ABSTRACT

Purpose: (i) To evaluate firefighters’ pre- and post-shift hydration status across two shifts of wildfire suppression work in hot weather conditions. (ii) To document firefighters’ fluid intake during and between two shifts of wildfire suppression work. (iii) To compare firefighters’ heart rate, activity, rating of perceived exertion (RPE), and core temperature across the two consecutive shifts of wildfire suppression work.

Method: Across two consecutive days, 12 salaried firefighters’ hydration status was measured immediately pre- and post-shift. Hydration status was also measured 2 h post-shift. RPE was also measured immediately post-shift on each day. Work activity, heart rate, and core temperature were logged continuously during each shift. Ten firefighters also manually recorded their food and fluid intake before, during, and after both fireground shifts.

Results: Firefighters were not euhydrated at all measurement points on Day one (292 ± 1 mOsm l⁻¹) and euhydrated across these same time points on Day two (289 ± 0.5 mOsm l⁻¹). Fluid consumption following firefighters’ shift on Day one (1792 ± 1134 ml) trended (P = 0.08) higher than Day two (1108 ± 1142 ml). Daily total fluid intake was not different (P = 0.27), averaging 6443 ± 1941 ml across both days. Core temperature and the time spent ≥ 70%HRmax were both elevated on Day one (when firefighters were not euhydrated). Firefighters’ work activity profile was not different between both days of work.

Conclusion: There was no difference in firefighters’ pre- to post-shift hydration within each shift, suggesting ad libitum drinking was at least sufficient to maintain pre-shift hydration status, even in hot conditions. Firefighters’ relative hypohydration on Day one (despite a slightly lower ambient temperature) may have been associated with elevations in core temperature, more time in the higher heart rate zones, and ‘post-shift’ RPE.

KEYWORDS: activity; firefighters; thermoregulation.

INTRODUCTION

Wildfire regularly ravages rural and regional areas in North and South America, Southern Europe, and Australia (Liu et al., 2010). To suppress these fires, salaried and volunteer firefighters can be required to work long (~ 12 h), often across multiple days...
North American researchers have documented firefighters’ work behaviour and selected physiological responses across 2–5 days (Ruby et al., 2002, 2003; Montain et al., 2008). In the main, the researchers have focussed on aggregate results across the work period, rather than shift-to-shift analyses. For instance, Ruby et al. (2003) found that firefighters’ total body water decreased significantly across the 5 days of a multiday fire deployment. The measures reported by these researchers could not show the changes in fluid balance between consecutive shifts, and since no other measures [e.g. heart rate, core temperature, worker activity, rating of perceived exertion (RPE)] were reported, the relationships between water loss, fluid consumption, work behaviour, and physiology over repeated days of fireground work could not be determined.

