



Original Research

No Impact of Heat Stress and Dehydration on Short Duration Simulated Motor-Racing Performance

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ABSTRACT

International Journal of Exercise Science 12(6): 960-970, 2019. Motor-racing drivers are often exposed to hot environments and may be susceptible to fluid loss and hydration issues, which could influence driving performance. This study assessed the effect of dehydration and heat stress on performance during a short, simulated motor-racing task. Nine healthy males (age: 26.6 ± 7.5 y, body mass: 78.8 ± 12.5 kg, mean \pm SD) completed two passive dehydration (sauna) procedures (targeting -1% and -3% body mass loss (BML)) on separate occasions. Driving performance was assessed pre-dehydration (Baseline), immediately post-dehydration (Hot) and following a cooling period (Cool). Measures of driving performance included lap time and sector-time for one section of the track. Subjective ratings of mood, thermal stress and comfort were also collected during trials. Mean lap times were not different between Baseline, Hot, Cool conditions for both 1% (68.44 ± 1.43 s, 68.06 ± 1.17 s, 68.23 ± 1.25 s) and 3% (68.33 ± 1.68 s, 68.01 ± 1.15 s, 68.06 ± 1.26 s) trials respectively. In addition, mean sector times were not different between Baseline, Hot, Cool conditions for both 1% (11.61 ± 0.28 s, 11.55 ± 0.45 s, 11.59 ± 0.35 s) and 3% (11.49 ± 0.33 s, 11.56 ± 0.33 s, 11.63 ± 0.71 s) trials respectively. Changes in participants' subjective ratings (i.e. decreased alertness, concentration and comfort; increased tiredness and light-headedness) were observed at both levels of dehydration (1% and 3% BML), irrespective of heat stress. Thus, fluid loss and heat stress are unlikely to affect driver's motor-racing performance during short duration events. However, the impact of dehydration and heat stress on tasks of longer duration that accurately represent the demands associated with motor-racing requires further consideration.

KEY WORDS: Driving, Cognition, Hypohydration, Fluid loss

INTRODUCTION

The safe and successful operation of a high-speed motor vehicle requires substantial cognitive processing (e.g. attention, concentration, decision making). Despite the obvious role drivers have in vehicle control, there is limited available empirical evidence on the physiological and psychological stresses experienced during motor-racing (23).

Motor-racing drivers are often exposed to hot environmental conditions (high ambient and cabin temperatures) whilst wearing protective race garments, the combination of which has been demonstrated to result in drivers experiencing fluid loss > 1 liter \cdot hour⁻¹ (2, 3, 8). Whilst evidence exploring the effect of fluid loss or dehydration on motor-racing performance is

limited, the effects of dehydration on discrete cognitive tasks have been summarized in a number of reviews (9, 18). Typically these studies indicate a detectable decline in cognitive performance tasks (e.g., reaction time, accuracy and depth perception) when fluid losses are equivalent to 2% body mass loss (BML), particularly when a concurrent heat stress is present (9, 18). However, the specific cognitive domains most affected by dehydration and whether these translate to real world application such as driving a motor vehicle have been highlighted as important considerations for future hydration research (19, 20).

To date, few studies have explored the impact of dehydration on driving performance, with a variety of measures used to define performance changes (e.g., lap times, lane drifting and contact points with other objects) (26, 27). A recent paper by Watson et al. (27) demonstrated a progressive decline in driver performance during a monotonous highway driving task performed whilst hypohydrated. Given the contextual differences associated with commuter style driving, the applicability of these findings to motor-racing is limited. More specifically, Walker et al. (26) explored the impact of two common problems experienced by motor-racing drivers (heat and exposure to high concentrations of carbon monoxide). Results of this study indicated a combination of heat and carbon monoxide exposure (~1.9% BML) produced an increase in driver errors (increased contact points), but no effect on average lap times, in comparison to heat exposure alone (~1.3% BML) or during cool conditions (~0.4% BML) (26). Whilst the authors attributed performance decrement to the combination of carbon monoxide and heat, the variation in fluid loss between the two heat trials (unable to be explained by the authors) may offer an alternative explanation for the difference in performance outcomes. In addition, the protocol employed by Walker and colleagues (26) makes the interpretation of the findings more challenging. Participants in this study undertook a short period of exercise (~15 min) prior to commencing the driving task. Evidence suggests that exercise has the potential to facilitate improvements in cognitive function (4). Hence, the influence of dehydration induced by passive heat exposure on driving performance, with and without concurrent heat strain, is poorly understood. Understanding the impact of dehydration on driving performance is important for the safety of motor-racing drivers.

