A Model of Metacognition for Bushfire Fighters

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ABSTRACT

Introduction: A large-scale bushfire is an example of a *macrocognitive* work system (Klein, et al.) in which many people (such as incident management teams, bushfire fighting crews, and residents) are required to respond to uncertain and changing conditions. In these situations people need to manage multiple (often competing) cognitive demands, and they use *metacognitive* skills to regulate their thinking. **Method:** We explored the metacognitive skills of career and volunteer bushfire fighters using human factors interviews on the fireground and visual-cued recall debriefs during command post simulation experiments (Frye & Wearing, 2011). **Results and Discussion:** These think-aloud techniques revealed an extensive use of metacognitive knowledge based on previous experiences, and previous experience was described as both a source of expertise and a source of human error (consistent with Kahneman & Klein, 2009). In this paper we use a model of metacognition to describe how expert fireground commanders regulate their thinking, and thus avoid errors associated with cognitive overload, during large-scale bushfires.

KEYWORDS

Learning and Training, Bushfire, Expertise, Decision Making, Metacognition, Cognitive Control

INTRODUCTION

Bushfires occur in Australia every year, and the worst large-scale bushfires have historically caused a significant loss of life and property. For example, the 1939 Black Friday bushfires resulted in 71 fatalities, 1300 destroyed homes, and 2 million hectares of burnt landscape (Stretton, 1939). Similarly, the 1983 Ash Wednesday bushfires resulted in 75 fatalities and over 2000 destroyed homes, while the 2009 Black Saturday bushfires resulted in the largest number of bushfire fatalities in Australia's recorded history, when 173 residents perished (Teague, McLeod, & Pascoe, 2009). The damage during these large-scale bushfires was due in part to extensive fire spotting (which occurs when embers travel ahead of the main fire front to start new fires), and loss of life was frequently associated with a sudden wind change (which rapidly turned the flanks of a bushfire into a new, and much larger, fire front; see Teague et al., p. 42). These conditions mean that the fireground is a unpredictable environment for making decisions and that all bushfires involve some level of risk.

Macrocognitive Work

It also means that large-scale bushfires are an example of *macrocognitive* work, in which: decisions are complex and often involve data overload; decisions involve risk, high stakes, and are made under extreme time pressures; goals are ill-defined and multiple goals often conflict; and decisions occur in conditions where few things can be controlled or manipulated (Klein, Ross, Moon, Klein, Hoffman & Hollnagel, 2003, p. 81). Bushfire fighters call these *'damned if you do, damned if you don't'* situations, and in these conditions people can experience 'stress, fear, panic and a collapse of clear thinking' (Putman, 1995), or cognitive overload (McLennan, Pavlou, & Omodei, 2005). Judicial investigations (such as coronial inquiries and royal commissions) have therefore recommended that practitioners need experience and mentoring (as well as technical training) to develop leadership and decision-making skills for bushfire response roles in Australia (see Teague, McLeod, & Pascoe, 2010; Johnson, 2002). These recommendations are also consistent with the advice of human factors and crisis management researchers (e.g., Ericsson, 2006; Fadde & Klein, 2011; Leonard, 2010; t'Hart, 2010).

Bushfire Fighters

However, while large-scale bushfires are high consequence events, they occur relatively infrequently, and opportunities to gain appropriate experience are therefore limited. Also, bushfires in Australia are fought by a largely part-time workforce, comprised of volunteers of the Country Fire Authority (or equivalent rural fire service in each state), and public land managers from the Department of Sustainability and Environment (or equivalent government departments in each state). This means that there are relatively few full-time bushfire fighters in rural Australia, and instead, people are deployed from their substantive roles to fight bushfires when they occur (see Frye, 2012). This is different to other macrocognitive work environments (such as aviation,

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medicine, or urban fire fighting) where practitioners frequently perform their role as a primary occupation, and therefore develop their decision-making skills in that context. Consequently, developing and maintaining expertise for large-scale bushfires is a challenge in Australia, and training programs need to support accelerated learning on the job.