Documenting firefighters’ fluid intake (including that derived from food), work behaviour, and physiology across a multiday wildfire deployment has important health and resource implications for fire agencies. At present, many fire agencies prescribe fluid intake in an attempt to alleviate firefighter strain in response to a range of occupational stressors (CFS, 2008; Langridge et al., 2003). The evidence base for such prescriptions is, however, small, drawing more on sweat rates and fluid prescription guidelines from sport and occupations other than wildfire suppression work (Raines et al., 2009). The risk of this approach is that some firefighters may not be receiving sufficient fluid, and may therefore suffer the adverse effects associated with hypohydration [i.e. critical elevations in core temperature and heart rate, impaired decision making, etc; (Sawka and Greenleaf, 1992)]. Other personnel, who may strictly follow fluid intake prescriptions, over and above their own sensations of thirst, could be at risk of over-drinking; including collapse and, in extreme cases, death (Department of Army, 1997; Garigan and Ristedt, 1999). The available evidence shows that when firefighters had ad libitum access to water and carbohydrate–electrolyte beverages when working to suppress Australian wildfires, they completed their shift euhydrated, as measured by plasma osmolality (Raines et al., 2012). Euhydration refers to a normal state of body water content, the absence of absolute or relative hydration or dehydration (Dorland’s Illustrated Medical Dictionary, 1988). The data presented by Raines et al. (2012), however, was collected across temperatures that were, on average, considered mild to warm (15.8–26.4°C), rather than the high heat that can often accompany wildfires (Cuddy and Ruby, 2011). Given the relationships between hypohydration and high ambient temperatures in other contexts (Sawka and Montain, 2000), it is premature to conclude that ad libitum drinking is sufficient to maintain firefighters’ hydration during wildfire suppression in the heat. A more detailed analysis of fluid intake, particularly following firefighters’ work shifts, could also provide greater insight into common observations that firefighters are not euhydrated before they commence their fireground work. Across experimentally lit fires in Australia (Hendrie et al., 1997), and emergency fires in North America (Cuddy et al., 2008; Ruby et al., 2003) and Australia (Raines et al., 2012), firefighters’ pre-shift urinary and/or plasma measurements indicate that firefighters did not start their shift euhydrated. Similar findings have been reported in other physically demanding occupations, such as mining (Miller and Bates, 2007), construction (Bates et al., 2010), forestry (Biggs et al., 2011), and power station (Finn, 2010) operations. It is also not always clear from the published literature whether these pre-shift measures follow a night ‘at home’ or following a night ‘in camp’ between consecutive shifts. Analyses of hydration status post one shift and into the next is limited to the construction (Irwin et al., 2013) and mining (Carter and Muller, 2007) industries. These studies revealed that workers’ urine-specific gravity immediately post-shift ‘Day one’ to pre-shift ‘Day two’ was stable. The percentage of workers considered ‘hypohydrated’ varied between studies, which could reflect interstudy differences in environmental temperature, work demands, and/or organizational culture (Miller and Bates, 2010). Accordingly, it is difficult to determine whether findings from either manufacturing (Irwin et al., 2013) or mining (Carter and Muller, 2007) can be extrapolated to the wildfire context. To this end, the first aim of this study was to evaluate firefighters’ hydration levels pre-shift, immediately after working on the fireground, then 2 h post-shift, across 2 days of wildfire suppression work in hot weather conditions.
Whether or not fire agencies move to *ad libitum* fluid intake recommendations or continue to prescribe fluid intake ranges, they are still likely to provide their firefighters with access to fluid before, during, and after their fireground shifts. At present, there are no data on firefighters’ *ad libitum* fluid intake following a wildfire suppression shift and/or between consecutive shifts at a multiday wildfire. At present, the recommendations for firefighters regarding their fluid intake after their shift can be very broad (CFS, 2008), rather than based on dedicated analysis of existing behaviours or controlled experiments demonstrating the efficacy of a particular fluid type (e.g. water, carbohydrate–electrolyte drinks), timing or volume. *Ad libitum* fluid intake has been documented during wildfire suppression in mild to warm (15.8–26.4°C) weather conditions (Raines *et al.*, 2012), but not across and between successive days in hotter ambient temperatures. Therefore, the second aim of this study was to document firefighters’ fluid intake during and between two shifts of wildfire suppression work.

Understanding the interplay between fluid intake, hydration, and work physiology may have critical safety implications for firefighters (Cuddy and Ruby, 2011) and the communities they serve. At present, there has been no study in wildland firefighters to document measures such as heart rate, core temperature, hydration, work activity, and subjective measures of exertion in hot weather. The available evidence is in case-study form (Cuddy and Ruby, 2011), focuses on only one or two measures (e.g. heart rate or core temperature, Rodríguez-Marroyo *et al.*, 2011, 2012), or evaluates a specific intervention (Cuddy *et al.*, 2008). Although a wider range of work physiology measures (described above) have been recorded during consecutive shifts of construction work in hot weather (Bates and Schneider, 2008), the researchers did not formally evaluate shift-to-shift differences in workers’ physiology or behaviour. As an increasingly large number of wildfires require firefighters to deploy for multiple, consecutive shifts (Aisbett *et al.*, 2012), the third aim of this study was to compare firefighters’ work physiology and rating of RPE across repeated days of wildfire suppression work in the heat.

**METHODS**

Twelve male salaried wildfire firefighters participated in two consecutive days of live-fire prescribed operations in the Mallee forests of Ngarkat National Park, South Australia. Six firefighters were in each cohort, with both cohorts working on Days two and three of their 5-day working week. These two days were their first 2 days of firefighting. Prescribed burning refers to the controlled and application of fire to strategically reduce fire fuel hazards (DEWNR, 2013). Prescribed burn operations are common for these firefighters, whereas wildfires make up a smaller percentage of their season (Reisen *et al.*, 2011). Further, whilst these prescribed burns were not emergency wildfires, the forest was burnt under hot, dry conditions at the end of the fire season. All firefighters stated that they performed the same tasks for similar durations during this prescribed burn as they have previously at emergency wildfires: building rake-hoe containment lines, chasing spot-fires, applying water, and back-burning with drip torches. These tasks are consistent with those identified during a recent job inventory for Australian rural firefighters suppressing bushfires (Phillips *et al.*, 2012). Firefighters wore standard fire retardant personal protective clothing (jacket, pants, gloves, boots, goggles, and helmet), designed to shield the firefighter from environmental hazards and injury throughout the shift as per fire agency guidelines. Prior to testing, firefighters provided written informed consent and the study was approved by the Deakin University Human Ethics committee (EC 322-2007) prior to the start of all data collection.

