Background briefings on emerging issues for fire managers from AFAC and Bushfire CRC.

bushfire CRC afac

FIRE NOTE

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AWAKE, SMOKY AND HOT – FIGHTING FIRE WITHOUT FIRE

▲ Participants in the ASH study from CFA, CFS and the NSW Parks and Wildlife Service undertaking the physical simulation tasks.

SUMMARY

An outline of the Awake, Smoky and Hot (ASH) simulation is combined with a literature review in this *Fire Note*. Together they present the most up-to-date research about the detrimental impacts of three key stressors – heat, smoke and sleep restriction – on the physical and mental capacities of firefighters. Where earlier research examined these stressors in isolation or various dual combinations, the ASH simulation is believed to be a world first in researching the impacts of all three stressors simultaneously. It achieves this by 'fighting fire without the fire' – simulating bushfire suppression activities within an indoor environment so that temperature, carbon monoxide levels and the sleeping environment can be controlled. The study is delivering credible data that can help fire agencies to better manage the health and safety of personnel during bushfire suppression.

Early findings from initial ASH simulations, together with educated estimates from the available literature, suggest that firefighters performing prolonged, intermittent work while exposed to the triple combination of heat, smoke and sleep restriction may experience greater physiological exertion and impaired mental performance than when faced with the stressors in isolation or dual combinations. Shorter exposures, adequate sleep, faster task rotations and breaks may more effectively maintain fireground productivity, community safeguards and bushfire firefighters' health and safety.

ABOUT THIS PROJECT

This two-part *Fire Note* features a literature review and an outline of the ASH simulation. The ASH study is being undertaken in the *Operational readiness of rural firefighters during bushfire suppression* project, part of the Bushfire CRC *Managing the threat* program. This project is jointly coordinated by CQUniversity and Deakin University.

AUTHORS

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CONTEXT

Exposure to smoke and high temperatures, coupled with little sleep, can impair firefighters' performance on the fireground. In isolation or in various dual combinations, heat, smoke, and sleep disruption can have negative effects on firefighters' cognitive (mental) and physical capacities. However, very little is known about the combined effects of these stressors on firefighters during suppression activities. This project is addressing this gap by providing fire agencies with the best available evidence to enable fire agencies to better manage the risks to their firefighters.

BACKGROUND

LITERATURE REVIEW

Bushfires can last anywhere between a few hours and a few months. As a result, firefighters may be deployed after a day at their regular employment, work long shifts across day and night in variable weather conditions (with or without the presence of bushfire smoke), be deployed for consecutive days with limited rest between shifts, and experience poor quality sleep in temporary accommodation.

Previous research looks at only one stressor (heat, smoke exposure or sleep deprivation) in isolation or in various dual combinations, but firefighters at work typically face these three conditions together. To the authors' knowledge, based on this comprehensive literature review, no published studies have explored the combined impact of sleep disruption, smoke and heat exposure on cognitive or physical work.

Bushfire-specific research is critical to developing evidence-based strategies to preserve the health, safety and productivity of firefighters fighting bushfires. Importantly, the goal is not to remove firefighters from the fireground; it is to provide fire agencies with the best available evidence that they can use to manage the risks to their firefighters.

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Shortened sleep

The available, relevant research comes from sustained military operations that often involved heavy physical and mental work combined with restricted sleep. In broad summary, this research shows that sleep restriction impairs performance (Haslam 1982).

In general, the research indicates that a minimum of six hours sleep per 24 hour period is needed to maintain cognitive (mental) performance. Laboratory-based studies show that physical performance on short tasks is generally not affected by sleep restriction, but when individuals are able to pace themselves on longer tasks, those who were sleep deprived worked more slowly (Rodgers *et al.* 1995; Symons *et al.* 1988).

Smoke exposure

Bushfire smoke is a complex mixture of particles, vapours and gases, including carbon monoxide (CO). The health impacts of smoke inhalation on the fireground can include short-term respiratory irritation and impairment (Reisen *et al.* 2011). In contrast, much less is known about the impact of smoke on firefighters' physical and cognitive performance.

Bunnell and Horvarth (1988) suggest that cognitive brain function is unaffected until significant levels of CO, within the range found on a fireground, are experienced. Rundell and Caviston (2008) report an association between exposure to high concentrations of various particles found in smoke with decreased work output.

However, little is known about the effects of bushfire smoke specifically. In particular, research still needs to expose participants to CO and other particulate matter in:

a) Concentrations consistent with the fireground.
b) Over durations that closely approximate typical fireground deployments.
c) In combination rather than just one compound at a time.

