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Prescribed fluid consumption and its effects on the physiology and work behaviour of Australian wildland firefighters

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ABSTRACT
The present study examined firefighters’ ability to consume a prescribed fluid volume (1200 mL·h⁻¹) during a wildland fire suppression shift and compare the effect of this additional fluid prescription with self-paced drinking on firefighters’ hydration status and plasma sodium concentration post shift and their heart rate, core temperature and physical activity during their shift. Thirty-four firefighters were evenly divided into two drinking groups: self-paced and prescribed. Prescribed drinkers did not meet the required 1200 mL·h⁻¹ intake, yet they consumed twice the fluid drank by the self-paced group. No differences were noted between groups in plasma sodium levels or hydration status before or after their shift. Prescribed fluid consumption resulted in significantly lower core temperature between two and six hours into the shift. This did not coincide with lower cardiovascular strain, greater physical activity when compared to the self-paced drinking group. Additional fluid consumption (above self-paced intake) did not improve firefighter activity or physiological function (though it may buffer rising core temperature). It seems that wildland firefighters, at least in mild to warm weather conditions, can self-regulate their fluid consumption and work behaviour to leave the fireground hydrated at the conclusion of their shift.

Introduction
Wildland firefighters typically perform physically demanding work intermittently, for long hours, in hot environments, whilst wearing heat-retaining personal protective clothing (Cuddy et al. 2007). These factors, in isolation, are likely to challenge body water balance and when combined, increase the likelihood of dehydration through increased sweating (Hendrie et al. 1997).

In many sports and other physically demanding occupations, dehydration has been associated with increased cardiovascular strain (Sharkey 1999), reduced physical work capacity (Adolph 1947; Craig and Cummings 1966; Bosco et al. 1974; Houston et al. 1981; Webster et al. 1990; Coyle 2004) and elevated core temperature (Sharkey 1999), all of which can eventually lead to exhaustion or collapse (Pitts et al. 1944; Adolph 1947; Greenleaf and Castle 1971; Sawka et al. 1985). To try and reduce the occurrence of...
Jenni Raines et al.: Prescribed fluid consumption and its effects on the physiology and work behaviour of Australian wildland firefighters

dehydration and associated health and safety risks, fire agencies in Australia and elsewhere around the world prescribe target drinking rates for their firefighters to follow whilst suppressing wildland fire (CFS 2008). However, research suggests that doing so could be unnecessary, at least in mild weather, where self-paced drinking is sufficient to keep hydrated in such conditions (Raines et al.).

Considerable variability exists in the target fluid volumes prescribed by Australian fire agencies, ranging from 500 to 3000 mL·h⁻¹ per firefighter across a twelve-hour fireground shift (Raines et al. 2009). To the authors’ knowledge, there is no data on firefighters’ compliance in following their agency’s fluid intake guidelines. Literature exploring compliance to fluid intake recommendations in other physically demanding occupations is also lacking. Research in dialysis patients indicates that adherence to fluid intake recommendations can be as low as 24% (Gilbert et al. 1994). Therefore, the first aim of this study was to examine the firefighters’ ability to consume the prescribed target fluid volumes during an emergency wildland fire suppression shift.

The consequences of the fluid volumes recommended by fire agencies on health and performance are currently unknown. Consuming too much fluid during physical work however, can have profound health risks (Sawka and Noakes 2007). Over-drinking and the resultant hyponatremia has been implicated in the death of otherwise healthy individuals (Department of Army 1997, 1999; Garigan and Ristedt 1999; Speedy et al. 2000; O’Brien et al. 2001; Farrell and Bower 2003; Noakes 2003; Noakes 2004; Almond et al. 2005; Hew 2005; Noakes and Speedy 2006; Sawka and Noakes 2007; Gardner 2002). In contrast, Wästerlund et al (2004) reported superior productivity in forestry workers when they consumed 1200 mL·h⁻¹ as opposed to 291 mL·h⁻¹ of water across their shift. Montain and Coyle (1992) found that cyclists consuming 1200 mL·h⁻¹ of carbohydrate-electrolyte beverage during two hours of laboratory-based cycling had a lower heart rate, rectal temperature and a preserved stroke volume when compared with those who consumed 300 mL·h⁻¹ or no fluid during the same exercise task, under the same environmental conditions. To explore whether these findings translate to the wildland fire suppression environment, the second aim of the study was to compare the effect of a 1200 mL·h⁻¹ fluid intake target with self-paced drinking on firefighters’ hydration status and plasma sodium concentration post shift and their heart rate, core temperature and physical activity across their fireground shift.

Methods
Thirty four firefighters (32 male, two female) deployed to emergency wildland fire suppression deployments were allocated to one of two experimental groups; self-paced firefighters self-selected the volume and timing of water or sports drink ingestion and prescribed target firefighters were instructed to consume 600 mL of water and 600 mL of sports drink each hour of their shift. The rate of drinking for the prescribed group was encouraged but not enforced. Each firefighter was matched to a partner from the other drinking group during deployment to ensure that each group experienced the same work and environmental conditions. They were instructed to adhere to normal work practices and reminded to eat as much or as little as they desired throughout the shift.