**Overview of experimental procedures**

Before deploying on shift, firefighters provided blood samples and were fitted with research equipment (heart rate, core temperature sensors, and physical activity monitors) that recorded data throughout the shift. Firefighters were strongly encouraged to adopt normal work practices (including to eat and drink as much or as little as they desired), and to record all food and drink intakes in a booklet provided. Firefighters were then released for their firefighting shift. At the completion of the work shift (12 h), blood samples were provided at the burn-site. Two hours following their deployment (14 h), firefighters again provided blood samples for analysis. Between the 12- and 14-h data collection points firefighters drove from the burn-site to nearby accommodation, showered, ate and drank freely.

**Fluid consumption**

Fluid and food consumption data were recorded according to the methods of Raines *et al.* (2013). Briefly, firefighters were required to record the time,
quantity, and detailed ingredients of all fluid and food consumed. Fluid and food data recording began first thing in the morning (including any food and fluid consumed before reporting to the research station) and continued until the end of the second day. Firefighters were provided with a pictorial guide of common portion sizes to assist their data recording. Of note, however, firefighters who normally consume tea/coffee maintained their usual daily intake of caffeine via consumption of these beverages. As reported by Maughan and Griffin (2003), the level of caffeine consumed is unlikely to influence hydration status. Caffeine ingestion has also been shown to lower RPE responses (Kellawan et al., 2009). However, firefighters’ pre-shift caffeine consumption occurred ~ 12 h before their post-shift RPE were recorded, so it is unlikely to influence post-shift RPE measurements. Two participants did not complete their food diaries across both days of fire suppression in sufficient detail to be included in subsequent analyses. The dietary record data (n = 10) was entered into the Foodworks (v3.02) nutrient analysis software (Xyris Software Pty Ltd., Brisbane, Australia) incorporating nutrient tables for use in Australia (AUSNUT, Canberra, 2000). For this article, only the outcome measure of fluid intake (from both food and fluid sources) will be presented.

Hydration markers
Plasma osmolality was measured to identify acute changes in firefighter hydration status. Blood samples were collected from each firefighter immediately pre- and post-shift and at a further 2-h post-shift. The collection and analyses of these blood samples follows procedures outlined in Raines et al. (2013). Firefighters’ absolute and relative hydration levels were interpreted using a suite of guidelines. Namely, ≤ 290 mOsm l⁻¹ as ‘euhydrated’ (Sawka et al., 2007), ≥ 301 ± 5 mOsm l⁻¹ as ‘clinically dehydrated’ (Cheuvront et al., 2010a), and a change in successive plasma osmolality measures of between 5 and 13 mOsm l⁻¹ to signal an 80% (likely) to 99% (near certain) probability of meaningful change in hydration status (Cheuvront et al., 2011). Recently, there has been some debate about assessing dehydration and the reader is referred to Armstrong et al. (2013) and Cheuvront et al. (2013) for their alternative views.

Heart rate response
Heart rate was recorded every 5 s using Polar heart rate monitors (Polar RS800G3, Pursuit Performance, Adelaide, Australia). The heart rate monitor watch was attached to the wrist and the chest band fitted by the researcher. Data (n = 12) was downloaded via an IrDA port into the Polar ProTrainer software (version 5.10.120) at the conclusion of the firefighters’ shift. Thereafter, the raw heart rate data was visually inspected for artefacts. Typically these artefacts presented as immediate (i.e. within one 5-s sample) increases in heart rate to 237 beats min⁻¹ and ‘flat-line’ for a period, before returning immediately (again in one, 5-s sample) to a more typical, oscillating physiological pattern. Once an artefact was identified and verified by a coauthor, they were removed. Heart rate data was then expressed as a percentage of each firefighter’s age-predicted maximum (HRmax = 207—0.7 × age) using the formula developed by Gellish et al. (2007). This was undertaken to normalize cardiovascular responses to the individual firefighter from the large spread in age across this population. Age-related prediction of HRmax was preferred over direct measurement of HRmax to avoid furthering participant burden, which already included invasive measurements and detailed food and drink recording before, during and after long working hours in a real-world setting. Nonetheless, the small prediction error (Gellish et al., 2007) may slightly alter the absolute time spent at or above 70% HRmax. The time spent at or above 70% HRmax (Pollock et al., 1998) was then chosen as a focal point to capture the most demanding aspects of wildfire suppression work (Rodriguez-Marroyo et al., 2011, 2012). These studies (in Spanish wildland firefighters) were performed in very similar environmental temperatures to the current study.

