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Review

Sleep in wildland firefighters: what do we know and why does it matter?

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Abstract. Wildland firefighters perform physical work while being subjected to multiple stressors and adverse, volatile working environments for extended periods. Recent research has highlighted sleep as a significant and potentially modifiable factor impacting operational performance. The aim of this review was to (1) examine the existing literature on firefighters' sleep quantity and quality during wildland firefighting operations; (2) synthesise the operational and environmental factors that impact on sleep during wildland firefighting; and (3) assess how sleep impacts aspects of firefighters' health and safety, including mental and physical health, physical task performance, physical activity and cognitive performance. Firefighters' sleep is restricted during wildfire deployments, particularly when shifts have early start times, are of long duration and when sleeping in temporary accommodation. Shortened sleep impairs cognitive but not physical performance under simulated wildfire conditions. The longer-term impacts of sleep restriction on physiological and mental health require further research. Work shifts should be structured, wherever possible, to provide regular and sufficient recovery opportunities (rest during and sleep between shifts), especially in dangerous working environments where fatigue-related errors have severe consequences. Fire agencies should implement strategies to improve and manage firefighters' sleep and reduce any adverse impacts on firefighters' work.

Additional keywords: health, performance, physical activity, planned burn, safety, sleep restriction, wildfire.

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Introduction

Wildfires have a debilitating impact on communities, resulting in the loss of property, livestock and human life (Hyde *et al.* 2008; Anton and Lawrence 2016). Australia and North America are particularly susceptible to wildfire, but areas of South America, south Asia, southern Africa and southern Europe also have regular wildfire activity (Flannigan *et al.* 2013). The economic cost of wildland fires is immense. In the United States, US$18 billion was allocated for fire suppression and fuel management between 2006 and 2015 (Hoover and Bracmort 2015). Notably, real estate devaluation and post-fire recovery efforts are estimated to cost up to 30 times the direct cost of firefighting (Association for Fire Ecology 2015). A major concern to fire agencies and communities is that climate change will increase wildfire frequency, duration and severity (Westerling *et al.* 2006; Albertson *et al.* 2010; Liu *et al.* 2010). This, in turn, will result in prolonged fire seasons and incidents of longer duration (Flannigan *et al.* 2013; Schoennagel *et al.* 2017). As such, work demands and health and safety risks for wildland firefighting personnel, whose operational performance is critical for safeguarding communities, will increase.

During deployments, wildland firefighters perform physical work while being subjected to a myriad of stressors and adverse, volatile working environments for extended periods (Aisbett *et al.* 2012). These stressors include, but are not limited to, restricted sleep, physically and mentally demanding work, high ambient temperatures and smoke inhalation (Aisbett *et al.* 2012). Of these, sleep, and the impact of restricted sleep, is a significant and potentially modifiable factor impacting operational performance (Jay *et al.* 2013; Vincent *et al.* 2016*a*; McGillis *et al.* 2017). Sleep is a basic requirement for survival and serves many critical physiological and psychological functions. These include neurobehavioural performance (Kerkhof and Van Dongen 2010), metabolism (Copinschi *et al.* 2014), appetite regulation (Knutson 2007), immune function (Besedovsky *et al.* 2012) and hormone regulation (Steiger 2003). A typical adult should obtain at least 7 h of sleep per night for optimal health and functioning (Watson *et al.* 2015), yet 45% of adults do not meet

