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Welcome from Editor

It is my pleasure to bring to you the compiled papers from the Science Day of the AFAC and Bushfire CRC Annual Conference, held in the Sydney Convention Centre on the 1st of September 2011.

These papers were anonymously referred. I would like to express my gratitude to all the referees who agreed to take on this task diligently. I would also like to extend my gratitude to all those involved in the organising, and conducting of the Science Day.

The range of papers spans many different disciplines, and really reflects the breadth of the work being undertaken, The Science Day ran four steams covering Fire behaviour and weather; Operations; Land Management and Social Science. Not all papers presented are included in these proceedings as some authors opted to not supply full papers.

The full presentations from the Science Day and the posters from the Bushfire CRC are available on the Bushfire CRC website www.bushfirecrc.com.

Richard Thornton

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Design of a valid simulation for researching physical, physiological and cognitive performance in volunteer firefighters during bushfire deployment.

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Abstract.

Every year, Australian firefighters protect our nation from the devastation of bushfire. Understanding the impact of consecutive long shifts in hot, smoky conditions is essential for making decisions during campaign fires. At present, the evidence-base for such decisions is limited to laboratory studies with little relevance to bushfire suppression or field research where the impact of environmental and workload stressors cannot be measured. To counter these limitations, we have developed a three-day simulation that mimics the work and environment of campaign bushfire suppression. Construction of the simulation involved three stages; 1) data collection and analysis; 2) design and development; and 3) trial and refinement. The frequency, intensity, duration and type of physical work performed on the fireground is well documented and a modified applied cognitive task analysis, using experienced firefighters was used as a framework to describe in detail the non-physical aspects of the work. The design and development of the simulation incorporated the physical and non-physical aspects of the work into simulated tasks. Finally, experienced firefighters participated in trials of the simulation and reviewed digital recordings to ensure that the simulation accurately represented campaign bushfire suppression work. The outcome of this project is a valid, realistic, and reliable simulation of the physiological, physical and cognitive aspects of a volunteer firefighter on a three-day bushfire deployment.

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Introduction

Every year, Australian firefighters protect our nation from the devastation of bushfire. The risks to firefighter health and safety are significant and need to be managed using an evidence-based risk management framework, as is the norm in all Australian workplaces (NOHSC 2002). One of the steps in this process is to identify the risks in order that they be assessed and managed. For individuals fighting campaign fires in particular, the risks extend beyond the obvious ones associated with the fire itself (e.g. burnover, radiant heat). Impaired performance as a result of cognitive fatigue, physical exhaustion or physiological strain can lead to errors in judgement, poor decision-making, diminished levels of work performance and deviations from standard operating practices (Belenky, Wesesten *et al.* 2003; Hancock, Ross *et al.* 2007; Harrison and Horne 2000; Takeyama, Itani *et al.* 2005). Occupational challenges such as consecutive long shifts that require extended wake and restrict sleep represent one risk (Aisbett and Nichols 2007; Cater, Clancy *et al.* 2007). Further, environmental challenges such as extreme heat and smoke exposure are also known to impact cognitive, physical and physiological performance (Amitai, Zlotogorski *et al.* 1998; Benignus, Muller *et al.* 1987; Nybo 2008; Walter, Ackland *et al.* 2001). Understanding the individual and interactive effects of these occupational and environmental challenges is essential for making decisions about manning, scheduling, workload and work tasks during campaign fires that manage extant risks. At present however, the evidence-base for such decisions is limited to laboratory studies with little relevance to bushfire suppression and to observational field research. While some aspects of the bushfire suppression task are well described by field studies, it is very difficult to assess the individual and interactive effects of occupational and environmental challenges on performance in any systematic manner.

To provide an evidence base, a large-scale program of work was designed to assess the effects of sleep restriction, smoke and heat on various aspects of firefighter performance. In order that the research is conducted in a controlled and replicable environment for all participants in each condition, a simulation was designed to assess the effects on physiological, physical and cognitive performance. Here we describe the stages in simulation development and the processes that were used for data collection, design/development and trial/refinement of the volunteer firefighter bushfire deployment simulator.