Worker activity
Firefighters’ physical activity was collected and analysed as per the methods outlined by Raines et al. (2013). Briefly, firefighters wore an Actical Activity Monitor (MiniMitter, Bend, Oregon) mounted on the centre of the heart rate belt, positioning the device over the firefighters’ xiphoid process (Raines et al., 2013). Firefighters’ activity was expressed as absolute counts and time spent in sedentary (0–100 counts min⁻¹), light (101–1500 counts min⁻¹), and moderate (1501–5000 counts min⁻¹) activity zones (Heil,
2002). No time was spent in the vigorous activity zone (> 5000 count min⁻¹) so this zone was omitted as a category in this study.

Temperature measurement
Ambient temperature was measured at 10-min intervals from portable weather stations (MAWS, CSIRO, Australia) on the perimeter of the burn-site. These sites were the closest to the firefighters’ work locations the weather stations could be safely positioned. Firefighters ingested a core temperature capsule (Jonah® MiniMitter, Bend, Oregon) 1.5–2 h before their shift began. This period falls within the 0–6 h timeframe where some authors (Wilkinson et al., 2008) assert that temperature readings are more susceptible to variation. However, there is disagreement in the literature regarding the optimal duration before taking core temperature readings from ingestible capsules (Wilkinson et al., 2008; Domitrovich et al., 2010). With firefighters’ shifts starting as early as 6 am, the researchers did not wish to burden the participants with ingesting their capsules before 4 am, nor risk firefighters passing the capsule if they had consumed it the night before either shift. Further, as all ingested beverages were stored on vehicles without cooling, they were likely to be near ambient temperature and, as such, the authors reasoned that the purported effect of cold beverages (Wilkinson et al., 2008) on masking true ‘core’ readings was not likely to be a major confounder to the reported results. It should also be noted that the firefighters only had access to hot beverages before their shift, as no hot fluids were taken onto the fireground. Again, the authors reasoned that these fluids had little impact on core temperature measurements across the ~12-h work shift. A VitalSense Monitor (Vitalsense® MiniMitter, Bend, Oregon) was attached to the firefighters’ belt loop, which received the intra-abdominal core temperature results every 15 s with a precision of ±0.25°C (MiniMitter, Bend, Oregon).

Rating of Perceived Exertion
Prior to their first shift, firefighters were familiarised with a 6- to 20-point scale to measure their RPE (Borg, 1970). Thereafter, the firefighters reported their RPE immediately after each fireground shift across the two days. These post-shift RPE assessments asked firefighters to rate their exertion across their shift.

Statistical analyses
All descriptive statistics are presented as means ± standard deviations. All dependent variables were analysed for normal distribution using Kolmogorov–Smirnov tests. The data was collected in two different cohorts. To investigate whether the characteristics of these two cohorts were different, an initial analyses was completed for the major outcome variables. Once normal distribution was confirmed, three-way analyses of variance (ANOVA), with cohort as a between-participant factor and day (one or two), time (either 2-h intervals in-shift, or pre-, post-, 2-h post) as the repeated measures were performed for hydration status, worker activity, heart rate, and core temperature. Furthermore, cohort was also used as a between-participant factor in a two-way mixed ANOVA, with day as a repeated measure to investigate differences in shift length, total fluid intake, post-shift RPE and fluid intake between days, and the two testing cohorts. Cohort was not a significant main effect (P ≥ 0.131) nor was a part of a significant interaction with either day (P ≥ 0.508) or time (P ≥ 0.294) or day × time (P ≥ 0.662) across all variables. For brevity, the results refer to only the effects of day, time or day × time. Where the interaction between day × time was significant, then simple main effects analyses was used to identify where the differences lay. Alcohol intake over successive days was not normally distributed, which was not restored following natural logarithmic transformation and hence analysed using a Wilcoxin Signed-Rank test. All analyses were carried out using the Statistical Package for the Social Sciences (SPSS 18, IBM, New York) and P < 0.05 was accepted as statistically significant.

