters may also expend less energy during bushfire suppression than novice crewmembers, delaying the onset of fatigue. Whether more experienced firefighters are more efficient is yet to be determined as the effect of experience (or skill) on the firefighter's work or physiology during bushfire suppression has not been investigated.

Conclusion

Firefighter fatigue arises from a number of sources with considerable interplay between firefighters' behaviour, physical condition, and the fireground environment. The many symptoms of fatigue are a precursor to more serious health and safety risks for the individual and, potentially, their crew. Research into the many factors contributing to volunteer firefighter fatigue is underway. Specific areas of investigation include; sleep loss, work activity, hydration, nutrition, heat load, smoke, and fitness. An overview of these topics has been presented here for both individuals and agencies to consider. Understanding and managing fatigue on the fireground is, indeed, the responsibility of both the individual firefighters and the fire agencies as a whole to ensure that each crewmember returns from duty safely and in good health.

References

AFAC (2002) AFAC guidelines for health and fitness monitoring of Australasian fire and emergency service workers, Australasian Fire Authorities Council, East Melbourne Australia, pp. 95.

American College of Sports Medicine, American Dietetics Association & Dietitians of Canada (2000) 'Joint position statement: Nutrition and athletic performance', *Medicine and Science in Sports and Exercise*, 32, 2130-2145.

Balady GJ, Chaitman B, Driscoll D, Foster C, Froelicher E, Gordon N, Pate R, Rippe J & Bazzarre T (1998) 'Recommendations for cardiovascular screening, staffing, and emergency policies at health/fitness facilities', *Circulation*, 97, 2283-2293.

Bennett BL, Hagan RD, Banta G & Williams F (1994) 'Physiological responses during shipboard firefighting', *Aviation, Space, and Environmental Medicine*, 66, 225-231.

Black J (1987) 'Heat stress in bushfire fighters: A practitioner's perspective' In *Heat stress: Physical exertion and environment* (Eds, Hales, J & Richards, D) Elsevier Science Publishers BV (Biomedical Division), Amsterdam, The Netherlands, pp. 37-51.

Brotherhood J, Budd G, Hendrie A, Jeffrey S, Beasley F, Costin B, Zhien W, Baker M, Cheney N & Dawson M (1997a) 'Project Aquarius 3. Effects of work rate on the productivity, energy expenditure, and physiological responses of men building fireline with a rakehoe in dry eucalypt forest', *International Journal of Wildland Fire*, 7, 87-98.

Brotherhood J, Budd G, Hendrie A, Jeffrey S, Beasley F, Costin B, Zhien W, Baker M, Cheney N & Dawson M (1997b) 'Project Aquarius 11. Effects of fitness, fatness, body size, and age on the energy expenditure, strain, and productivity of men suppressing wildland fires', *International Journal of Wildland Fire*, 7, 181-199.

Budd G, Brotherhood J, Hendrie A, Jeffrey S, Beasley F, Costin B, Zhien W, Baker M, Cheney N & Dawson M (1997a) 'Project Aquarius 1. Stress, strain, and productivity in men suppressing australian summer bushfires with hand tools: Background, objectives, and methods', *International Journal of Wildland Fire*, 7, 69-76.

Budd G, Brotherhood J, Hendrie A, Jeffrey S, Beasley F, costin B, Zhien W, Baker M, Cheney N & Dawson M (1997b) 'Project Aquarius 6. Heat load from exertion, weather, and fire in men suppressing wildland fires', *International Journal of Wildland Fire*, 7, 119-131.

Budd G, Brotherhood J, Hendrie A, Jeffrey S, Beasley F, Costin B, Zhien W, Baker M, Hoschke B, Holcombe B, Cheney N & Dawson M (1997c) 'Project Aquarius 13. The thermal burden of high insulation and encapsulation in wildland firefighters' clothing', *International Journal of Wildland Fire*, 7, 207-218.

Budd GM & Cheney N (1983) Bush fire safety and physiological stresses on fire fighters, *9th National Conference, Australian Fire Protection Association*, pp. 1-12.