Stages of simulation development

A critical first stage was to construct a simulation that could create physical and cognitive workload comparable to real bushfire suppression work, whilst having a high level of realism (known as fidelity) for firefighters. At the same time, the research requires tightly controlled and repeatable conditions. Simulation in the research environment must therefore, achieve a balance between various dimensions of fidelity and the rigours of experimental control. This balance results in inevitable trade-offs, each of which must be carefully considered in order to maximise the overall value of the research process.

The design of the simulation must achieve an appropriate level of fidelity to ensure the research is successful, but does not require a completely faithful reproduction of the fire-ground. Research of this nature involves manipulation of certain variables (such as temperature), which are called the independent variables. At the same time other variables (such as light) must be controlled to ensure they are kept constant and do not influence the research in unanticipated or unmeasured ways - these are called confounding variables. The fire-ground is a highly dynamic environment in which a wide range of variables (e.g., heat, wind, noise, etc) is constantly changing. Thus, a truly high-fidelity simulation would be unable to provide sufficient experimental control to examine the effects of the key variables of sleep restriction, smoke and heat for our program of research. Accordingly, a simulated representation of key tasks and skills involved in safe and efficient fire-ground performance was designed, which balanced the need for fidelity in simulating the work of rural firefighters, but simultaneously allowed for effective measurement of key performance variables.

Construction of the simulation, assessment of fidelity issues, and ensuring appropriate research design involved three stages; 1) data collection and analysis; 2) design and development; and 3) trial and refinement.

Data collection and analysis.

Table 1 highlights dimensions of simulation fidelity derived from the extant literature (Hays 1980; Liu, Nikolas *et al.* 2008; Rehmann, Mitman *et al.* 1995; Stanton 1996) that are relevant to the current research design. Each of these dimensions was considered with respect to the design of the simulation.

The frequency, intensity, duration and type of physical work performed on the fireground is well documented; (Phillips, Netto *et al.* 2011)) and represents the first dimension of fidelity (Table 1). Specifically, seven physically demanding tasks were identified as common during bushfire suppression activities for all rural firefighters. Three of the tasks involved fire hoses (dragging hose to position, lateral repositioning of hose or returning hose to tanker) and four tasks involved the use of hand tools (e.g., digging and raking to build mineral earth fire breaks; (Phillips, Payne *et al.* 2011)) In addition to identifying the major tasks of tanker-based bushfire suppression crews, the researchers also determined the average time spent doing each task . The specific work tasks and the time spent engaged in each task were included in a simulation in a manner that mimicked the work done on the fireground. In particular, pilot testing of the physical test battery incorporated physiological measures collected on the fireground. Physiological parameters are used routinely to validate simulations and demonstrate high levels of fidelity (Lord, Netto *et al.* In Press).

Focus groups were conducted with experienced firefighters using the framework of an applied modified applied cognitive task analyses to define and dissect the non-physical aspects of the volunteer firefighter role (Militello and Hutton 1998). The process involved asking the firefighters to talk through the various aspects of their work, from the moment the initial page or phone call is received, through to the drive home after the completion of the shift or incident. Researchers asked participants to expand on specific aspects of task elements where necessary. For rural firefighters working on the ‘back of the truck’ undertaking fire suppression activities, a number of key cognitive elements were drawn from the analysis. Specifically, information retention from short-term memory was discussed in relation to the key details about the incident (time, place, event etc). Participants also identified communication and decision-making as cognitive elements of the work. Vigilance, concentration, and maintaining awareness of critical cues in the environment, while simultaneously focusing on the primary task were also identified as being key cognitive elements of the work. As outlined in Table 1, key dimensions of simulation fidelity are cognitive task representation and the degree of similarity between cognitive workload in the real task and the simulated task.