RESULTS

Firefighter characteristics
The firefighters were aged 29 ± 11 years, had a body mass of 83.8 ± 15.8 kg, stature of 1.8 ± 0.1 m and their body mass index was 25.9 ± 4.1 kg m⁻².

Shift conditions
Firefighters’ shift lengths on Day one (12.0 ± 2.6 h) were 15.0 ± 15.7 min longer (P < 0.01) than on Day two (11.8 ± 2.4 h). Ambient temperatures across the shifts were considered hot. Day one mean temperature was 30.9°C ± 3.6 (peak, 37°C) whilst Day two mean temperature was 32.8°C ± 5.7 (peak, 39°C). Across
the work shift, the temperature was 1.9 ± 4.1°C hotter ($P = 0.02$) on Day one than Day two.

**Fluid intake**
The total fluid intake (from both ingested food and fluid) was not different between Day one and Day two ($P = 0.27$), averaging 6443 ± 1941 ml (or 420 ± 132 ml h$^{-1}$) across both days. There was a trend ($P = 0.08$) that the post-shift fluid intake on Day one (1792 ± 1134 ml) was higher than Day two (1108 ± 1142 ml). Approximately 20% of firefighters’ fluid intake post-shift was consumed from alcoholic beverages (i.e. beer: 1376 ± 801 ml) where the alcohol content was 35.8 ± 35.8 g. There were no differences in firefighters’ alcoholic fluid consumption ($P = 0.51$) or alcohol content ($P = 0.53$) of this fluid following their work on Day one or Day two.

**Plasma osmolality**
There was no interaction for day × time ($P = 0.73$) or effect for time ($P = 0.99$). Plasma osmolality results revealed a main effect for day ($P = 0.01$), with firefighters’ plasma osmolality averaged across all measurement points on Day one (292 ± 1 mOsm l$^{-1}$) was 3.0 ± 0.9 mOsm l$^{-1}$ (0–4 mOsm l$^{-1}$ 95%CI) higher than at all measurement points (i.e. pre-shift, immediately post- and 2-h post-shift) on Day two (289 ± 0.5 mOsm l$^{-1}$; Fig. 1). On Day one, nine of 12 firefighters’ average plasma osmolality across Day one exceeded 290 mOsm l$^{-1}$, with one recording a plasma osmolality within one standard deviation of 301 ± 5 mOsm l$^{-1}$. On Day two, 7 of 12 firefighters’ average plasma osmolality was below 290 mOsm l$^{-1}$, and none came within one standard deviation of the 301 ± 5 mOsm l$^{-1}$. Four of the firefighters’ Days one to two change was ≥ 5 mOsm l$^{-1}$ and nine firefighters recorded lower plasma osmolality readings on Day two, compared to Day one.

**Heart rate**
There was a day × time interaction ($P < 0.01$) observed for the time firefighters spent at or above 70%HRmax. On Day one, firefighters spent 1.6 ± 0.4, 4.9 ± 0.6, and 8.4 ± 2.6 min longer in these higher heart rate zones between hours 4–6 ($P = 0.02$), 6–8 ($P = 0.05$), and 8–10 ($P = 0.04$) than during the same periods across Day two (Fig. 2). Across the shift, firefighters spent 22.4 ± 8.2 min of their shift with their heart rate above 70%HRmax on Day one, compared to 8.4 ± 4.1 min on Day two ($P = 0.04$)

**Activity**
There was no interaction ($P ≥ 0.90$), effect of time (in each 2-h period; $P ≥ 0.25$) or day ($P ≥ 0.87$) observed in the time spent in sedentary, light, or moderate activity zones.

**Thermoregulation**
There was no interaction for day × time ($P = 0.66$). There was a main effect for day, such that core temperature was 0.59 ± 0.03°C higher ($P < 0.01$) on Day one (37.25 ± 0.40°C) than Day two (36.66 ± 0.29°C). A main effect for time ($P < 0.01$) was also identified, with firefighters’ core temperature increasing across their shifts on
both days (Fig. 3). There were no differences in peak core temperature \((P = 0.49)\) across Day one \((37.47 \pm 0.71{}^\circ C)\) and Day two \((37.72 \pm 0.44{}^\circ C)\) on the fireground.

**Rating of perceived exertion**

Firefighters’ end-shift RPE (where they reflected on their exertion across their shift) on Day one \((15 \pm 3)\) was \(4 \pm 1\) units higher \((P < 0.01)\) than at the same time point on Day two \((11 \pm 4)\).