Therefore, the aim of this study was to assess the impact of mild (1% BML) and moderate (3% BML) levels of dehydration induced by passive heat exposure on simulated driving performance. It was hypothesized that deterioration in driving performance would not be observed following heat exposure inducing mild fluid loss, irrespective of concurrent heat strain. However, a moderate level of dehydration would cause decrements in driving performance, irrespective of concurrent heat strain.

METHODS

Participants

Nine healthy males (age: 26.6 ± 7.5 y, body mass (BM): 78.8 ± 12.5 kg, BMI: 24.4 ± 3.3 kg · m⁻²; mean ± SD) participated in this study. For inclusion in this study, participants must have taken part in a previous investigation determining the sensitivity and reliability of measures of driver performance in simulated motor-racing (16). In addition, participants had to have met specific

performance criteria outlined in the previous study (i.e. produced mean lap times (LT) of ≤ 70.00 s).

Protocol

Each participant attended the laboratory on two occasions to complete trials involving 1% and 3% BML. Trials were administered in a randomized, crossover design and were separated by a minimum of seven days. Following an initial Baseline drive, participants undertook a dehydration protocol that involved passive fluid loss via exposure to a heated environment using a portable sauna. On exiting the sauna, Hot and Cool measures of driving performance were examined (Figure 1).

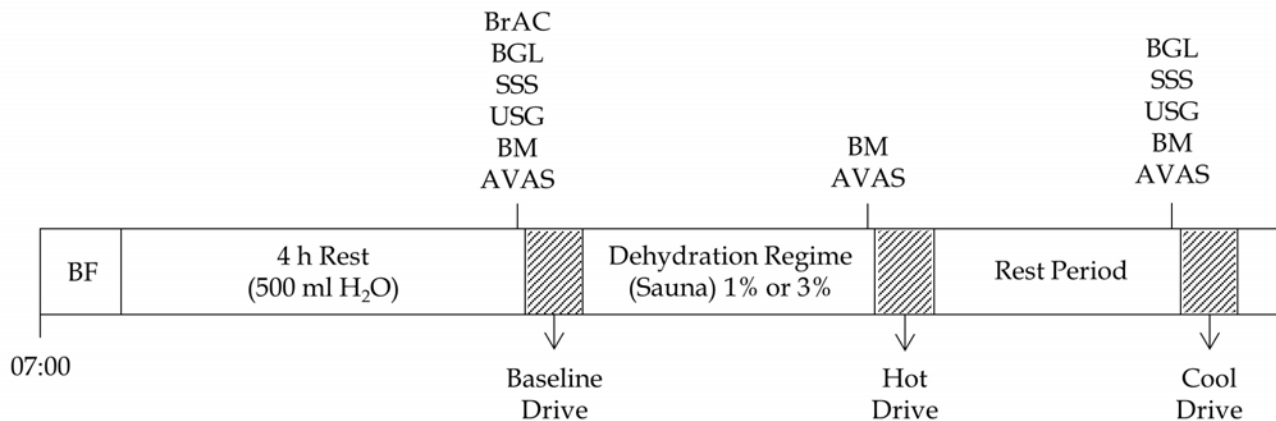


Figure 1: Study experimental design. BF, Breakfast; AVAS, Adaptive visual analog scales; BM, Body mass; BrAC, Breath alcohol concentration; BGL, Blood glucose level; USG, Urine specific gravity; SSS, Stanford sleepiness scale.