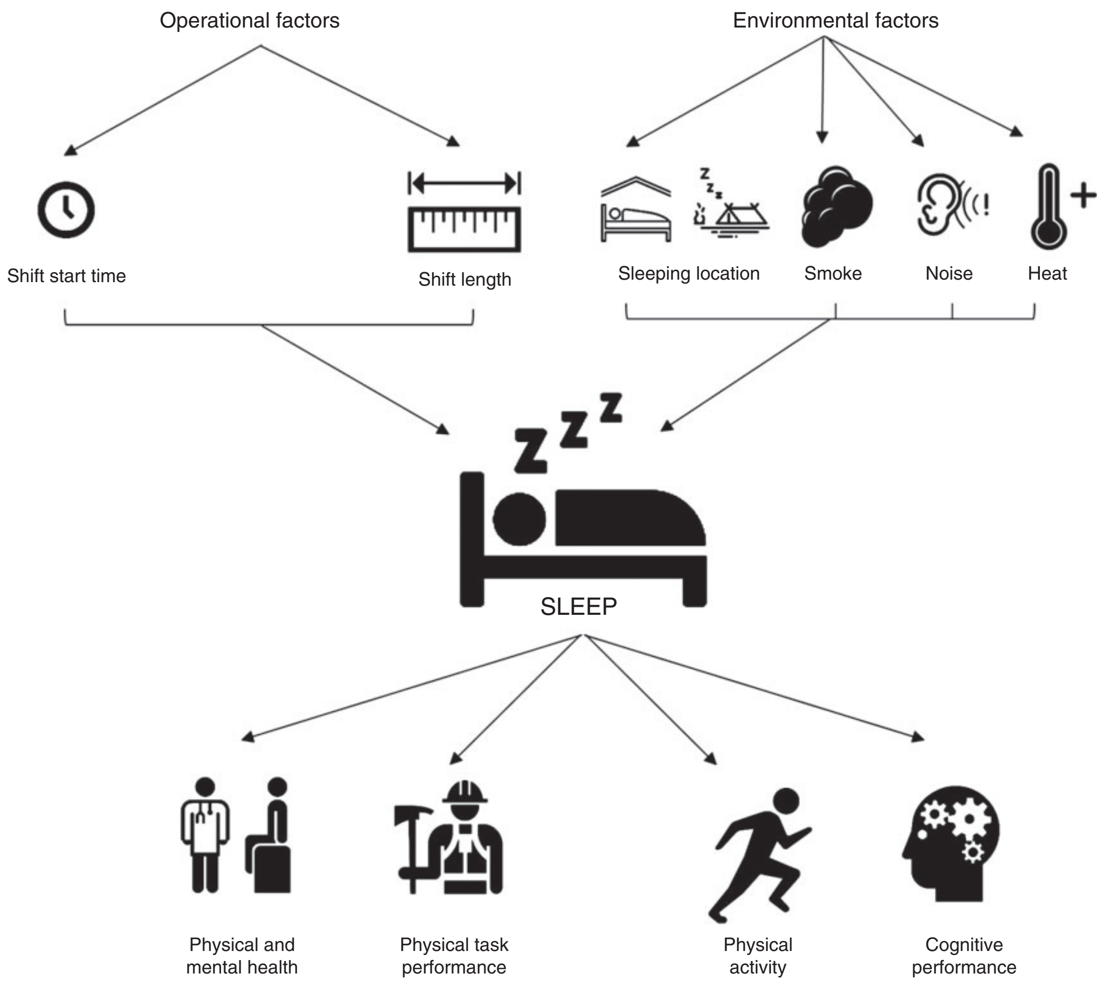

Fig. 1. Schematic overview: the operational and environmental factors that affect sleep during wildland firefighting, and the ways in which sleep impacts on aspects of firefighters' health and safety.

this recommendation (Centers for Disease Control Prevention 2011; Adams *et al.* 2016). Therefore, the aim of this review was to (i) examine the existing literature on firefighters' sleep quantity and quality during wildland firefighting operations; (ii) synthesise the operational and environmental factors that impact on sleep during wildland firefighting; and (iii) assess how sleep affects key aspects of firefighters' health and safety (Fig. 1). For the purposes of the present review, literature pertaining to the two forms of wildland firefighting is discussed: (1) wildfire suppression (e.g. emergency scenarios); and (2) planned burn operations (e.g. prescribed burning, back-burning), where fires are purposely lit to reduce the size, number and intensity of future wildfires (King *et al.* 2006; Reisen and Brown 2009).

Wildland firefighters' sleep

This section outlines methods for measuring sleep, discusses the most appropriate measurement practices in wildland firefighting scenarios, and synthesises current literature on wildland firefighters sleep quantity and quality.

The measurement of sleep

The three primary methods for measuring sleep in laboratory or field studies include: polysomnography, activity monitoring (also known as actigraphy) and subjective (self-report) measures. Polysomnography is the gold standard method for measuring sleep (Kushida *et al.* 2005), integrating the measurement of brain activity (electroencephalogram), eye movement (electrooculogram), muscle activity (electromyogram) and cardiac activity (electrocardiogram). Together, these measures enable the identification of periods of sleep and wake, as well as individual sleep stages. Variables derived from polysomnography include: total sleep time, sleep-onset latency, wake after sleep onset, sleep efficiency, sleep fragmentation index, number of awakenings and time in each sleep stage.

Activity monitoring provides an objective, non-invasive and practical alternative to polysomnography (Signal *et al.* 2005; Morgenthaler *et al.* 2007). Activity monitors indirectly assess sleep by sensing motor activity at the wrist and use validated algorithms to distinguish sleep from wakefulness (Ancoli-Israel *et al.* 2003; de Souza *et al.* 2003; Signal *et al.* 2005). These devices can collect data continuously for long periods of time and concurrently measure physical activity and sleep (Weiss *et al.* 2010). Although activity monitors can collect similar information as polysomnography, they cannot be used to evaluate the specific sleep stages. In healthy adults, activity monitor-derived total sleep time has been shown to be reliable (Littner *et al.* 2003) and valid when measured against polysomnography in both laboratory (de Souza *et al.* 2003) and field settings (Signal *et al.* 2005).

Subjective sleep assessments can be obtained using sleep diaries or logs (Lockley *et al.* 1999). Sleep diaries enable the collection of large amounts of data at low cost, and provide information on an individual's perceptions regarding their sleep (Signal *et al.* 2005). For example, sleep quality can be subjectively measured by asking participants to provide numerical ratings of perceived sleep quality and restfulness upon waking, and to report the number of night awakenings. Compared with activity monitors, sleep diaries yield similar data for sleep timing, duration, onset and offset, but not for sleep latency, number and duration of night awakenings, or number of naps (Lockley *et al.* 1999). Although activity monitoring is preferable to subjective sleep assessments when directly compared with polysomnography (Monk *et al.* 1999), the accuracy of objective sleep assessments using activity monitors can be improved when analysed in conjunction with subjective self-report measures (Kushida *et al.* 2001; Acebo *et al.* 2005). For example, using both measures minimises the possibility of incorrectly scoring periods of sedentary wakefulness (e.g. watching television) as sleep, or restless sleep as wake, and accuracy is further improved when low thresholds (i.e. cut points) of activity are used to determine wake periods (Ancoli-Israel *et al.* 2003). In situations where polysomnography is not feasible, concurrent use of activity monitors and self-report measures should be implemented.