**DISCUSSION**

The aims of this study were to measure hydration status, fluid intake and work physiology (and RPE) across two consecutive day shifts of wildfire suppression in hot weather conditions. The major findings were that firefighters’ plasma osmolality was significantly higher at all measurement time-points on Day one compared to these same time points across Day two. Firefighters’ fluid intake averaged \(420 \pm 132\) ml h\(^{-1}\) per shift and did not differ across the two shifts of wildfire suppression work. Across the first shift, firefighters’ core temperatures were higher; they spent more time at or above 70%HRmax and recorded a higher end-shift RPE than for Day two. There were no differences in firefighters’ activity counts between the two shifts.

Plasma osmolality was significantly lower on Day two, compared to Day one (Fig. 1) but it is debatable if this change is biologically meaningful? The absolute

**Figure 2**  Time spent at or above 70%HRmax across 2 days of wildfire suppression work in hot weather. h; hours, HRmax; age-predicted heart rate maximum. Day one higher (*\(P < 0.05\)) than Day two.

**Figure 3**  Core temperature across 2 days of wildfire suppression work in hot weather. °C; degrees Celsius, h; hours. Main effect for time (*\(P < 0.01\)). Main effect for day (*\(P < 0.01\)).
Day one and Day two readings fall just above, and just below, respectively, the 290 mOsm l⁻¹ euhydration level published by the American College of Sports Medicine (Sawka et al., 2007). It cannot be determined how the Day one and Day two results relate to individual ‘baseline’ levels of plasma osmolality (the remote nature of this study prevented serial baseline measures of plasma osmolality pre data collection). Nevertheless, the majority of firefighters’ plasma osmolality results were above above 290 mOsm l⁻¹ on Day one and below this level on Day two. On balance, it is reasonable to label the firefighter group as ‘euhydration’ on Day two. However, the small (though significant) change score and relatively low (all participants ≤ 297 mOsm l⁻¹ on Day one) plasma osmolality results mean it is premature to categorise the group as ‘hypohydration’ on Day one. Instead, it would seem more appropriate to state that they were ‘not euhydrated’. To assist clinicians diagnose meaningful relative differences in hydration, Cheuvront et al. (2011) proposed a nonogram where a 5–13 mOsm l⁻¹ difference in plasma osmolality would signal an 80–99% probability of a real change in hydration status. In this study, the magnitude of the average ‘Day one’ to ‘Day two’ difference was less than 5 mOsm l⁻¹ indicating that this difference was not biologically significant. Four firefighters did, however, record a ≥ 5 mOsm l⁻¹ change (nine firefighters Day one plasma osmolality readings > than their Day two values). As debated recently by Armstrong et al. (2013) and Cheuvront et al. (2013) these dehydration cut-points do not preclude the possibility that some individuals may experience the potentially adverse consequences of dehydration with smaller changes in plasma osmolality. Accordingly, the remainder of this discussion will explore whether results for the other variables can further contextualise the biological meaning of the Day one to Day two change in plasma osmolality.

Firefighters’ in-shift fluid intake was not different between shifts, averaging 420 ± 132 ml h⁻¹. On the surface, this finding could suggest that the 3.0 ± 0.9 mOsm l⁻¹ Day one to Day two change in plasma osmolality was not meaningful since blood hypertonicity (and hypovolemia) is purported to cause an increased drive to drink (Greenleaf, 1992). It should be remembered, however, that on average, firefighters’ Day one plasma osmolality was marginally lower than the 295 mOsm l⁻¹ level proposed to stimulate thirst (Greenleaf, 1992). Interestingly, once firefighters stopped working, the post-shift fluid consumption on Day one trended higher (Day one minus Day two: 684 ± 194 ml h⁻¹; \(P = 0.08\)) than post-Day two. Adolph (1947), supported in a later review by Greenleaf (1992), proposed that physical activity decreased fluid intake, whilst leisure time facilitated drinking. It is possible, post-shift, when firefighters were not focussed on their suppression duties, their relative hyperosmolality (however marginal) at the end of shift one contributed, at least in part, to a higher consumption than when they were euhydrated on Day two (Fig. 1). Such conclusions need to be tempered given the finding did not quite reach statistical significance (\(P = 0.08\)). Nevertheless, assuming a larger post-shift fluid intake on Day one could also provide one plausible explanation for the euhydration status immediately pre-shift on Day two (Fig. 1).