Human Factors Research

At the same time, there has been a substantial amount of research about how people make decisions (and errors) in dynamic, uncertain, and time-pressured situations (like bushfires). For example, Klein, Calderwood and Clinton-Cirocco (1988) found that expert fireground commanders use previous experiences to recognise cues in a new situation and to deploy strategies that have been successful in the past (called Recognition Primed Decision Making; Klein, 1999). Several researchers (e.g., Gigerenzer & Goldstein, 1996; Connolly, 1999) also propose that heuristics, or rules of thumb, enable experienced practitioners to make fast decisions that are good enough to get the job done (called satisficing; Simon, 1956), while Cohen, Freeman & Wolf (1996) found that *metacognition* enables experienced practitioners to recognise, critique and correct their decisions (and errors) while they are implementing a course of action (see also Anderson, Oats, Chong & Perlis, 2006). Metacognitive strategies therefore enable practitioners to operate within the constraints (or boundary conditions) that typically exist in macrocognitive work settings, and to make decision tradeoffs, such as tradeoffs between efficiency and thoroughness (bounded cognizance; Hoffman & Woods, 2011; Valot, 2002).

Bushfire Training

However, until recently this empirical human factors research has had little impact on the way that end users are trained for large-scale bushfires in Australia (cf. Frye, 2012; Owen et al.; Slijepcevic et al.; Stack & Owen, 2012). Instead, lessons learned from judicial proceedings have historically resulted in lengthy policies and standard operating procedures (SOPs), which were then integrated into standardised technical skills training. These initiatives may improve decision-making (and reduce human errors) in routine situations, but are inadequate for dealing with unique or rapidly deteriorating situations (for similar issues in aviation training, see Adams & Ericsson, 2000). This is because one of the underlying causes of human error during large-scale bushfires is *cognitive overload* (see Teague, McLeod, & Pascoe, 2009, p. 235; Johnson, 2002, p. 602).

A COGNITIVE ENGINEERING APPROACH

A cognitive engineering approach would therefore ensure that fire agencies are aware of the cognitive demands that people face during large-scale bushfires, and in turn, design effective 'technology, training, and processes to manage cognitive complexity' (Militello, Dominquez, Lintern & Klein, 2009, p. 263). To achieve this, human factors research needs to be domain-specific (for large-scale bushfires), and the findings presented in a format that can be easily understood by end-users and integrated into fire training progams (i.e., by training managers, incident management teams, career and volunteer bushfire fighters).

Method

Metacognition refers to cognition about other cognitions (Cohen, Freeman & Wolf, 1996), and Pressley (2002) recommended the use of think-aloud protocols to obtain qualitative data (such as descriptions of metacognitive knowledge), and grounded theories (such as methods of constant comparison) to identify patterns or regularities in behaviours and thoughts. To this end, we used human factors interviews on the fireground, and visual-cued recall debriefs during command post simulation experiments, to explore the metacognitive skills of career and volunteer bushfire fighters. The Central Mountain Fire studies are described in more detail at Frye & Wearing (2011).

The samples for these studies were small (n = 4 on the fireground, n = 2 in a repeated measures simulation experiment, and n = 4 in a high cognitive load simulation rated by expert observers). Nonetheless, they had a high degree of ecological validity (Frye & Wearing, 2011, p. 40), and provided a rich source of qualitative data about how experienced domain practitioners (>10 years experience) make decisions during large-scale bushfires. Two participants were also rated as experts, which means that we were able to compare the metacognitive skills of expert fireground commanders (who also reported feeling cognitively in control), with their peers (who described feeling frequently overloaded in high cognitive load conditions).

Cognitive Errors

In the high cognitive load experiments (Frye & Wearing, 2011, p. 36), experienced fireground commanders were susceptible to the same types of cognitive errors that are observed with trained novices, such as:

1. Focussing on what is happening in front of them, but losing sight of the bigger picture (or vice versa).
2. Focussing on what is happening right now, but losing sight of what might happen next (or vice versa).
3. Focussing on situational awareness, but leaving it too late to make decisions (or rapidly making decisions with inadequate situational awareness).
4. Persisting with a goal, but failing to change plans when the situation changes (or failing to establish goals and priorities).

