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The sleep architecture of Australian volunteer firefighters during a multi-day simulated wildfire suppression: Impact of sleep restriction and temperature

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ABSTRACT

Wildland firefighting exposes personnel to combinations of occupational and environmental stressors that include physical activity, heat and sleep restriction. However, the effects of these stressors on sleep have rarely been studied in the laboratory, and direct comparisons to field scenarios remain problematic. The aim of this study was to examine firefighters' sleep during a three-day, four-night simulated wildfire suppression that included sleep restriction and physical activity circuits representative of firefighting wildfire suppression tasks in varied temperatures. Sixty-one volunteer firefighters (37.5 ± 14.5 years of age, mean ± SD) were assigned to one of three conditions: *control* ($n = 25$; 8 h sleep opportunities and 18–20 °C), *awake* ($n = 25$; 4 h sleep opportunities and 18–20 °C) or *awake/hot* ($n = 11$; 4 h sleep opportunities and 33–35 °C during the day and 23–25 °C during the night). Results demonstrated that amounts of N1, N2 and R sleep, TST, SOL and WASO declined, whilst sleep efficiency increased significantly in the *awake* and *awake/hot* conditions compared to the *control* condition. Results also demonstrated that SWS sleep remained relatively stable in the *awake* and *awake/hot* conditions compared to *control* values. Most importantly, no significant differences were found for any of the sleep measures between the *awake* and *awake/hot* conditions. Thus, working in hot daytime temperatures in combination with sleep restriction during the night did not affect patterns of sleep compared to working in temperate conditions in combination with sleep restriction during the night. However, the effects on sleep of high (>25 °C) night-time temperatures with sleep restriction in addition to physical activity remains to be studied.

1. Introduction

Firefighting exposes personnel to combinations of occupational and environmental stressors including sleep restriction (Cater et al., 2007), long shifts of variable intensity physical activity (Cuddy et al., 2007; Phillips et al., 2012), and environmental extremes (Aisbett et al., 2012). Australian wild fires are known for hot temperatures (>45 °C) (Cheney, 1976), and require firefighters to work extended periods (up to 16 h per shift) (Cater et al., 2007; Phillips et al., 2012) in deployments that can last for days to weeks (Hunter and Authority, 2003; Rodriguez-Marroyo et al., 2012). As a result, cumulative sleep loss can occur, with firefighters reporting on average 3–6 h sleep per night during multi-day fire deployments (Cater et al., 2007; Gaskill and Ruby, 2004). Inadequate sleep has implications for performance and places individuals at increased risk of error and incident (Åkerstedt and Wright, 2009). Although data on Australian firefighters' sleep patterns are sparse, laboratory and military studies focusing on the individual and combined effects on sleep architecture of physical activity, sleep restriction and/or ambient temperatures provides some insight.

Laboratory studies on the effects of exercise on sleep reveal consistent increases in slow wave sleep (SWS) (Horne and Porter, 1975; Horne and Staff, 1983) and in some cases, associated reductions in rapid eye movement (REM) sleep (Horne and Moore, 1985) if exercise is conducted late in the afternoon and without a sufficient daytime recovery period. The effects of sleep restriction on sleep architecture are also well established, with declines in amounts of

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stage 1, 2, and REM sleep, and a conservation of SWS from sleep doses of 3–6 h per night for 7–14 consecutive days (Belenky et al., 2003; Van Dongen et al., 2003). However, the effects of varying ambient temperatures on sleep patterns are less clear.

Research using temperatures between 21 and 37 °C (Haskell et al., 1981) demonstrated that cold, rather than warm temperatures were generally more disruptive to sleep. Specifically, increases in stage 1 sleep and decreases in stage 2 and REM sleep were reported with 21 °C the most disruptive temperature. In contrast, no significant effects on the total duration of REM sleep or latency were reported during two consecutive nights sleep at temperatures of 13 °C, 16 °C, 19 °C, 22 °C, or 25 °C (Muzet et al., 1983). The effects on sleep during sleep restriction in cool and warm temperatures have also been examined.

Sleep restriction to 4 h for four nights at 20 or 35 °C was associated with decreased amounts of stage 1 sleep and wake after sleep onset (WASO) (Bach et al., 1994). Duration of stage 4 sleep increased over nights of sleep restriction at 20 °C but not 35 °C. Similar military research combining the effects of 4 h sleep restriction for 6 nights with an initial 90 h total sleep deprivation (TSD) period, during a tactical defence exercise in cold winter temperatures, revealed stage 2 sleep decreased whilst all other stages remained constant (Haslam, 1982).

Laboratory and field studies provide insight into the effects on sleep architecture of single or dual stressor combinations of physical activity, sleep restriction, and/or ambient temperatures however the combination of all three has not been studied in the laboratory. Further, where combinations of stressors (i.e., physical activity, sleep restriction and environmental extremes) are similar to that of firefighting, such as in military operations, direct comparisons are limited because such studies typically include periods of TSD at the beginning of experimental trials, in addition to limited control of extraneous variables such as fluctuations in natural weather conditions (Haslam, 1982; Lieberman et al., 2005). The aim of this study was to determine whether changes in sleep architecture from sleep restriction in combination with heat and physical activity are significantly different from those of sleep restriction and physical activity alone, and if these conditions differ from full sleep opportunities during a multi-day simulated wildfire suppression.