The simulated driving task was identical to that completed in a previous investigation indicating sensitive and reliable performance measures of simulated motor-racing (16). The driving task was completed using hardware and software components (SCANeR studio simulation engine, v1.2r95, OKTAL, Paris, France) that have been previously described (15). Briefly, the task involved driving 5 laps of a simulated racetrack (~2.3 km), which took about ~5 min to complete. Participants were instructed to drive in a competitive manner (i.e. as fast as possible within the confines of the circuit). Lap time (LT) and sector time (ST) for a dedicated section of the track were recorded each lap. These measures were identified as sensitive and reliable in the previous investigation (16). During each drive, participants wore a full-face motorcycle helmet (Arai, Saitama, Japan) and their normal clothing (i.e. shoes, t-shirt etc.). During the Hot drive, participants also wore a non-breathable suit (Kimberly-Clark Inc., USA) over their clothing.

Participants were instructed to abstain from alcohol for 24 h, and caffeine-containing substances and moderate-strenuous exercise for 12 h prior to experimental trials. During the 12 h period immediately preceding the trial, participants were asked to follow a set fluid regime to assist with maintaining hydration status. The fluid regime involved consuming 1000 ml of water between 1900-2000 h.

Participants arrived at the laboratory at the same time for each trial (~0700 h) following an overnight fast. On arrival, participants were screened for breath alcohol and verbally confirmed compliance with pre-trial standardization procedures. Once compliance was confirmed participants were given a standardized breakfast (~40 kJ · kg⁻¹ BM and ~2 g · kg⁻¹ BM carbohydrate), which consisted of fruit bread, jam, Powerbar® and sports drink. All dietary preparation and analysis was performed using FoodWorks dietary analysis software (Xyris Software, Brisbane, Australia). With breakfast, participants also consumed a telemetric core temperature pill (HQ Inc., Palmetto, FL, USA) to allow monitoring of core body temperature for the remainder of the trial. Following breakfast, participants rested in a quiet environment for 4 h to allow adequate time for the core temperature pill to pass into the small bowel as per the manufacturer's recommendations. During this time, participants consumed ~500 ml of water and a muesli bar (2 h prior to Baseline drive).

Approximately 20 min prior to the Baseline drive, participants provided a urine sample to determine urine specific gravity (USG; UG-α, Atago Co. Ltd, Japan). A finger prick blood sample was then collected (Accu-Chek Performa II, Sydney, Australia) to measure BGL to ensure participants were not in a hypoglycemic state when performing the driving task. A baseline core temperature reading was also taken. Participants' then voided their bladder prior to providing a baseline nude BM measurement (HV-G Platform Scales, A&D Company Ltd., Tokyo, Japan). Participants' then rated their level of sleepiness using the Stanford Sleepiness Scale (SSS) (25) and completed a series of adaptive visual analog scales (AVAS) to assess participants' feelings of thermal sensation, level of comfort, light-headedness, concentration, alertness and tiredness before commencing the first of three simulated drives (Baseline). The perceptual scales were administered on the screen of a desktop computer using the AVAS software program (21). Participants were asked to indicate on a 100 mm line for each descriptor how they felt at that moment with the left and right anchors indicated as "Not at All" and "Very Much" respectively. The scales employed were adapted from previous research investigating the effects of hydration on mood/cognition (13, 14) and exploring use of visual analog scales for assessment of thermal sensations (17).