Another aspect of data collection relevant to the simulation design relates to the scheduling of volunteers for campaign fires (those extending beyond a single work period or shift). The most commonly used pattern of work for tanker-based crews on campaign fires involves 12-hour shifts, and generally up to three shifts in succession (Cater, Clancy *et al.* 2007). Firefighters travel to the incident as soon as they are required, and stay in the area for the length of their deployment. As fires frequently flare in the heat of the afternoon, volunteers who have worked during the day experience an extended period of wake (and work) on the first shift of fire suppression. Given the role of volunteers in fighting bushfires in Australia, this is a common and largely unavoidable circumstance and was therefore deemed important to incorporate into the simulation. Thus, key elements of scheduling that were included in the simulation were: 12-hour shifts, three consecutive shifts, 'passive travel time' to incident, extended wake/work period on first 'shift'.

Environmental data related to smoke and heat have been studied in Australian rural firefighters during bushfires (Raines, Petersen *et al.* Accepted August 14 2011; Reisen and Brown 2009) and are both important to the simulation design. Ambient temperatures will be manipulated in the simulation to mimic the higher end of the range of temperatures experienced on the fireground (with lower but still relatively high temperatures during the night). Further, as previous research has shown that CO strongly correlates with other elements within bushfire smoke (e.g., particulate matter, formaldehyde, etc) (Reisen, Hansen *et al.* 2011), smoke will be simulated using CO in the air.

The simulation includes the requirement for participants to be dressed in their own personal protective clothing (PPC), as they would be on the fireground (Table 1). This includes trousers, coat, goggles, helmet, gloves and safety boots. Participants will wear full PPC during the completion of the physical task batteries and remove helmet, gloves, goggles and coat for physiological and cognitive testing. In addition, physical tasks will involve the use of couplings and dimensions of hose that are identical to those used in the field. Lengths of hose will also be filled to mimic the weight of charged (i.e., pressurized) water ensuring that the physical and functional characteristics of the equipment match the real world task (Table 1).

Each dimension of simulation fidelity relevant to the current simulation design required the collection or collation of data such that all elements were based bushfire suppression deployment tasks. Data on physical, physiological, cognitive, environmental and logistical elements of these tasks were then incorporated into the simulation design in such a way as to maximise fidelity and control relevant variables.

Design and Development

Design involves four major components:

Structure of whole ‘deployment’;

Structure of each day/night within the ‘deployment’ which includes scheduling of meals, breaks, toilet breaks, shower opportunities and bed times and wake times;

Structure of individual test sessions; and

Structure of days preceding and following the actual data collection period.

Each element is discussed below.

The length of the simulation was set at three days and three nights, based on existing scheduling information from observational studies in Australia (Cater, Clancy *et al.* 2007). Each day was designed to mimic a workday on the fireground – breakfast, work, lunch, work, dinner, preparation for bed, and sleep. The work periods were then divided into six two-hour blocks for physical tasks (55 minutes), physiological measurements (25 minutes) and cognitive testing (20 minutes). The remaining 20 minutes in each two-hour block was provided for hydration, toilet breaks and snacks. Confounding factors such as food and fluid intake will be recorded and included in analyses. The time allocated to physical and ‘non-physical’ data collection was based on the work patterns of Australian rural firefighters during emergency bushfire suppression shifts (Aisbett, Phillips *et al.* 2007) as described above.

The test batteries were designed to tap into key elements of the work as determined through the data collection phase. The time spent engaged in each physical task in the battery is representative of the time firefighters spend doing each task on the fireground. For example, lateral repositioning of hoses was done on average 103 times in each shift for a period of approximately twenty seconds each time (Phillips, Netto *et al.* 2011). The rakehoe task was performed on average 24 times for approximately 25 seconds each shift (Phillips, Netto *et al.* 2011). The distribution of each task in each test battery is thus indicative of the work done in the field.