A potentially greater fluid intake post-shift on Day one may also be attributed to location. This theory arises from contrasting firefighters’ plasma osmolality on Day one (when they were not euhydrated), after deploying from home against their pre-shift euhydration on Day two, after a night ‘in camp’. It is possible, that when in camp, away from family and domestic duties, the firefighters are able to focus on food and fluid intake to replenish after a day’s work, in preparation for the next day. This premise aligns with findings in truck and train drivers who reported they could afford more time to sleep between shifts when ‘on the road or rails’ than when at home where they preferentially engaged with their family (Jay et al., 2008; Darwent et al., 2008). It is also possible that peers or supervisors also positively influenced food and fluid consumption post-shift (Irwin et al., 2013). Investigation into post-work fluid consumption in miners (Carter and Muller, 2007) and manufacturing workers (Irwin et al., 2013) reveal that the type of fluid, including alcohol can influence fluid consumption. Whether these behaviours are further influenced by a workers’ environment, such as being at home or in camp, has not been investigated. The ensuing findings of such a study, however, could produce valuable outcomes for agencies striving to promote and preserve the health and safety of their workers deploying to local and remote incidents.

Despite small but statistically significant differences in hydration status across the two shifts (Fig. 1), there
was no difference in firefighters’ activity profile across shifts. It should be acknowledged, that whilst the firefighters’ responsibilities were the same across both days, that is suppress spot fires and curtail fire spread, it cannot be determined whether individual tasks were completed for the same durations across both days. However, there were no differences in the physical activity counts or ‘time spent’ in specific activity zones between the 2 days, providing further evidence of the similarity in work profile across the 2 days. This limitation notwithstanding, the stability of the firefighters’ activity pattern, despite the 3.0 ± 0.9 mOsm l−1 difference (main effect) in plasma osmolality is not surprising. Firstly, the level of hypohydration, estimated to be equivalent to 1–3% body mass (Popowski et al., 2001), is unlikely to be associated with suboptimal endurance performance (Goulet, 2011). Secondly, previous research by the current group has shown that firefighters’ physical activity across a wildfire suppression shift is not influenced by increasing fluid intake (and presumably hydration, though it could not be measured ‘in shift’) before (Raines et al., 2012) or during (Raines et al., 2013) a shift.

Before concluding that firefighters’ physical activity is not influenced by fluid balance within the range reported in the present study, it should be acknowledged that the ambient temperature on Day two was 1.9 ± 4.1°C hotter than Day one. Previous researchers have shown humans pace their physical activity in hotter conditions to preserve a level of comfort (see Cheung (2010) for review). However, it is not clear whether changes in work pace would occur with such small differences in temperature. So it is possible that the slight influence (if any) of relative hyperosmolality to reduce work rate on Day one was counterbalanced against a slight decrease (if any) in worker activity in the marginally hotter conditions on Day two. Firm conclusions on the relative impact of ambient temperature and hydration on self-paced physically demanding work (e.g. firefighting) are, however, premature. It is also worth acknowledging that ambient temperature for this study was recorded at the perimeter of the burn site, whereas firefighters also worked within the site. More rigorous experiments with tight control over independent factors and precise measurement of worker output (not always possible in the field) are required to further understand this area.

Across Day one, firefighters’ core temperatures (37.25 ± 0.40°C) were 0.59 ± 0.03°C hotter (P < 0.01) than across Day two (36.66 ± 0.29°C; Fig. 3). These mean values on Days one and two could be considered only mildly hyperthermic and normothermic, respectively (Taylor et al., 2008). The higher mean values appear to reflect an elevation of core temperature across the shift, rather than being increased by a peak period of core temperature. There was no difference in the peak core temperatures recorded on Days one or two. Firefighters’ higher core temperature on Day one occurred despite a 1.9 ± 4.1°C lower mean ambient temperature and no difference in physical activity. It is possible, therefore, that the higher core temperature was mediated, at least in part, by firefighters’ relative hyperosmolality on Day one (compared to Day two; Fig. 1). In a seminal review, Sawka (1992) presented that core temperature during exercise increased by 0.1–0.4°C for every 1% loss in body mass. This relationship is mediated through a reduction in heat dissipation through either a decrease or delayed onset of sweating for a given core temperature (Sawka and Greenleaf, 1992). In turn, the reduced sweating rate is thought to be mediated through increases in plasma osmolality (Sawka and Greenleaf, 1992). Though sweat rate was not measured in this study, it is possible that the firefighters’ relatively small but still significant hyperosmolality on Day one reduced their sweat rate, increasing heat storage and elevating core temperature despite marginally (though significant) cooler ambient temperatures. Indeed, the magnitude of the differences in plasma osmolality and core temperature observed in this study align with those purported in relationships proposed between plasma osmolality and body mass loss (Popowski et al., 2001), body mass loss and core temperature (Sawka, 1992), respectively.