Following the Baseline drive, participants commenced the passive dehydration regime. This required sitting in a portable sauna until a desired BML was achieved. The dehydration protocol involved an initial 20 min interval in the sauna at ~70.0 °C, followed by a ~5 min rest period outside of the sauna. During the break periods, nude BM and core temperature were recorded to measure progressive fluid loss and ensure the safety of participants. This was followed by repeat intervals of 10 min in the sauna and 5 min breaks. Target BML was 0.8% for the 1% trial and 2.8% for the 3% trial; to account for expected additional fluid loss via sweat once removed from the sauna. Sauna time was capped at maximum of 120 min.

Once the desired BML was achieved participants were then fitted in a non-breathable suit (Kimberly-Clark Inc., USA) and racing helmet, to minimize radiant heat loss while travelling from the sauna to the driving simulator (~2 min travel time). Core temperature readings were recorded prior to commencing the second drive (Hot). On completion of the Hot drive participants were instructed to have a cool shower before resting in a thermo-neutral

environment until their core body temperature had returned to baseline or after 60 min, whichever occurred first. Prior to commencing the final drive, participants provided a urine sample to retest USG. A finger prick blood sample was also collected at this time to determine BGL and a core temperature reading was recorded. The participant then completed the final drive (Cool). A final measure of nude BM was taken to establish total body fluid-loss. Directly prior to commencing the Hot and Cool drives, participants repeated the visual analog scales to rate their alertness, concentration, tiredness, light-headedness, comfort and thermal stress.

Statistical Analysis

All statistical analyses were completed using SPSS Statistics for Windows, Version 22.0 (SPSS Inc, USA). Mean LT and mean ST were calculated using laps 2-5. Lap one data was omitted to account for the proximity of the starting position to corner one (vehicle unable to reach maximum speed). All measures were examined for normality using the Shapiro-Wilko test prior to subsequent analysis. One-way repeated measures analysis of variance (ANOVA) were used to determine differences between conditions (Baseline, Hot and Cool) for mean LT and mean ST. Where a significant interaction was identified, pair-wise comparisons (applying Bonferroni correction for multiple comparisons) were used on any significant F values. All other measures (e.g. physiological measures and BM changes) were also analyzed by one-way repeated measures ANOVA and pairwise comparisons (Bonferroni) performed where significant main effects were present. Differences were considered significant at $p < 0.05$.

RESULTS

Table 1 provides a summary of fluid loss, USG and BGL for all 9 participants. Mean values for USG indicated participants were not hypohydrated prior to commencing the dehydration protocol for both the 1% and 3% BML trials. Participants displayed significantly higher readings of USG post dehydration for both the 1% ($p < 0.001$) and 3% ($p < 0.001$) BML trials. Mean values for BGL remained within normal ranges (4.0-7.8 mmol/L) (12) and did not significantly differ between pre and post dehydration.

Table 1. Body mass loss, urine specific gravity and blood glucose levels associated with dehydration protocols targeting 1% and 3% BML ($n = 9$).

Variable	BML (%)	USG		BGL (mmol/L)	
		Pre-Dehydration	Post-Dehydration	Pre-Dehydration	Post-Dehydration
1% BML	1.24 (0.16)	1.006 (0.004)	1.022 (0.004) ^b	5.9 (0.6)	5.5 (0.5)
3% BML	2.87 (0.34) ^a	1.009 (0.007)	1.026 (0.005) ^b	6.0 (0.6)	5.7 (0.4)

Note: BML, Body Mass Loss; USG, Urine Specific Gravity. ^aSignificant difference ($p < 0.001$) compared to 1% BM loss trial. ^bSignificant difference during 1% & 3% BML trials ($p < 0.001$) compared to pre-dehydration values. Values are mean (SD).

Table 2 provides a summary of core temperature measures documented at Baseline and prior to Hot and Cool drives. Core temperature increased significantly from Baseline in the Hot condition for both 1% ($p = 0.005$) and 3% BML trials ($p = 0.001$). There was no difference in core

temperature between Baseline and Cool conditions in both the 1% ($p = 0.612$) and 3% ($p = 0.601$) BML trials.