More information on firefighters exposure to smoke on the fireground is available in *Fire Note* 30 (Meyer *et al.* 2009).

Heat exposure

Bushfires are synonymous with hot, dry and windy weather conditions. The limited research in this area reports that firefighters' body temperatures rose more rapidly and their work capacity fell when ambient temperature increased from 25°C to 35°C. Due to the nature of bushfires, firefighters are more likely to be working when temperatures are around the upper reaches of these measurements.

▲ The ASH simulation has been designed with input from firefighters to ensure realism. Here, a firefighter performs a rake task.

Additionally, in temperatures above 35°C, individuals were unable to keep working at a sustained pace. In an emergency, they were likely to maintain the required pace for shorter periods in hotter conditions and also to find the work more physiologically stressful. When setting their own pace, such as during clean up, firefighters were likely to work more slowly for longer periods of time, but find the work more physiologically taxing than in cooler conditions.

The impacts of heat on mental performance were studied at very high temperatures (51.5°C). Alertness, learning and reasoning were all significantly impaired. Additionally, cognitive tasks were performed more slowly in these hotter conditions in order to avoid mistakes. While these temperatures are extreme, the research confirms that the extremely high temperatures typically encountered on the fireground do negatively impact mental performance.

Shortened sleep and heat exposure

Evidence informing this review about the direct impacts of hot working conditions and limited sleep on physical work was drawn from just one study. Kolka and Stephenson (1988) reported that in 35°C heat, the body's cooling response may differ depending on the amount of sleep the individual has had.

Smoke exposure and heat exposure

Field simulations of bushfire suppression showed that physical performance was significantly impaired when working near fire, and that combining high temperatures with elevated CO was more taxing than either stressor in isolation. As CO in the blood increased during moderate intensity exercise at 40°C, heart rate and breathing rate also increased. Another study looked at performance on a 60 minute driving simulator following 60 minutes of moderate intensity exercise in three different combinations of temperature and blood CO concentrations (Walker *et al.* 2001). Driving performance was significantly more affected under conditions combining high temperature (50°C) and CO (10-12% concentration) compared to high temperature alone. Additionally, performance that required both mental and physical coordination (for example driving a vehicle) was particularly susceptible to high temperatures, and may be further impaired by elevated CO.

END USER STATEMENT

The findings from this project will be of significant value to the fire industry. It is well known that firefighters are exposed to fatigue and often work through that fatigue to 'get the job done'. The rule of thumb is to try and restrict shifts to a maximum of 12 hours, but we do not know for sure that this is the optimum shift duration to achieve peak performance.

Historically it has been challenging for operational commanders to manage timely crew changeovers in a dynamic fire environment. This research will help determine how firefighters are really affected during fire suppression activities and allow agencies to manage the health and safety of firefighters in a more structured, and possibly more flexible, manner, based on the type of exposure they are presented with.

– Gavin Freeman, Deputy Chief Officer, Tasmania Fire Service

Heart rate, breathing rate and blood pressure are measured to understand the effects of heat, smoke exposure and lack of sleep on tasks the firefighters perform regularly, such as rolling a hose.

Shortened sleep and smoke exposure

There are no published studies on the combined impact of smoke and sleep disruption on physical and cognitive performance. Studies on smoke and sleep disruption in isolation indicate that increasing each stressor decreased cognitive performance. This suggests that shortened sleep and CO exposure could combine to further degrade mental performance. The combined impacts of the two could also be expected to slow self-paced work capacity and possibly increase firefighters' exposure to CO.

Heat, smoke and fatigue – where to from here?

Predictions from the individual and dual stressor studies suggest that experiencing shortened sleep, smoke and heat exposure simultaneously will have a strong negative impact on firefighters' performance. These conditions are most likely to be encountered between the latter stages of the first day of a large-scale fire, to when the fire is controlled, which could be several days later. In a situation like this, the dose-dependent impairment of cognitive function through sleep deprivation and heat exposure could combine with elevated CO levels to further degrade mental performance.

This raises a critical management dilemma for firefighting agencies: how to balance the health and safety risks to firefighters exposed to these combined stressors, against the risks to people and property of withdrawing firefighters from the fireground. The ASH simulation is providing the evidence to help agencies address this dilemma.