The influence of firefighters’ relative hyperosmolality on Day one, though small, may also be implicated in their heart rate (Fig. 2) and whole shift RPE results. On Day one, firefighters spent ~15 min longer at or above 70% HRmax from 4 to 10 h (Fig. 2). Further, firefighters’ RPE (based on their perception of exertion across the whole shift) on their Day one shift was 4 ± 1 units higher (P = 0.01) than on Day two. Although these findings may be coincidental, the statistical significance of the Day one to Day two differences argues against random variation. Moreover, there is a plausible interplay between hydration
Hypohydration can lead to a decrease in blood volume, which in turn reduces stroke volume and results in a concomitant increase in heart rate to preserve cardiac output (Sawka and Greenleaf, 1992). A hypohydration-mediated increase in heart rate later in the day one shift could also materialise in the end-shift RPE results. As reviewed by Cheuvront et al. (2010b), cardiopulmonary factors, and in particular, heart rate makes a prominent contribution to RPE. As such, firefighters in this study may have recalled or still felt the additional exertion (as shown by the elevated heart rate) late in their Day one shift when completing their end-shift RPE questionnaire. It could also be argued that firefighters’ lower RPE on Day two reflects an attenuated stress response on Day two of stress exposure (Kirschbaum et al., 1995). Kim et al. (2010) have shown that workers’ stress response (morning cortisol) is elevated across the first 2 days of the working week. Although the present data comes from firefighters’ first and second day of firefighting, they had worked (e.g. office duties) the day before deploying. On balance, it seems unlikely that higher Day one end-shift RPE results observed in this study could be attributed to differences in morning stress levels (Kim et al., 2010) rather than the concomitant elevations in in-shift heart rate, core temperature and pre- and post-shift plasma osmolality results on Day one.

For fire agencies, the presented findings may have important implications in two areas. Firstly, the 420 ± 132 mL h⁻¹ fluid consumed is ~ 200 mL h⁻¹ higher than reported for wildfire fighters during a single shift in mild to warm weather (Raines et al., 2012). These values, together with those in previous literature (Cuddy et al., 2008) give agencies a guide on how much fluid they may need to provide firefighters in hotter or milder temperatures. The second implication for occupational health and safety personnel may be to encourage workers to pay attention to their fluid intake before they are deployed in hot temperatures. In this study, an increase in post-shift fluid intake (on Day one) was followed by firefighters starting their Day two shift euhydrated. Once on shift, ad libitum fluid intake appeared sufficient to maintain the firefighters’ hydration level across their shift, whether they started their day not euhydrated (Day one) or euhydrated (Day two). In this study being not euhydrated was accompanied by small, but significant elevations in core temperature, time spent in higher heart rate zones and RPE on Day one. Future research may like to explore the operational implications of these clustered observations, such as the impact on physical or cognitive task performance. This work may be best performed using a high-fidelity simulation where researchers could more precisely investigate cause and effect, which is not always possible in field-based studies.

The authors contend that the relevance of the current findings extends beyond prescribed burns and can be reasonably extrapolated to firefighters working to suppress wildland fire in temperatures above 30°C (peak 37–39°C). The experimental fire parameters were conceived by fire behaviour researchers, in concert with local fire authorities to study (i) wildfire behaviour and (ii) firefighter suppression tactics. Anecdotally, the firefighters’ in this study noted that their work profile (e.g. intensity, duration, type of tasks) was similar to their work suppressing emergency fires. Furthermore, the experiments were conducted late in the fire season, in hot weather, comparable to those reported by researchers studying firefighters’ physiology during emergency wildfires (Rodriguez-Marroyo et al., 2011, 2012). Whether the additional challenges of an emergency setting (e.g. emotional stress) significantly alters firefighters’ physiology, fluid consumption and work behaviour remains a question for future research. Further research may also investigate whether the responses reported in this study (age range: 18–44 years) are replicated in older firefighters as Australian volunteer crews can include members older than 70 years (Wolkow et al., 2014).

CONCLUSIONS
This study found that firefighters’ were not euhydrated at all measurement points on Day one, and euhydrated across Day two of consecutive wildfire suppression shifts in hot weather conditions. The relative hypohydration on Day one may have been associated with an increase in core temperature and time in the higher heart rate zones, despite no interday differences in physical activity and slightly lower (though still hot) ambient temperatures.

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