Table 2. Core temperature (°C) readings associated with dehydration protocols targeting 1% and 3% BML ($n = 9$).

Variable	Time of Testing		
	Baseline	Hot	Cool
1% BML	37.26 (0.69)	38.60 (0.55) ^a	37.31 (0.75)
3% BML	37.39 (0.41)	38.37 (0.46) ^a	37.76 (0.32) ^b

Note: BML, Body Mass Loss. ^aSignificant difference in core temperature during 1% ($p = 0.005$) and 3% ($p = 0.001$) BML trials compared to Baseline. ^bSignificant difference in core temperature during 3% ($p = 0.014$) BML trials compared to Hot condition. Values are mean (SD).

Table 3 summarizes driving performance measures for Baseline, Hot and Cool conditions in the two dehydration trials. No significant main effects were observed for any of the performance measures throughout either the 1% or 3% BML trials (all p values > 0.05).

Table 3. Driving performance measures for Baseline, Hot and Cool conditions in 1% and 3% BML trials.

Variable	Time of Testing			F (2,7)	p-value
	Baseline	Hot	Cool		
1% BML					
LT (s)	68.44 (1.43)	68.05 (1.16)	68.29 (1.25)	3.313	0.097
ST (s)	11.60 (0.28)	11.55 (0.45)	11.58 (0.35)	0.136	0.870
3% BML					
LT (s)	68.33 (1.68)	68.06 (1.15)	68.06 (1.26)	0.315	0.739
ST (s)	11.49 (0.33)	11.55 (0.33)	11.62 (0.71)	0.638	0.556

Note: BML, Body Mass Loss; LT, Lap Time; ST, Sector Time. Values are mean (SD).

Figure 2 displays the mean AVAS ratings prior to commencing each drive (Baseline, Hot, Cool). Feelings of thermal stress increased significantly from Baseline to Hot conditions in both the 1% and 3% BML trials ($p = 0.001$), however there was no difference between Baseline and Cool conditions for both the 1% ($p = 0.445$) and 3% ($p = 0.651$) BML trials. Participant's feelings of concentration, alertness and comfort significantly decreased from Baseline to Hot conditions and Baseline to Cool conditions ($p < 0.05$) for both levels of dehydration. Feelings of tiredness and light-headedness increased significantly from Baseline to Hot conditions and Baseline to Cool conditions ($p < 0.05$) for both trials. No significant differences were observed for comparisons between 1% and 3% BML trials at any of the time points (Baseline, Hot and Cool) for any of the subjective ratings.