Activity monitors and self-report measures allow sleep measurement with minimal disruption to normal behaviours, thus are typically preferred in occupational settings. In wildfire environments, polysomnography is considered impractical for measuring firefighters' sleep, as sleeping locations are often remote and often without electricity. Furthermore, the arrangement of electrodes required for polysomnography would restrict firefighters' ability to respond to urgent calls to perform wildfire suppression work.

Sleep quantity

Wildfires can last hours, days, or even weeks, during which time fire agencies are required to sustain continuous around-the-clock operations (Aisbett *et al.* 2012). These work arrangements can result in firefighters being sleep-restricted, or in some cases being awake in excess of 24 h (total sleep deprivation), particularly during the initial containment phase (Cater *et al.* 2007). A summary of the relevant literature pertaining to the *Sleep quantity* and *Sleep quality* sections can be found in Table 1.

In Australia, it is common for volunteer firefighters to be called to work a wildfire suppression shift after having already worked a full or partial day at their usual employment (Aisbett and Nichols 2007). When interviewed post-deployment, firefighters reported an average sleep duration of 3–6 h (Cater *et al.* 2007). Of concern, some firefighters recounted driving 2–3 h from the fireline to their sleeping location after having already worked shifts in excess of 16 h. In a study of United States firefighters, 40% of individuals reported sleep durations <7 h (Gaskill and Ruby 2004).

More recently, three studies have used activity monitors to examine firefighters' sleep behaviour during multiday wildfire suppression (Vincent *et al.* 2016*a*; McGillis *et al.* 2017) and planned burn operations (Vincent *et al.* 2016*b*). During wildfire suppression, Australian firefighters obtained 6.1 h sleep per 24 h, 54 min less than on days not fighting wildfire (Vincent *et al.* 2016*a*). Pre- and post-sleep fatigue (self-reported) were also greater on fire days compared with non-fire days (Vincent *et al.* 2016*a*). In a Canadian study, total sleep time during the initial wildfire suppression deployment (Initial Attack; 4.8 h) was significantly less than when firefighters performed border suppression deployments (Project Fires; 6.2 h), and non-fire work on base (Base; 6.2 h) (McGillis *et al.* 2017). The finding that non-fire work on base was also associated with suboptimal sleep was particularly concerning, as this could increase the risk of predeployment sleep debt (McGillis *et al.* 2017). Self-reported fatigue was also greater for Initial Attacks compared with Base (McGillis *et al.* 2017). Notably, McGillis *et al.* 2017 also analysed sleep during different deployment lengths. Although there were no significant differences in deployment length and sleep, all deployment lengths were associated with less than the recommended sleep hours (McGillis *et al.* 2017). Overall, these findings highlight that firefighters' sleep is restricted during multiday wildfire suppression.

To the authors' knowledge, only one study has investigated firefighters' sleep quantity during planned burn operations (Vincent *et al.* 2016*b*). No differences were seen in total sleep time when comparing planned burn days and non-burn days (Vincent *et al.* 2016*b*). Furthermore, only 19% of all sleep episodes were less than 6 h in duration (Vincent *et al.* 2016*b*), compared with 43% during wildfire suppression (Vincent *et al.* 2016*a*). Therefore, although the physical demands of these two types of firefighting appear to be similar (Chappel *et al.* 2016; Vincent *et al.* 2016*c*), the likelihood of fatigue (due to inadequate sleep) during planned burn operations is considerably less when compared with wildfire suppression. These differences may be due to (i) planned burn operations having more predictable rostering systems that are more easily adhered to, potentially minimising the number of extended shifts, and preserving night-time sleep opportunities; (ii) planned burn operations typically occurring before the fire season, and thus firefighters may feel less physically and mentally fatigued, compared with during the fire season; (iii) the sleeping locations during planned burn operations being either at homes or motels, whereas during wildfires, 22% of sleep periods occurred in temporary accommodation (e.g. tents, vehicles, cabins) (Vincent *et al.* 2016*b*); (iv) although not all wildfires are physically demanding (Robertson *et al.* 2017), the heightened physiological stress response caused by dangerous wildfire events or arduous fire seasons can influence sleep quantity and quality (Åkerstedt *et al.* 2007; Petersen *et al.* 2013).

Sleep quality

Although adequate sleep quantity is important, the quality of sleep during deployments should also be considered. Vincent *et al.* (2016*a*) found during wildfire suppression that there were no differences between fire and non-fire days in subjective sleep

Table 1. Summary of studies investigating firefighters' sleep quantity and quality during wildfire suppression and planned burn operations (ordered by year of publication)