5. Accepting responsibility, but micromanaging or failing to escalate issues to others (trained novices who lack confidence may also defer too many responsibilities to others).
6. Focusing on safety, but focussing so much on one safety issue that they lose sight of another (whereas trained novices may also overlook safety, while pursuing higher order goals).

These errors represent different types of *tunnel vision*, in that focussing (or fixating) on one aspect of the bushfire results in a blind spot to other aspects of the situation. Additional training about policies and procedures is unlikely to help, because instead, the situation requires cognitive regulation skills.

Cognitive Overload

For example, in one of our simulation studies an experienced fireground commander forgot to deploy a fire tanker to protect a bulldozer. He was not oblivious to safety issues (or the standard operating procedure), in fact he was so pre-occupied with the safety of one fire crew (facing a burnover situation) that he lost sight of the big picture, and therefore the safety of another fire crew (also facing a burnover situation). In this respect, he became cognitively overloaded and susceptible to errors.

> *Quote 1*
>
> *'I got so focussed on one (tanker) that I lost focus on the other, and I end up having to go through the same scenario again with them. Can you get out? Are you safe?...this is when I realised, Bugger!...I'd missed one of our cardinal rules…I didn't have a fire unit with the dozer…and I need to be stepping back again, to what's coming at them around the corner, but my big (problem) was the speed of the way things were happening at the incident…we should have faith in the crew leaders to (manage safety), but at the end of the day, in this position, you're responsible for that safety.'*

These types of conflicting cognitive demands are common during large-scale bushfires, and while standard operating procedures (SOPs) can help, they do not improve safety (or productivity) unless practitioners can successfully implement them in real-world situations. In this case (Quote 1) the cognitive demands of implementing multiple procedures exceeded the cognitive capacity of the operator, and he became overloaded.

Expertise and Cognitive Control

In contrast, expert fireground commanders described feeling in control during high cognitive load conditions, and they articulated a high degree of self awareness (metacognitive awareness):

> *Quote 2*
>
> *'It's a recognition of your capability, it's your own self…inner recognition of…this is what I'm capable of. It's just years of experience, you've just got to know…this is what I can do, this is what I'm capable of, but it's the…the trigger to say, flick the switch, no, this is going to go beyond me...'*

In this case, the expert fireground commander gave the (confederate) incident controller an early *'heads up'* that things were going to get beyond his span of control. Then, once the Incident Controller acknowledged the message and assigned that area of the fire to someone else, the participant '*switched off, and didn't worry about that anymore, and got back to concentrating, and prioritizing what was in my own span of control'*. In this way, he maintained cognitive control while other participants described: '*fighting a losing battle*', persisting with strategies that they described as *futile*, and experiencing cognitive overload.

Recognition Primed Decisions

Experienced fireground commanders also described making decisions automatically based on previous experiences, which is consistent with a Recognition Primed Decision model (RPD; Klein, 1999). However, while this was an effective strategy for reducing cognitive load, experts also cautioned that pattern matching could sometimes lead to errors:

> *Quote 3*
>
> *'...automatically making decisions, it just becomes automated, you just do it. I suppose I don't even think about it. Too automated sometimes (because) you do it naturally and (if) you don't question yourself you can fall into a trap…you can miss something...'*

In this respect, the participants' descriptions are consistent with previous research (see Cohen, Freeman & Wolf, 1996; and Kahneman & Klein, 2009), and highlight the need for judgement and expertise in fireground command, as well as the successful implementation of practiced rule-based procedures.

A MODEL OF METACOGNITION FOR BUSHFIRE FIGHTERS

These examples (Quotes 1, 2 & 3) show that fireground commanders need to regulate their cognitive activity during large-scale bushfires to maintain situational awareness (and notice anomalies), make decisions, and manage dynamic activity, as shown in Figure 1.