Over the course of each firefighters’ day, the time, quantity and detailed ingredients of food and drink consumed was recorded. Plasma osmolality (P_{osm}) and plasma sodium

Jenni Raines et al.: Prescribed fluid consumption and its effects on the physiology and work behaviour of Australian wildland firefighters

concentration were measured from venous blood samples, before and after each shift to identify acute changes in hydration status. During the shift, firefighters recorded the time and volume of urine produced using a 1.0-L measuring jug. Heart rate (HR) was recorded every five seconds (Polar HR monitor, Polar RS800G3, Pursuit Performance, Australia) and physical activity (Actical Activity Monitor, MiniMitter, Bend, Oregon) was recorded throughout the shift. Lastly, firefighters ingested a core temperature capsule prior to deploying on shift, to attain measurement of intra-abdominal temperature every 15 seconds via a VitalSense monitor (VitalSense™ MiniMitter, Bend Oregon) attached to the firefighters’ belt loop.

Statistical analyses
Pairwise comparisons of the two groups’ personal characteristics was performed using independent t-tests following confirmation that the data was normally distributed. Data was analysed using a mixed analysis of variance with group and time and the between and within subject factors, respectively. When a significant difference was observed, post-hoc analyses were performed using pairwise comparisons with Bonferroni correction. Significance was assumed at p ≤ 0.05.

Results
There were no differences between the drinking groups in regard to age (p = 0.24), body mass (p = 0.78), body mass index (BMI; p = 0.94), the duration of the shift (p = 0.44) or the ambient temperature on shift (p > 0.05).

Fluid Intake and Urinary Output
Firefighters chose to consume greater volumes of water than sports drink per hour, as opposed to sports drink and over the entire shift (Figure 1A, B, C; p < 0.01), despite prescribed drinkers being instructed to consume equal amounts of both beverages. Although they drank more (p < 0.01) fluid per hour (532 ± 232 mL·h⁻¹) than self-paced drinkers (218 ± 198 mL·h⁻¹), the prescribed drinkers did not consume their target intake of 1200 mL·h⁻¹. Urine output was significantly higher (p < 0.01) for the prescribed drinkers (3.6 ± 2.7 L) compared to the self-paced drinkers (1.6 ± 1.0 L) throughout the fire suppression shift.

Hydration Status
Plasma sodium values decreased over time (p < 0.01) from 141.4 ± 1.8 mmol·L⁻¹ before the shift to 140.3 ± 1.5 mmol·L⁻¹ after the shift. All firefighters were classified within the normal sodium range, pre- and post-shift, with no main effect for effect of drinking condition (p = 0.72) or interaction between drinking condition and time (p = 0.12). Plasma osmolality results also showed no main effect for drinking condition (p = 0.37) or interaction between drinking condition and time (p = 0.89). Firefighters in both drinking groups arrived to their shift dehydrated however post-shift, $P_{osm}$ was reduced (p < 0.01) to achieve adequate hydration (Figure 2).
**Heart Rate Response and Thermoregulation**

Despite the different volumes of fluid ingested, the time firefighters spent in hard heart rate zones (70 - 89\% of age-predicted heart rate maximum (Gellish et al. 2007)) was not different ($p = 0.83$) between the drinking groups. Across both groups, firefighters spent $2.6 \pm 5.4$ min and $4.4 \pm 9.9$ min of each two-hour period, respectively, in hard heart rate zone. Self-paced drinkers displayed higher core temperatures than the prescribed drinkers, at 2-4 h ($p < 0.01$) and 4-6 h ($p < 0.05$) into the shift (Figure 3).

**Physical Activity**

Self-selected physical activity over the work day was not different ($p = 0.22$) between drinking groups. Additionally, there was no difference ($p = 0.78$) in the breakdown of time spent at each work intensities between drinking groups. Across both groups, firefighters spent $3.2 \pm 5.8$ min, $40.1 \pm 22.5$ min, and $68.8 \pm 24.5$ min in the moderate, light, and sedentary activity zones, respectively, per two-hour period.

**Discussion**

The results of this study show that firefighters in the prescribed fluid consumption group were unable to meet the required 1200 mL·h$^{-1}$ volume. The effect of fluid intake on hydration and plasma sodium were not different between groups, with both groups achieving adequate hydration and maintaining normal sodium levels at the conclusion of their shift. The two drinking groups spent similar amounts of time in the hard heart and intense activity zones across their shift. Core temperatures were lower in the prescribed group compared to the self-paced drinking group during the first six hours of the emergency shift.

Reasons for firefighters' low compliance to prescribed drinking targets include both behavioural (Mateos Campos and Camacho Alvarez 1997; Shenolkar et al. 2006) or physiological (Costill et al. 1970; Noakes 2007) mechanisms. For instance, gastrointestinal discomfort with larger volumes may prompt firefighters to slow their fluid consumption. The voluntary reduction in drinking volume, coupled with normal plasma sodium levels is further evidence that humans, when not forced to drink, will self-select volumes that minimise the risk of developing critically low sodium levels (i.e., hyponatremia, (Noakes 2007)).