Reference	Sample	Country	Methodology	Main findings	
				Sleep quantity (average sleep duration)	Sleep quality
Wildfire suppression					
Gaskill and Ruby (2004)	Hotshot firefighters ($n = 56$; 47 males, 9 females)	United States	Self-report	7.0 ± 1.4 h. NB: 40% of firefighters reported sleep durations <7 h	Not reported
Cater *et al.* (2007)	Wildland firefighters ($n = 66$; 39 males, 27 females)	Australia	Self-report	3–6 h	Not reported
Vincent *et al.* (2016*a*)	Wildland firefighters ($n = 40$; 31 males, 9 females)	Australia	Self-report and activity monitors	6.1 ± 1.7 h; 54 min less sleep duration when comparing days suppressing wildfire compared with non-fire days.	No difference (between days supressing wildfire and non-fire days) in subjective sleep quality, number of times woken and objective measures of sleep latency and efficiency
McGillis *et al.* (2017)	Wildland firefighters ($n = 21$; 21 male, 0 female)	Canada	Self-report and activity monitors	Initial Attack: 4.8 ± 1.2 h; Project Fire: 6.2 ± 0.9 h; Base: 6.2 ± 1.0 h	Initial attacks: two-thirds below recommended sleep efficiency (<85%). Wake after sleep onset was above recommended (>31 min) indicating poor sleep quality across all deployment types
Planned burn operations					
Vincent *et al.* (2016*b*)	Wildland firefighters ($n = 33$; 25 males, 8 females)	Australia	Self-report and activity monitors	Self-reported: 7.0 ± 1.1 h; activity monitors: 7.8 ± 0.8 h; no difference in average sleep duration when comparing days conducting a planned burn and non-burn days	No difference (between days conducting a planned burn and non-burn days) in subjective and objective measures of sleep quality

quality and number of times woken, as well as objective measures of sleep latency and efficiency (Vincent *et al.* 2016*a*). However, McGillis *et al.* (2017) found that two-thirds of firefighters' sleep periods during Initial Attack deployments fell below recommended sleep efficiency (<85%). In addition, wake after sleep onset during all deployment types (Initial Attack, Project Fires, Base) was above recommended levels (>31 min), indicating poor sleep quality in general (McGillis *et al.* 2017). Although sleep quality was below recommendations for all deployment lengths, no differences in sleep quality were observed (McGillis *et al.* 2017). Differences in sleep quality between these studies (Vincent *et al.* 2016*a*; McGillis *et al.* 2017) may be reflective of the sleeping environments, or differences in the firefighting tasks performed between countries (Australia *v.* Canada). During planned burn operations, no differences in objective and subjective sleep quality were observed between planned burning days and non-burn days (Vincent *et al.* 2016*b*). Future research is needed to determine how certain operational and environmental factors may affect sleep quality.

Factors that influence sleep during wildland firefighting

Sleep is impacted by a range of operational and environmental factors (Åkerstedt 2003; Muzet 2007; Folkard 2008). Operational factors (i.e. shift length and shift start time) as well as environmental factors (i.e. sleeping location, smoke and noise; Fig. 1) are major contributors to inadequate sleep in both the wildfire suppression context (Cater *et al.* 2007; Vincent *et al.* 2016*a*) and planned burn operations (Vincent *et al.* 2016*b*). Although there are many factors that can influence sleep, these factors may explain the variability in sleep quantity and quality reported in most wildfire suppression studies, and also provide modifiable targets for intervention.

Operational factors: shift length and shift start time

Round-the-clock operations such as wildland firefighting have traditionally used shift work rosters that provide one long period of work and one primary sleep opportunity per 24-h period. Prescriptive rules regarding shift length and number of consecutive shifts vary between countries and across fire agencies. In Australia, firefighters are typically rostered to work a 12-h day or night shift, but owing to the unpredictable nature of wildfire and wildfire suppression, can work shifts of up to 16 h for 3–5 consecutive days (Cater *et al.* 2007). In North America, firefighters work 10–16-h shifts and can be deployed for up to 14 days at a time (Heil 2002; Ruby *et al.* 2002; Ruby *et al.* 2003; Gordon and Lariviere 2014; McGillis *et al.* 2017; Robertson *et al.* 2017). Although work schedules facilitate 24-h provision of services, the long shifts and early start times that accompany such work schedules may further truncate firefighters' opportunity for sleep (Kurumatani *et al.* 1994; Sallinen *et al.* 2003).

During wildfire suppression, extended shifts are common, often resulting from a lack of replacement personnel or fires that require urgent attention. Objective data indicate that shifts longer than 14-h duration were associated with 48 min less sleep than shifts less than 14 h (Vincent *et al.* 2016*a*). For Canadian firefighters on Project Fire deployments, there was a downward trend (albeit not statistically significant) in sleep quantity with increasing shift length (e.g. 16 min more sleep on shifts <12 h compared with >13-h shifts) (McGillis *et al.* 2017). Further, planned burn shifts that were greater than 12-h duration resulted in 28 min less sleep compared with those shifts less than 12-h duration (Vincent *et al.* 2016*b*). The reduced total sleep time observed in the two Australian studies (28 and 48 min) is of a scale similar to that shown to cause progressive deterioration in cognitive performance in other occupations (e.g. doctors, navy watchmen) over successive days (Anderson *et al.* 2012; Skornyakov *et al.* 2017). Further research is needed on the implications of cumulative sleep loss in a wildland firefighting context.