The cognitive elements of the work are not as well defined as the physical elements. Further, based on the information provided by the subject matter experts, many of the cognitive aspects of the work occur simultaneously with physical tasks. In developing the cognitive test battery, the cognitive skills identified in the initial data collection from the subject matter experts were mapped onto components of a cognitive task battery that could be integrated into the simulation design. Accordingly, the cognitive task battery is composed of well-validated, neurocognitive tests that are known to tap into the critical cognitive functions identified in the data collection phase, despite the fact that they do not necessarily ‘look like’ firefighting. For instance, short-term memory is assessed by asking participants to recall pieces of information provided to them on a pager. This approach provides some face validity for the abstracted cognitive assessment task. Other cognitive skills identified by the subject matter experts such as vigilance, reaction time and hand-eye coordination are assessed using tools that have been validated for use in laboratory and field settings (Dinges and Powell 1985; Lamond, Dawson *et al.* 2005).

In addition to the days of testing that occur during the three-day simulation, activities prior and following the deployment are important for the research and are therefore included in the simulation. Participants arrive on-site the evening prior to day 1 and sleep with recording electrodes affixed to their head and face. The adaptation night is important in ensuring the participants' first night of sleep is not compromised by the lack of familiarity with the equipment. Further, sleep/wake patterns during the three days prior to the study will be collected to account for any sleep restriction on entering the study. A pre-briefing will be conducted prior to the 'deployment' to ensure participants are fully prepared and informed. Post-deployment interviews will allow participants to provide feedback for future refinements or improvements to the processes.

Following design and development of the simulation, trial and refinement were conducted.

Trial and refinement

Trial and refinement of the simulated bushfire suppression deployment is ongoing. To date the steps have included:

- reliability testing of physical work battery
- trial runs of test batteries with non-firefighters both off-site and on-site
- trial run with firefighters across two-days on-site, including aspects of the simulation such as test batteries, meals, sleep recording and simulation debrief
- videos of all trials reviewed by subject matter experts at various forum
- a full simulated deployment with five participants on-site for four days

Refinements of the simulation were based on recommendations from participants and other subject-matter experts at each step of the trial and refinement stage. The final step will involve a fidelity evaluation exercise with subject matter experts in the fields of volunteer firefighting (bushfire suppression), cognitive psychology, human factors, exercise science and human physiology. Results of the fidelity evaluation will be reported elsewhere.

Summary.

The development of the volunteer firefighter bushfire deployment simulator involved three stages - data collection, design and development, and trial/refinement. The outcome is a valid, realistic, and reliable simulation that will produce meaningful research outcomes for the current program of work but may also be extended to use answer future questions about team-work, recovery from deployments and alternative work practices such as split shifts. The bushfire deployment simulator may also be adapted for use in training or testing protocols.

Table 1 – Dimensions, constructs and definitions of simulation fidelity. Compiled from (Hays 1980; Stanton 1996)

Dimension	Constructs	Definition
Physical/Behavioural	Task Realism	*How well the simulated task matches the real work-task.*
	Physical Workload	*The degree of similarity between workload experienced in the real and simulated tasks.*
Psychological	Perceived Realism/Perceptual	*The degree to which the simulation is perceived by participants as being a duplicate of the real world.*
	Cognitive Task Representation	*How well the simulated tasks match the types of cognitive activities during real work.*
	Cognitive Workload	*The degree of similarity between workload experienced in the real and simulated tasks.*
Environmental	Temperature	*The degree of similarity between temperature ranges during the real and simulated tasks.*
	Light	*The degree of similarity between light ranges during the real and simulated tasks.*
	Noise	*The degree of similarity between noise ranges during the real and simulated tasks.*
	Additional Stressors	*The inclusion of additional work stressors present in the real working environment.*
Equipment	Physical	*The degree to which the physical characteristics of the equipment used matches that used in the real world task.*
	Functional	*The degree to which the equipment works in the same way to that used in the real world task.*

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