Carlisle AJ & Sharp NCC (2001) 'Exercise and outdoor ambient air pollution', *British Journal of Sports Medicine*, 35, 214-222.

Cheney N (1976) 'Bushfire disasters in Australia, 1945-1975', *Australian Forestry*, 39, 245-268.

Cheuvront S, Carter R & Sawka M (2003) 'Fluid balance and endurance exercise performance', *Current Sports Medicine Reports*, 2, 202-208.

Cian C, Koulmann K, Barraud P, Raphel C, Jimenez C & Melin B (2000) 'Influence of variations in body hydration on cognitive function: Effect of hyperhydration, heat stress, and exercise-induced dehydration.' *Journal of Psychophysiology*, 14, 29-36.

Convertino VA, Armstrong LE, Coyle EF, Mack GW, Sawka MN, Senay LC, Jr. & Sherman WM (1996) 'American College of Sports Medicine Position Stand. Exercise and fluid replacement', *Medicine & Science in Sports & Exercise*, 28, i-vii.

Coyle EF (1995) 'Substrate utilization during exercise in active people', *American Journal of Clinical Nutrition*, 61, 968S-979S.

Coyle EF & Gonzalez-Alonso J (2001) 'Cardiovascular drift during prolonged exercise: New perspectives', *Exercise and Sport Science Reviews*, 29, 88-92.

Dawson D & McCulloch K (2005) 'Managing fatigue: It's about sleep', *Sleep Medicine Reviews*, 9, 365-380.

Ellis S & Gilbert L (1997) In *AFAC Guidelines: National Approach to Physical Performance Assessment for Firefighters*, Australasian Fire Authorities Council, East Melbourne, Australia, pp. 9.

Febbraio M (2001) 'Alterations in energy metabolism during exercise and heat stress', *Sports Medicine*, 31, 47-59.

Febbraio M (2003) 'Exercise in the heat' In *Physiological bases of sports performance* (Eds, Hargreaves, M & Hawley, J) McGraw-Hill, Sydney, pp. 254-276.

Gaskill S, Ruby B, Heil D, Sharkey B, Hansen K & Lankford D (2002) *'Fitness, workrates and fatigue during arduous wildfire suppression'*, Medicine & Science in Sports & Exercise, 34 Suppl., S195.

Gledhill N & Jamnik VK (1992) 'Characterization of the physical demands of firefighting', *Can J Sport Sci*, 17, 207-213.

Gopinathan P, Pichan G & Sharma M (1988) 'Role of dehydration and heat stress-induced variations in mental performance', *Archives of Environmental Health*, 43, 15-17.

Hamilton MT, Gonzalez-Alonso J, Montain SJ & Coyle EF (1991) 'Fluid replacement and glucose infusion during exercise prevent cardiovascular drift', *J Appl Physiol*, 71, 871-877.

Harger S, Gaskill S & Ruby B (2004) 'Effects of carbohydrate supplementation on salivary immuno-globulin during long duration arduous work', *Medicine and Science in Sports and Exercise*, 36 Suppl., S320.

Hendrie A, Brotherhood J, Budd G, Jeffrey S, Beasley F, Costin B, Zhien W, Baker M, Cheney N & Dawson M (1997) 'Project Aquarius 8. Sweating, drinking, and dehydration in men suppressing wildland fires', *International Journal of Wildland Fire*, 7, 145-158.

Kay D & Marino FE (2000) 'Fluid ingestion and exercise hyperthermia: Implications for performance, thermoregulation, metabolism and the development of fatigue', *Journal of Sports Sciences*, 18, 71 - 82.

Lamond N & Dawson D (1999) 'Quantifying the performance impairment associated with fatigue', *Journal of Sleep Research*, 8, 255-262.

Lieberman H, Falco C & Slade S (2002) 'Carbohydrate administration during a day of sustained aerobic activity improves vigilance, as assessed by a novel ambulatory monitoring device, and mood', *American Journal of Clinical Nutrition*, 76, 120-127.