Shifts with early start times also substantially reduce sleep length (Ingre *et al.* 2008; Ferguson *et al.* 2010; Roach *et al.* 2012). This is largely due to circadian physiology that dictates lowest sleep propensity (or sleep drive) at ~ 2000 hours (Lack and Lushington 1996). Although an earlier bedtime (in anticipation of an early rise time) will increase opportunity for sleep, this may not always result in more actual sleep. During wildfire suppression, shifts that started before 0600 hours were associated with 60 min less sleep than those starting after 0600 hours (Vincent *et al.* 2016*a*). In a Canadian study, early shift start times (0500–0600 hours) reduced total sleep time by 45–75 min compared with later shift start times (McGillis *et al.* 2017). In contrast, total sleep time was unaffected by shift start time during planned burn operations as no shifts started before 0600 hours (Vincent *et al.* 2016*b*). Collectively, these findings highlight the importance of the timing of sleep periods and demonstrate that sleep opportunities of equivalent duration but at different times of day may not equate to equivalent total sleep (Jay *et al.* 2006).

Environmental factors: sleeping location, smoke, noise and heat

During wildfire deployments, firefighters can sleep at home, in a motel or in temporary accommodation near the fireground (e.g. tent, vehicles) (Cater *et al.* 2007; Aisbett *et al.* 2012). Total sleep time obtained in a tent (5.2 h) was significantly less compared with sleep at home (6.1 h) or in a motel (6.2 h) (Vincent *et al.* 2016*a*). Sleep in a vehicle (e.g. a fire truck) was also significantly reduced (4.5 h) compared with sleep at home or in a motel, but is not common practice for fire agencies (Vincent *et al.* 2016*a*). Notably, there was no impact of sleep location during planned burn operations, as all sleep opportunities were in motels or at home (Vincent *et al.* 2016*b*). Sleep onset and total sleep time may be reduced owing to environmental conditions such as smoke, noise and heat (Cater *et al.* 2007). Firefighters cited 'heat', 'noise' (e.g. snoring) and 'the number of other people in the sleeping location' as the major factors contributing to less sleep during wildfire suppression deployments (Vincent *et al.* 2016*a*).

To the authors' knowledge, no studies have investigated whether smoke exposure affects sleep quantity or quality (Aisbett *et al.* 2012). However, concurrent exposure to restricted sleep and stress could further degrade cognitive function (Bunnell and Horvarth 1988; Van Dongen *et al.* 2003). Although the impact of noise on sleep has been established (Muzet 2007), no research has specifically assessed the impact of noise on sleep during wildland firefighting operations.

Results from recent work have highlighted how sleep may be affected by heat during simulated wildfire suppression (Cvirn *et al.* 2015, 2017). The 3-day (4-night) study compared sleep (8-h or 4-h time in bed) under thermoneutral (18–20°C) or slightly elevated (23–25°C) night-time temperature conditions. In brief, there was no discernible impact of the elevated night-time temperature on measures of sleep architecture (stages of sleep) in either rested (8 h) or restricted (4 h) sleep. These same results also suggest that the added stressor of higher ambient temperatures (33–35°C) during the day before sleep did not have significant carry-over impacts for sleep architecture that night. Sleep restriction in and of itself (i.e. under thermoneutral conditions) altered architecture in ways supported by previous literature with reduced time in sleep stages N1, N2, rapid eye movement sleep and wake, but maintenance of slow wave sleep. Similarly, another study from the same simulation found that working under hot (33–35°C) or temperate (18–20°C) ambient conditions while sleep restricted did not impact firefighters' physiological responses, hydration status, rating of perceived exertion and motivation (Vincent *et al.* 2017). Although sleep during wildfire suppression is restricted, these data (in simulated conditions) suggest that sleep architecture and firefighters' physiological responses are maintained when sleeping temperatures are between 18 and 35°C.

How does sleep restriction impact firefighters' health and safety during wildland firefighting operations?

This section of the review appraises existing literature that has identified how restricted sleep can affect firefighters' physical and mental health, physical task performance, physical activity and cognitive performance, all of which are major contributors to firefighters' health, safety and operational performance (Fig. 1).

Physical health

Short sleep has been associated with cardiovascular health-related outcomes (Gangwisch *et al.* 2006; Buxton and Marcelli 2010; Cappuccio *et al.* 2011; Xiao *et al.* 2014). Occupations that involve work-related sleep restriction, such as firefighting, have an increased risk of cardiovascular disease (CVD) and related mortality (Soteriades *et al.* 2011). For instance, in the United States, heart attacks were the third-leading cause of death for salaried wildland firefighters between 1990 and 2006 (21.9%), preceded only by aircraft (23.2%) and vehicle (22.9%) accidents (Mangan 2007). Fatalities due to heart attacks are even higher among volunteer personnel in the United States (42%) (Mangan

2007). In Australia, volunteer firefighters' coronary heart disease risk is reported to exceed other volunteer and paid emergency services (Wolkow *et al.* 2014).