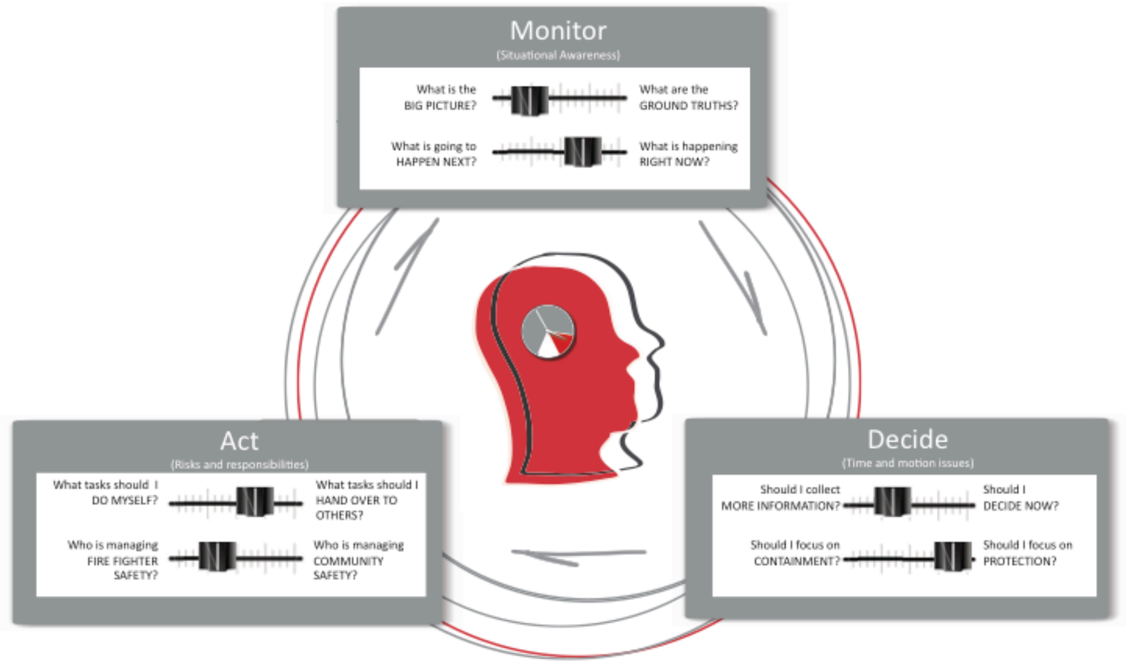

Figure 1. A model of metacognition for bushfire fighters

Fireground commanders also described using feedback from previous decisions and activity to build situational awareness and inform subsequent decisions, consistent with a metacognitive loop (Figure 1, see also Anderson, Oats, Chong & Perlis, 2006). Their descriptions were consistent and repetitive, and thus provide useful examples for training bushfire fighters about cognitive regulations skills. In particular, experienced fireground commanders described switching the focus of their attention to regulate their cognitive performance within particular boundary conditions (or tolerance limits; Hoffman & Woods, 2011; Valot, 2002).

Monitor (Situational Awareness)

For example, experienced fireground commanders gained (and maintained) situational awareness by monitoring different perspectives (big picture and ground truths), and different temporal distances (what will happen next versus what is happening right now). They adjusted the focus of their attention regularly, and seemed to be aware of potential blind spots. They communicated with other people in the chain of command to address gaps in situational awareness, and to update their own and other peoples' picture of the situation. In this respect, their descriptions are consistent with previous research (such as Cohen, Freeman & Wolf, 1996; Endsley, 1995; Hoffman & Woods, 2011; Klein, 1999).

Decide (Time and motion issues)

Similarly, expert fireground commanders regulated the tempo of their decision-making (balancing speed with accuracy), and knew when to change goals. For example, they described clear *trigger points* for shifting from an offensive goal (such as containing the bushfire) to a defensive goal (such as protecting life and property), and they quickly resorted to prepared fallback options when initial plans failed. In contrast, non-experts persisted with goals that they described as futile (often describing overconfidence and optimism biases), found the situation getting ahead of them, and implemented poor strategies.