Firefighters in the prescribed drinking group were also non-compliant towards the type of beverage prescribed. Both groups chose to consume greater volumes of water than sports drink, which is a contrast to previous work which showed that industrial workers who perform prolonged periods of work at low metabolic rates found electrolyte-carbohydrate sports drinks more palatable than water even though they consumed the same volume of each fluid (Clapp et al. 1999). Thus, prescribing only one beverage type is unlikely to be accepted and practiced by firefighters as it appears their own preference overrides their desire to follow recommendations.

Blood markers of hydration show that firefighters from both drinking conditions arrived to their shift in a dehydrated state, however both groups became adequately hydrated upon completion of their shift. These results confirm earlier findings results by our group (Raines et at.). Probable reasons which may have enabled firefighters to achieve adequate hydration post-shift include: i) the intermittent work profile which allowed for breaks to drink; ii) the mild-warm weather conditions which may have reduced the fluid lost in sweat.
Jenni Raines et al.: Prescribed fluid consumption and its effects on the physiology and work behaviour of Australian wildland firefighters

compared to work in hotter weather; iii) fire agencies providing free access to food and drink at staging areas and iv) fire agency education on the importance of regular fluid consumption.

The current study demonstrated that ingesting a greater fluid volume than consumed through self-paced drinking did not increase physical activity during emergency wildland fire suppression. This is supported by a number of laboratory exercise studies that showed no differences in performance markers when self-paced fluid consumption was compared to higher enforced rates of fluid intake in a number of activities including treadmill running ‘as far as possible in 30 min’ (Daries et al. 2000), time trial cycling (Backx et al. 2003) or cycling until exhaustion (McConell et al. 1997).

Firefighters in the prescribed fluid consumption group displayed slower rises in core temperature. This could possibly been aided by the greater fluid volumes consumed acting as a heat sink, thereby buffering the rise in core temperature. These differences in core temperature were observed two to six hours into firefighters’ shift. Though the core temperature differences here could be interpreted to represent a measurement artefact of the larger fluid volume (Wilkinson 2008), we’ve previously shown (albeit in a small sample) that excessive fluid at ambient temperatures does not lower core temperature in rural firefighters (Raines et al.). If core temperature was truly lowered, the firefighters in the prescribed fluid consumption group did not choose to perform more physical work. The wildland fire suppression environment could therefore represent a fundamental difference to sporting contexts where physiological benefits transfer to higher work rates in pursuit of optimal performance. In emergency responses, it is highly possible that workers pace themselves for the whole shift leaving some reserves in case of sudden urgency, and don’t transiently increase their work rate (unless they have to) even when physiologically able to do so.

In conclusion, the current findings show that additional, prescribed fluid consumption does not convey improvements in firefighters’ sodium balance, hydration status, cardiovascular strain or physical activity when fighting wildland fire. It seems that when firefighters have free access to food and fluid, they are able to self-regulate their fluid consumption behaviour and physical activity to leave the fireground adequately hydrated, at least in mild to warm weather conditions.

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References

Jenni Raines et al.: Prescribed fluid consumption and its effects on the physiology and work behaviour of Australian wildland firefighters


Jenni Raines et al.: Prescribed fluid consumption and its effects on the physiology and work behaviour of Australian wildland firefighters


Noakes TD, (2007) Drinking guidelines for exercise: What evidence is there that athletes should drink "as much as tolerable", "to replace the weight lost during exercise" or "ad libitum"? *Journal of Sports Sciences* 25, 781-796.


Jenni Raines et al.: Prescribed fluid consumption and its effects on the physiology and work behaviour of Australian wildland firefighters


Jenni Raines et al.: Prescribed fluid consumption and its effects on the physiology and work behaviour of Australian wildland firefighters

Figure 1. A) Fluid consumption over the entire shift, B) beverage choice during wildland fire suppression, C) average fluid consumption per hour of the wildland fire suppression shift.

Data presented are means ± standard deviation (n= 16 Self-paced, n= 14 Prescribed) Effect of time *** p < 0.01, effect of beverage type ** p < 0.01, effect of drinking condition ^^^ p < 0.01. Dotted line in A) denotes prescribed fluid target (2.4 L per two-hour period).
Jenni Raines et al.: Prescribed fluid consumption and its effects on the physiology and work behaviour of Australian wildland firefighters

Figure 2. Plasma osmolality before and after wildland fire suppression:

Data presented are means ± standard deviation (n=16 Self-paced, n= 17 Prescribed pre-shift and n=16 AD, n=12 PR post-shift). ### p < 0.01, effect of time.

Figure 3: Average core temperature response over time.

Data presented are means ± standard deviation (n= 5 Self-paced, n= 6 Prescribed). ** p < 0.01, * p < 0.05, effect of drinking condition.