2. Methods

2.1. Participants

Participants were active volunteers recruited from the South Australian Country Fire Service, Country Fire Authority (Victoria), Tasmania Fire Service, New South Wales National Parks and Wildlife Service, and Australian Capital Territory Fire and Rescue. In groups of up to five, participants took part in a multi-day simulated wildfire suppression. Participants were assigned to one of three conditions. The *control* condition consisted of 25 participants (3 females (f)), 22 males (m) (mean = 36.7 y, SD = 15.9 y) with a mean BMI of 27.0 kg/m^2 (SD = 4.8 kg/m^2). The *awake* condition consisted of 25 participants (5 f, 20 m) (mean = 38.5 y, SD = 13.2 y) with a BMI of 29.2 kg/m^2 (SD = 4.9 kg/m^2). The *awake/hot* condition consisted of 11 participants (1 f, 10 m) (mean = 37.5 y, SD = 15.6 y) with a BMI of 26.7 kg/m^2 (SD = 4.6 kg/m^2). Power analyses indicated that a total sample size of 75 participants (across three groups) would be required ($\alpha = 0.05$, $1 - \beta = 0.80$), using an estimated effect size of $f = 0.16$ from previous research investigating changes in REM sleep and SWS with ambient temperature changes of 3 °C (Muzet et al., 1983, 1984). However, due to operational time constraints only 11/25 participants could be collected for the *awake/hot* group resulting in a total sample of 61 participants. This yielded an achieved study power of 0.71. Ethics approval was obtained from the CQUniversity and Deakin University Human Research Ethics Committees.

2.2. Procedure

The three-day, four-night multi-day simulated wildfire suppression consisted of a baseline night with an 8 h sleep opportunity (time in bed (TIB) 22:30–06:30 h), followed by two experimental nights with either 8 h or 4 h sleep opportunities (TIB 22:00–06:00 h or 02:00–06:00 h) for the *control* or *awake* and *awake/hot* conditions, respectively. The fourth night was a recovery sleep with all conditions provided with an 8 h sleep opportunity (TIB 22:00–06:00 h). For the *control* and *awake* conditions, day- and night-time temperatures remained between 18 and 20 °C throughout the protocol. From 11:30 h on experimental day one, temperature in the *awake/hot* condition was set to 33–35 °C during the day (06:00–18:00 h), and 23–25 °C during the two experimental nights and recovery (18:00–06:00 h). Temperature was monitored using a wireless temperature and humidity logger (HOBO ZW_003, One Temp Pty Ltd, Australia), data receiver (HOBO ZW_RCVR, One Temp Pty Ltd, Australia), and associated software (HOBO Pro Software, One Temp Pty Ltd, Australia). During the simulated dayshift firefighters performed physical-cognitive test circuits, three to five per day. Each 2 h circuit consisted of 55 min of physical work involving wildland firefighter suppression tasks (for a detailed methodology and the effects of sleep restriction on physical task performance the reader is referred to Vincent et al., 2015), 20–25 min of physiological testing (for a detailed methodology and the effects of heat on physiology and work performance the reader is referred to Larsen et al., 2015) and 20–25 min of cognitive testing (reported elsewhere), followed by a 15–20 min rest period.

2.3. Activity monitors

Actiwatch-64 (Mini-Mitter Philips Respironics, Bend, OR) or Actical Z-series (Mini-Mitter Philips Respironics, Inc.) devices were worn on the non-dominant wrist, prior to and during the experiment. Both activity monitors contain an omnidirectional piezoelectric accelerometer sampling movement at 32 Hz. Data collected with the Actical and Actiwatch (Mini Mitter Co., Inc., Bend, OR) correlated strongly with activity energy expenditure (AEE) and physical activity ratio (PAR) (Puyau et al., 2004) and the outputs from both accelerometers were also highly correlated ($r = 0.93$). As such, both activity monitors provide valid measures of AEE and PAR and can be used to discriminate sedentary, light, moderate and vigorous levels of physical activity.

2.4. Polysomnography and sleeping conditions

Sleep was recorded using the Siesta Portable electroencephalography (EEG) system (Compumedics, Melbourne, Victoria, Australia). A standard montage of electrodes was applied; two channels of EEG (C4-M1, C3-M2); left and right electro-oculograms (left outer canthus, right outer canthus); and two channels of chin electromyography. One and a half hours prior to bedtime each participant had polysomnography Grass^{TM} gold-cup electrodes (Astro-Med, Inc., West Warwick, RI) applied to their face and scalp. All sleep records were blinded and analyzed by a sleep technician in 30 second epochs in accordance with standard criteria (Iber et al., 2007). Participants slept in individual beds located in a single room. Signals from each portable siesta transmitted wirelessly to designated participant laptops located in a separate room monitored overnight by a sleep technician. Ten minutes prior to scheduled bedtimes all sleep and monitoring equipment was placed in position and participants made themselves comfortable prior to lights