Act (Risks & Responsibilities)

Finally, expert fireground commanders knew the limits of their own cognitive ability (see Quote 2), and described personal performance boundaries that signalled a need for change. Consequently, they did not attempt to manage everything themselves, but managed the distribution of cognitive load between themselves and other people in the chain of command (including both subordinate and superior positions; consistent with Valot, 2002). In this way, experts delegated (or escalated) risks and responsibilities to levels where they can be appropriately managed, and maintained cognitive control (consistent with McLennan, Pavlou & Omodei, 2005).

CONCLUSIONS

The current research shows that training and experience are necessary, but not sufficient conditions for developing expertise in fireground command (consistent with McLennan, Pavlou & Omodei, 2005). Indeed, many experienced fireground commanders are susceptible to the same types of cognitive errors (and blind spots) as trained novices, particularly under high cognitive load conditions. However, expert fireground commanders use metacognitive knowledge based on previous experience to monitor, decide, and act (a metacognitive loop), which enables them to keep their thinking on track and adapt to changing conditions (consistent with Cohen, Freeman & Wolf, 1996; and Anderson, Oats, Chong & Perlis, 2006). In these studies, expert fireground commanders also described higher levels of self-awareness (metacognitive awareness) than their poorer performing peers, consistent with earlier research (McLennan et al.).

Recommendations

For this reason, we recommend that fire agencies encourage deliberate practice for large-scale bushfires, so that practitioners develop the necessary metacognitive knowledge (and cognitive regulation skills) to:

- Change perspectives (e.g., between the big picture and ground truths).
- Employ anticipatory thinking (e.g., what might happen next, worst case scenarios).
- Regulate operational tempo (e.g., tradeoff between mistakes, and missed opportunities).
- Recognise trigger points for changing goals (e.g., offensive versus defensive goals).
- Recognise personal performance limits, and manage distribution of cognitive load.
- Manage risks and responsibilities appropriately within a chain of command.
- Apply rule-based procedures effectively, including watchouts and safety drills.
- Identify potential blind spots and errors in situational awareness, and develop mitigation techniques.

Furthermore, because expertise involves mental simulations (e.g., predicting likely and worst-case scenarios; Klein, 1999), we recommend development activities that are ecologically valid for the bushfire context, such as: case studies, scenarios, simulations, staff-rides, exercises, and coaching on the job (e.g., Fadde & Klein, 2011; Frye, 2012; Slijepcevic et al.). These types of activities would encourage the application of technical knowledge (including rule-based and standard operating procedures), whilst also developing the metacognitive knowledge (and cognitive regulation skills) required for work in macrocognitive environments. A significant goal should be to reduce cognitive overload, and therefore human errors, during large-scale bushfires in Australia.

Future Research

The Australian Bushfire Cooperative Research Centre has collected a large number of fireground interviews in the last 10 years. For example, the Human Factors Interview Protocol (HFIP; Omodei, McLennan & Reynolds, 2005) was used to conduct 120 interviews with bushfire fighters during the 2003-2006 bushfire seasons. A Bushfire Research Taskforce also conducted 600 interviews with survivors of the 2009 Black Saturday bushfires (Bushfire CRC, 2010) and similar taskforces interviewed residents affected by the Perth Hills bushfires (2011), and the recent Tasmanian and New South Wales bushfires (2013). These interviews could be used to further test the model described in the current research (Figure 1), and to validate, modify, or refute it's application for training about large-scale bushfires in Australia. Further analysis with larger samples would also highlight examples of fireground decision-making that can be used in fire training (e.g., as case studies, scenarios, staff rides, or exercises). With this in mind, the authors used the model (Figure 1) to analyse how survivors (bushfire fighters and residents) of a small rural community made decisions during the 2009 Victorian Black Saturday bushfires (Frye & Wearing, *in preparation*).

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