MTDC (2003) Fatigue awareness, Retrieved Jan 8th, 2005, http://www.fs.fed.us/fire/training/fatigue/fatigue.pdf.

Nieman D (2003) *Exercise testing and prescription*, McGraw-Hill, New York.

Noble BJ & Robertson RJ (1996) *Perceived exertion*, Human Kinetics, Campaign, IL.

Payne W, Payne K & Harvey J (2005), Review of the firefighter fitness assessment for the Victorian Department of Sustainability and Environment, University of Ballarat, Ballarat, pp. 51.

Poole P & Ross B (1983) 'The energy cost of sheep shearing', *Search*, 14, 103-105.

Raub J, Mathieu-Nolf M, Hampson N & Thom S (2000) 'Carbon monoxide poisoning – a public health perspective.' *Toxicology*, 145, 1-14.

Rehrer N (2001) 'Fluid and electrolyte balance in ultra-endurance sport', *Sports Medicine*, 31, 701-715.

Reilly T & Ekblom B (2005) 'The use of recovery methods post-exercise', *Journal of Sports Sciences*, 23, 619-627.

Ruby B & Gaskill S (2002) *Fatigue, sleep and mood state in wildland firefighters.*, Retrieved February, 19th, 2007, http://www.wildfirelessons.net/documents/Mood_State_Fatigue_2001-02.pdf.

Ruby B, Gaskill S, Heil D, Sharkey B, Hansen K & Lankford D (2002a) *Changes in salivary IgA during arduous wildfire suppression relative to work shift length*, Retrieved February 19th, 2007, http://www.wildfirelessons.net/documents/Salivary_IgA_Relative_to_Work_Shift_Length.pdf.

Ruby B, Gaskill S, Heil D, Sharkey B, Hansen K & Lankford D (2002b) 'Changes in salivary IgA during arduous wildfire suppression relative to work shift length', *Medicine & Science in Sports & Exercise*, 34 Suppl., S195.

Ruby B, Gaskill S, Lankford D, Slivka D, Heil D & Sharkey B (2003) 'Carbohydrate feedings increase self-selected work rates during arduous wildfire suppression', *Medicine & Science in Sports & Exercise*, 35 Suppl., S210.

Ruby B, Schriver T, Zderic T, Sharkey B, Burks C & Tysk S (2002c) 'Total energy expenditure during arduous wildfire suppression', *Medicine and Science in Sports and Exercise*, 34, 1048-1054.

Salvendy G & Pilitsis J (1974) 'Improvements in physiological performance as a function of practice.' *International Journal of Production Research*, 12, 519-531.

Sawka M & Pandolf K (1990) 'Effect of water loss on physiological function and exercise performance' In *Perspectives in exercise science and sports medicine*, Vol. 3 (Eds, Gisolf, C &Lamb, D) Benchmark Press, Indianapolis, pp. 1-38.

Sharkey B (1997) *Fitness and work capacity*, U.S. Department of Agriculture, Forest Service, Missoula Technology and Development Centre, Missoula, Montana.

Sharkey B (1999) In *Wildland Fire Fighter Health and Safety Conference* (Ed, Sharkey, B) Missoula Technology and Development Centre, Missoula, Montana, pp. 20-25.

Sparrow W & Newell K (1998) 'Metabolic energy expenditure and the regulation of movement economy', *Psychonomic Bulletin & Review*, 5, 173-196.

Von Duvillard SP, Braun WA, Markofski M, Beneke R & Leithauser R (2004) 'Fluids and hydration in prolonged endurance performance', *Nutrition*, 20, 651-656.

Westerblad H, Allen DG & Lannergren J (2002) 'Muscle fatigue: Lactic acid or inorganic phosphate the major cause?' *News Physiol Sci*, 17, 17-21.

Wilmore J & Costill D (1994) *Physiology of sport and exercise*, Human Kinetics, Champaign, Illinois.

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