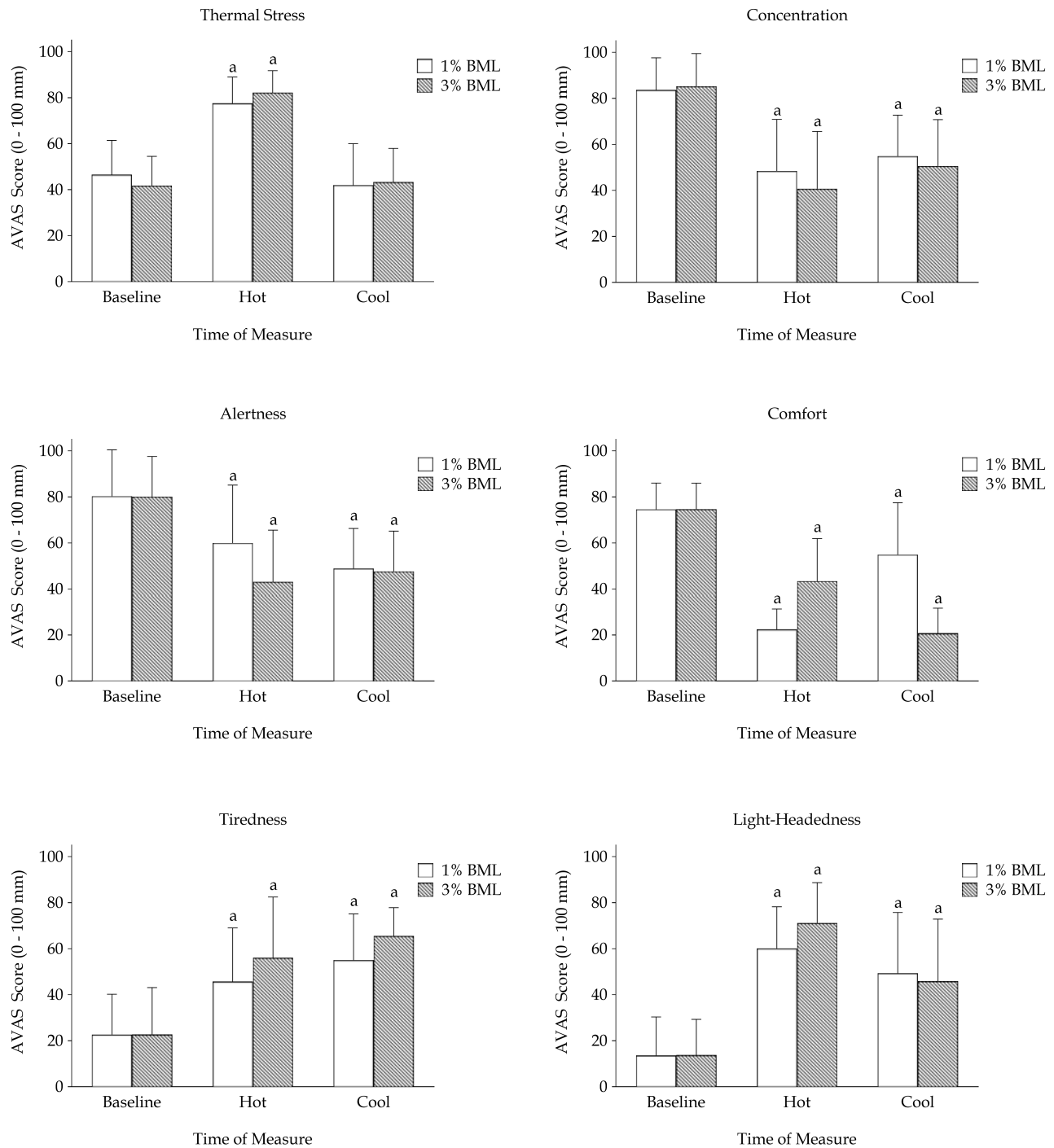


Figure 2. Adaptive visual analog scale (AVAS) results for ratings of thermal stress, concentration, alertness, comfort, tiredness and light-headedness. BML, Body Mass Loss. ^aSignificant difference compared to Baseline ($p < 0.05$). Bars indicate mean values; error bars are standard deviation.

DISCUSSION

This study examined the impact of mild (1% BML) and moderate (3% BML) levels of dehydration, with and without concurrent heat stress on simulated motor-racing performance. Overall, findings from the study indicate that passive dehydration to both 1% and 3% BML did not impact on measures of driving performance previously demonstrated as being sensitive and reliable performance variables.

Driving performance based on LT and ST remained unchanged from Baseline irrespective of trials (1% or 3% BML) during Hot and Cool conditions. This suggests that either dehydration has no effect on simulated driving performance; or if it does, the effect was less than the level of sensitivity able to be determined by the LT and ST outcome variables. These results support the previous work of Walker et al. (26) who found no effect of prolonged heat exposure (~60 min at 50 °C, resulting in ~2% BML) on simulated motor-racing performance measures of LT. However, the authors did observe significantly greater driver error measured via “contact points” (i.e. points being allocated according to the number and severity of contacts with the surrounding environment). The present study involved a single car travelling on a circuit without fixed borders (e.g. barriers or guard rails), hence contact points were not assessed. Clearly, there are many factors that contribute to driving performance and the relationship between dehydration and driving performance is complex. Future driving research should consider the use of as many sensitive and reliable outcome variables as possible as a means of assessing performance.