Inflammatory mechanisms play an important role in the pathogenesis of CVD (Ridker *et al.* 2000; Libby *et al.* 2002), with growing evidence that sleep loss may contribute to CVD risk via inflammatory processes involving shifts in the release of cytokines, C-reactive protein (CRP) and other inflammatory markers (Mullington *et al.* 2010). However, owing to a large variation between studies in the methods used to assess sleep duration and inflammation (Irwin *et al.* 2016), the impact of acute sleep loss on inflammatory markers remains unclear. For example, 2 consecutive nights of sleep restricted to 4 h time in bed did not accentuate the rise in pro-inflammatory cytokine levels among firefighters completing a simulated wildfire deployment (Wolkow *et al.* 2015*b*). Conversely, modest sleep restriction (i.e. 4–5 h) for 5 and 7 nights has been found to affect inflammatory cytokines in healthy subjects (Vgontzas *et al.* 2004; van Leeuwen *et al.* 2009; Axelsson *et al.* 2013; Pejovic *et al.* 2013). Given that firefighters can face extended deployments (e.g. >5 days) (Ruby *et al.* 2002), future research should investigate the effect of chronic sleep restriction on inflammatory markers in personnel. Moreover, research characterising firefighters' sleep beyond a single deployment is needed (i.e. sleep across a fire season and out-of-season). Shift workers with chronic sleep debt show higher CRP and leukocytes compared with day workers (Kim *et al.* 2016), but no differences have been found for cytokines (van Mark *et al.* 2010). Several of these inflammatory markers, most notably CRP, have also been reported to predict adverse physical health outcomes among firefighters exposed to particulate matter (Weiden *et al.* 2013). Further, exposure to wildfire smoke elicits transient inflammatory responses (Dorman and Ritz 2014), which is associated with increased cardiovascular morbidity and mortality (Pope *et al.* 2004). Although further research is needed to better understand the interactions between acute sleep restriction and inflammation, it is likely chronic multiple stressors, including sleep loss, contribute to the high cardiovascular strain involved in firefighting (Soteriades *et al.* 2011).

Mental health

Short sleep has also been linked to adverse mental health outcomes (Zhai *et al.* 2015), which are prevalent in emergency service personnel (McFarlane and Papay 1992; Psarros *et al.* 2008; Leykin *et al.* 2013). In Australia, high rates of post-traumatic stress disorder (PTSD) (12.5%) and depression (8.5%) have been reported among firefighters exposed to a large wildfire (McFarlane and Papay 1992). Similarly high rates of PTSD have been reported among firefighters deployed to fight wildfires in Israel (12.3%; Leykin *et al.* 2013) and Greece (18.6%; Psarros *et al.* 2008). High rates of job stress have also been reported among wildland firefighters in Canada (Gordon and Lariviere 2014). However, in comparison with their urban counterparts, research examining mental health in wildland firefighters is limited.

The exact role of sleep loss in adverse mental health outcomes is still unclear. However, firefighters exposed to sleep restriction during a simulated wildfire deployment revealed acute increases in afternoon and evening cortisol (Wolkow *et al.* 2016), which may negatively alter emotional memory processes (Nagamine *et al.* 2017) and therefore a range of stress-related psychopathologies (e.g. PTSD and depression; Wolf 2008). These results highlight a potential stress response pathway that, over time, may adversely impact mental health in firefighters.

The limitation of prior studies is that most have only examined the acute effects of sleep loss on physiological indices of health in personnel. Given the lack of data on chronic effects, additional longitudinal studies are needed to understand if and how repeated exposure to sleep restriction over a fire season, and over multiple fire seasons, affects cortisol and inflammatory responses in the long term (Wolkow *et al.* 2015*a*). Alternatively, Walker and colleagues (2016) have suggested a case-control approach whereby firefighters with mental (e.g. PTSD or mood disorders) as well as physical health conditions (e.g. CVD) are compared against healthy personnel to characterise relationships between physiological responses and health outcomes. Future insights will help fire agencies in determining whether additional precautions are required to mitigate the potential risks that sleep restriction poses to firefighters' physical and mental health in the context of a fire season, as well as over their life cycle.

Physical performance

The demands of wildland firefighting, containment and recovery work can vary between fire agencies, even within a state or region (Phillips *et al.* 2012; Robertson *et al.* 2017). Generally, the more intense work periods typically comprise carry, drag or raking movements (Dwyer and Brooker 2005; Phillips *et al.* 2012), separated by periods of standing or walking. The more physically demanding tasks on the fireground can last from ~5 s to >10 min and be completed between 1 and 100 times across a 10- to 16-h work shift (Phillips *et al.* 2015*a*). The intensity of these individual tasks can elicit near-maximal heart rates (Phillips *et al.* 2015*b*) and high levels of muscle contraction (Neesham-Smith *et al.* 2014).

Measuring physical performance on firefighting work tasks in field settings is difficult. This is due, in part, to the wildland firefighting environment, which is hazardous to researchers and equipment and contains multiple stressors (e.g. heat and smoke exposure; Reisen and Brown 2009; Larsen *et al.* 2015). These can confound cause-and-effect relationships, making it difficult to accurately ascertain how restricted sleep directly impacts firefighters' performance on physical work tasks. Under self-paced simulated wildfire conditions, 4 h of sleep restriction did not adversely affect firefighters' physical task performance on work tasks, or their physiological and perceptual responses, compared with those firefighters who received an 8-h sleep opportunity (Vincent *et al.* 2015). The domain-specific nature of the firefighting tasks, such as variable intensities, frequent task rotation and repeated rest breaks, and working in teams (Faber *et al.* 2015) possibly enabled firefighters to maintain physical task performance despite being sleep-restricted. Further, it is also conceivable that reduced physical activity during rest breaks (Vincent *et al.* 2015) mitigated the adverse effects of sleep restriction and allowed firefighters to maintain their physical task performance. Fire agencies should encourage firefighters to take regular rest breaks and, where feasible, rotate work tasks throughout multi-day deployments, especially when firefighters' sleep is restricted.