BUSHFIRE CRC RESEARCH

DESIGNING THE ASH SIMULATION

The ASH project team is investigating the effects of high temperatures, CO and disrupted sleep on firefighters. The team has collaborated with the project's lead end user, Robyn Pearce, Director Human Services at Tasmania Fire Service, as well as partner agencies, volunteer firefighters, key industry advisers and human factors design specialists to develop a simulation of bushfire suppression activities. The simulation can be run indoors, enabling control of temperature, CO levels and the sleeping environment – in essence, the fighting without the fire.

The simulation focuses on creating realistic physical and cognitive workloads, crew scheduling and activities, combined with sufficient researcher control to enable conditions to be repeated across groups at different research sites.

The project focuses on replicating the specific tasks that firefighters do on the fireground, rather than trying to measure 'fireground performance'.

Using information collected on the timings of a deployment, and activities undertaken, the simulation was designed in collaboration with firefighters.

Creating a realistic firefighting simulation

In preparing for this study, researchers collected information about firefighters' physical and cognitive tasks, and measured changes to heart rate, breathing and blood pressure that occurred as they worked. Through the first phase of the Bushfire CRC (2003-2010), Dr Brad Aisbett and his team completed a series of studies analysing the major tasks conducted by tanker-based firefighters during bushfire suppression. This research, previously highlighted in *Fire Note* 80, identified the seven most physically demanding tasks and determined the length of time firefighters spent doing each task (Aisbett *et al.* 2011). This study included designing a circuit of physical tasks that mimicked the tasks done on the fireground, such as advancing a charged hose.

Initial tests of this circuit were conducted in the laboratory to ensure that measurements such as heart rate, breathing rate and blood pressure were similar to documented experience of firefighters on the fireground. This created confidence that the simulation's physiological effects are similar to real conditions.

The project team also collected information about the cognitive aspects of the work by tanker-based firefighters. This included

interviewing experienced firefighters about the cognitive abilities and skills they used on the fireground. These interviews covered a call-out and incident, from the first pager alert to the drive home. Aspects discussed included decision making, effective communication and information recall. Based on these interviews, a cognitive test circuit was created, incorporating tasks that measured responses such as short-term memory and reaction time.

ASH simulation conditions

The ASH simulation requires firefighters to volunteer their time to take part. Participation requires a three-and-a-half day commitment (four nights), and is designed around a three-day campaign fire scenario.

Volunteers arrive on site on the pre-study evening. They then 'work' three, 12-hour day shifts and one two-hour morning shift and sleep on site each night. Participants undertake physical work tasks and computer-based tests designed to approximate the demands placed on firefighters during multi-day bushfire deployments. The tests involve intermittent physical hard work and cognitive tasks which challenge attention, concentration and memory.

Participants are randomly allocated to one of eight different conditions involving various combinations of raised heat, raised CO levels and reduced sleep. There is approximately 50% chance of experiencing any one of the specific conditions, either alone or in combination with another condition.

Heat conditions involve 33°C days and 23°C nights. Raised CO levels are 15 parts per million during the day and five parts per million during the night (within the Occupational Health and Safety guidelines for Australia). Sleep deprivation conditions involve sleeping four hours per night.

Each of these elements contributes to the realism of the simulation. These parameters are based on published observations from Australian bushfires in the last five years. The tasks undertaken during the work periods are designed to simulate the specific tasks that firefighters complete when fighting a bushfire.

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While the physical and cognitive tasks are conducted separately, tests have shown that the cognitive elements of the physical tasks have a very high level of realism and do assess the cognitive performance elements required of firefighters on the fireground.

A number of ASH simulations have already been completed, with more scheduled throughout 2013. It is expected that the overall results will be the basis of a future *Fire Note* (see Future Directions below).

HOW COULD THE RESEARCH BE USED

The ASH simulation's focus on measuring the combined impacts of heat, smoke and restricted sleep on firefighters' performance will provide valuable insights that will feed directly into policy and practice in the industry. The findings from this research will provide an evidence base on which to develop specific training and guidelines to better assist the health and safety of firefighters. The project may also in future answer questions about teamwork, recovery from deployments, the effectiveness of protective clothing and equipment, eating and drinking practices and alternative work practices such as split shifts. There are potential applications that extend well beyond bushfire incidents.

FUTURE DIRECTIONS

Initial simulations have been completed but many more are needed to gather enough data to inform the results. The research team is seeking more firefighters from all national agencies. Simulations will take place in Adelaide and Melbourne in 2013, with the possibility of testing at other sites. A short video that shows the simulation in action can be viewed on the Bushfire CRC YouTube. For more information, contact the author of this *Fire Note*.

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