Physical activity

Wildfire suppression and planned burns generally require intermittent physical activity across a shift (Cuddy *et al.* 2015; Chappel *et al.* 2016; Vincent *et al.* 2016*c*). However, the influence of sleep restriction on subsequent physical activity levels during a shift has been largely unexplored. In a case report, North American wildland firefighters' total accumulated daily activity counts were moderately but negatively correlated with firefighters' reported sleep duration the night before (Gaskill and Ruby 2002). This suggests that sleep-related fatigue may have adverse consequences on firefighters' physical activity levels, meaning that firefighters may be either less productive, or unable to perform the work required. Similarly, during simulated wildfire suppression, sleep-restricted firefighters were less physically active across a simulated shift (Vincent *et al.* 2015). This was attributed to behavioural adaptations made during rest periods, where passive rest (such as sitting still and lying down) was preferred over active rest activities (such as walking) (Vincent *et al.* 2015). Only one study has examined whether the amount of sleep that firefighters obtain may influence on-shift physical activity levels using objective measures (activity monitor). Vincent and colleagues (2016*c*) found that sleep duration between shifts did not moderate firefighters' shift-to-shift physical activity levels during actual wildfire suppression. However, the acute impacts of sleep restriction may not be sufficient to influence physical activity in the short term and future studies should be implemented to further examine how firefighters' physical activity may change in response to sleep restriction or irregular sleep over longer periods.

Cognitive performance

Firefighting involves a large cognitive demand including assessing emergency scenarios, executing critical decisions and situational awareness of surroundings (Williams-Bell *et al.* 2017). Operational studies documenting cognitive impairment during wildland firefighting (real-world or simulation) are lacking (Ferguson *et al.* 2016; Smith *et al.* 2016; McGillis *et al.* 2017). In order to determine the aspects of cognitive performance critical for wildland firefighting performance, researchers conducted focus groups with wildland firefighters in a simulation study (Ferguson *et al.* 2011). Information retention from short-term memory, communication and decision-making were identified as key cognitive elements of work (Ferguson *et al.* 2011). Further, vigilance, concentration and maintaining awareness of critical cues in the environment while concurrently focusing on the primary task were also identified as key cognitive elements of work (Ferguson *et al.* 2011). Using a range of measures (including sustained attention and short-term working memory), the impact of heat and sleep restriction (in isolation and combination) on cognitive performance was assessed across 4 consecutive 12-h day shifts (Smith *et al.* 2016). In the absence of sleep restriction, performance on a 5-min sustained attention task declined with increasing days on 'deployment', suggesting that even without additional stressors, the nature and duration of the tasks during wildfire suppression will impair cognitive performance (Smith *et al.* 2016).

Restricted sleep (<6 h) is commonplace in both wildfire suppression (43%) (Vincent *et al.* 2016*a*) and planned burn operations (19%) (Vincent *et al.* 2016*b*). The consequences of sleep restriction on cognitive performance (e.g. slower reaction times, reduced vigilance) in healthy, non-shift working populations are well established (Belenky *et al.* 2003; Van Dongen *et al.* 2003). Therefore, it stands to reason that firefighters will also suffer cognitive impairment, particularly during longer deployments when sleep has likely been restricted for consecutive days. For example, daytime performance following restricted (4-h) sleep opportunities resulted in greater cognitive decline compared with a control condition (8-h opportunities) (Ferguson *et al.* 2016; Smith *et al.* 2016). Furthermore, the addition of the stressor heat (33–35°C) to sleep restriction was associated with the poorest performance overall. Additionally, firefighters were unreliable in their ability to perceive declines in cognitive performance following 4-h sleep opportunities (Smith *et al.* 2016). In a real-world study, McGillis *et al.* (2017) observed reduced morning reaction time performance during Initial Attacks compared with Base. Future research should focus on data collection in the field as well as during night shift across a broad range of cognitive performance domains relevant to wildland firefighting (e.g. response time, memory, decision-making).

Implications for fire agencies

This growing body of literature on wildland firefighters' sleep has important implications for fire agencies. Depending on the organisation and jurisdiction, these findings warrant re-evaluation of existing policies and formalisation of beneficial but currently *ad hoc* practice, or provide support for current procedures. Further, implementation of specific findings needs to be considered as part of the whole system such that changing one policy to improve firefighters' sleep, for example, does not adversely impact productivity or wellbeing for them, or other groups in the organisation. For example, changing shift start times to after 0600 hours may increase sleep, but may reduce the opportunity for firefighters to work productively in cooler morning conditions. Balancing these priorities may vary across incidents and deployments and depend on environmental factors such as weather, terrain and access to the fireground. Another clear insight from the present review, consistent with previous work by our group (Jay *et al.* 2013), is the value of providing cool, dark and quiet sleeping environments for workers sleeping 'on site', including firefighters on deployment. Setting up the sleeping area away from arriving crew members, or supplying firefighters with ear plugs, may make the sleeping environment more conducive to obtaining adequate sleep (Jay *et al.* 2013). Optimising firefighters' sleep hygiene through permanent (e.g. motels, rather than temporary – vehicles, tents) accommodation is already a priority for many agencies. Where suitable permanent facilities are not available, and firefighters are attempting to sleep in noisy, warmer or lighter surrounds, incorporating their likely higher fatigue risk into next-day (or night) planning is critical. Fire agencies should use prior sleep–wake history and work history to identify those firefighters at elevated fatigue-related risk and implement appropriate controls to manage this risk (Gander *et al.* 2011). For the sleep-restricted firefighter, incorporating other fatigue-countermeasures such as frequent rest breaks (Tucker 2003), caffeine administration (Lorist and Tops 2003), or increased communication or supervision (Lerman *et al.* 2012) may help agencies balance individual health and safety against operational effectiveness. The value of these short-term countermeasures for preserving firefighters' physical and cognitive performance is another example of the importance of considering system-wide risk. At the individual level, it may be tempting to stand down a firefighter who has suboptimal sleep in the night(s) or day(s) before their shift. However, if replacement (and well-rested) personnel are not available, then removal of that firefighter increases the workload of the remaining workers, which could reduce overall productivity and increase collective fatigue risk for a crew or crews. The trigger points for employing these countermeasures may change within and between deployments and depend on factors such as the available number of personnel, predicted length of the campaign and number of campaigns the firefighters' have faced in a single or consecutive season(s).

The first critical step towards a change in sleep-culture is education. Equipping fire agencies with up-to-date, accessible knowledge about sleep (e.g. how sleep is regulated, how sleep can be disturbed, what happens when you do not get enough sleep, how much sleep is enough) will place them in a strong position to improve the aspects of their sleep within their control (e.g. sleep environment, priority of sleep, promoting a positive sleep-culture) and minimise the impact of the aspects that are not (e.g. shift work). At an organisation level, increasing sleep knowledge will also inform the structure of work patterns and facilitate commitment to, or development of, fatigue risk management policy and practice (Gander *et al.* 2011; Dawson *et al.* 2012). To support behaviour change, commercially available sleep and activity trackers (e.g. Fitbit, Garmin) can be used (Salmon and Ridgers 2017). These devices can provide feedback on physical activity levels during a shift in real time, and sleep duration between shifts.

Although current research indicates that sleep-restricted firefighters' physical performance and physical activity are maintained, safe working practices could be compromised. A recent systematic review and meta-analysis estimated sleep problems increased the risk of being injured at work by 62% (Uehli *et al.* 2014). Further, work-related injury risk increases with increased working hours (Lombardi *et al.* 2010) and high levels of sleepiness (Melamed and Oksenberg 2002). Therefore, while firefighters may be capable of physically performing tasks, they are also at increased injury risk. It is also possible that because physical performance appears to be unaffected by sleep restriction, firefighting personnel may be less likely to detect other performance changes (e.g. cognitive performance), increasing risk of incident.

Future research directions

To the authors' knowledge, all existing wildland firefighting research has focused on daytime wildfire suppression or planned burn work, yet multi-day deployments involve night-shift work. No research has characterised firefighters' physical activity levels, physical task performance, physiological and psychological stress responses, or sleep behaviour during night-shift deployments. All components of 24-h operations, including night work, should be investigated to inform policy relating to shift length or timing. This could be achieved objectively by measuring firefighters' sleep and physical work during night-shift operations and by conducting a work task simulation using night-time shifts and daytime sleeps.

It should also be acknowledged that the environmental and operational factors covered in this review are not all-inclusive. Other factors such as insects, cold weather and location of nap opportunities are examples of additional considerations that require further research. Although research is limited, psychosocial factors such as stress, hostility, depression and job control should be further investigated in a wildfire context. For example, one study found that 48% of Canadian firefighters self-reported high levels of job stress over the course of a fire season (Gordon and Lariviere 2014). The impact of psychosocial factors that can change across the fire season on sleep must be explored.

It must be noted that the majority of the research has focused on the acute impacts of sleep restriction. However, deployments in Australia commonly last 3–5 days (Aisbett *et al.* 2012) and in North America, deployments can last up to 14 days (Heil 2002), which may result in more chronic sleep restriction. To determine the long-term health impacts of restricted sleep, future research employing a longitudinal or case-control approach is needed to determine how repeated exposure to sleep restriction on the fireground may chronically alter cortisol and immune activity and associated physical (Rosmond *et al.* 2003; Nijm and Jonasson 2009) and mental health outcomes (Yehuda 2009; Furtado and Katzman 2015).

It is important to identify whether certain tasks, or particular task characteristics are more susceptible than others (or at all) to sleep restriction and the magnitude of sleep-related decline. This could inform the composition of crew (i.e. assign tasks to those individuals who have obtained the most sleep), rotation of those tasks that are most susceptible to sleep restriction, or implementation of more frequent rest breaks or shorter work shifts. Further research is also needed on how firefighters pace themselves throughout a work shift. If firefighters reduce their incidental level of physical activity on the fireground when sleep restricted, it is possible that they may be less likely to perform other activities (e.g. returning to the staging area to eat or drink), which could consequently adversely affect their health and safety.

Conclusion

Firefighters' sleep is restricted during wildfire deployments. In light of the predicted increase in wildfire frequency and severity, this could further compromise firefighters' health, performance and safety. Work shifts should be structured to provide rest periods during shifts and sufficient recovery opportunities between shifts. For fire agencies to continue to defend local communities against wildfire, it is critical that a high level of investment in preserving firefighters' long-term health and wellbeing is maintained. This includes implementing strategies to improve and manage firefighters' sleep and reduce any adverse impacts on firefighters' work.

Conflicts of interest

The authors declare that they have no conflicts of interest.

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