One possible explanation for the insignificant results observed in the present study, may be due to the duration of driving task employed. The protocol for the current experiment involved a short duration performance task lasting ~5 min. A recent study by Watson et al. (27) exploring the impact of fluid restriction resulting in mild dehydration (1% BML) on a monotonous driving task (120 min) observed a significant increase in minor driver errors (e.g. lane drifting) when participants were dehydrated compared to euhydrated conditions. While it is unclear whether the minor driver errors in the Watson et al. (27) investigation originated from a physiological impairment caused by a reduction in total body water and/or electrolyte imbalance; or were simply due to changes in mood state from the monotonous driving task employed, the cognitive function literature indicates that dehydration can negatively affect tasks of greater duration. For example, two previous studies by Cian et al. (6, 7) observed a significant decline in aspects of cognitive performance using a cognitive test battery lasting approximately 40 min. Thus, it is possible that a longer task may indicate effects of dehydration on driving performance which are not apparent in short duration drives. Motorsport events do have components of shorter duration such as qualification rounds or practice laps, which can determine important race proceedings such as grid (starting) position. Drivers may commence these events in a mildly dehydrated state or lose small amounts of fluid during the event itself. However, the majority of professional motor-racing occurs over a longer duration (60+ min). Future research should investigate the effects of dehydration on a driving task of extended duration to ensure that all aspects of the motor-racing environment are assessed. This research may also benefit sectors outside of motor-racing. For instance, findings could be applied to military settings, wildland

firefighters and heavy machine operators, as these individuals are often at risk of significant fluid deficits while undertaking demanding cognitive and physical tasks in warm environments and over extended durations (1, 22, 28).

No statistically significant differences were observed for driving performance measures between conditions (Baseline, Hot, Cool). However, absolute values of performance during the Hot condition displayed a trend towards improvement for LT at 3% BML and both LT and ST at 1% BML. The impact of heat exposure on short duration cognitive function assessed via performance measures and brain imaging has been explored (11). Results indicate increased brain activity when participants complete performance tasks during thermally strained conditions compared to that of thermo-neutral controls (11). This suggests a greater utilization of neural resources or effort is required by participants to maintain level of performance under heat duress compared to completing the same task without a concurrent heat strain. This may help to explain the findings of the present study, as anecdotal reports from participants were that higher perceived mental effort was required to complete the driving task during the Hot condition compared to the Cool or Baseline conditions. Thus, participants may have displayed a degree of over-compensation under the Hot driving condition that had flow on effects to improve LT. The length of time in which participants can manage a heat load and apply greater mental effort to maintain or enhance performance on cognitive related tasks currently remains unknown.

Previous review papers have suggested that dehydration of ~2% BML without concurrent heat strain significantly impairs cognitive performance (9, 18, 19). However, some studies suggest that performance can return to baseline levels after an extended period of rest prior to re-testing (6, 7). The results of the present study indicate that passive dehydration followed by a cooling period had no effect on measures of driving performance. This suggests that drivers undertaking events of short duration interspersed with periods where they are removed from a hot environment (e.g. practice sessions where drivers are often outside the vehicle with helmet/clothing removed) are unlikely to experience substantial effects from mild to moderate dehydration. In contrast, many racing situations see drivers performing under substantial thermal strain (2). Hence, understanding the impact of hydration with and without a concurrent heat load has application to different aspects of motor sport performance.

Ratings of mood and comfort in the present study were significantly impaired during both Hot and Cool conditions. Participants' mean AVAS scores indicated a reduced level of concentration, comfort and alertness, as well as increased feelings of tiredness and light-headedness post-dehydration for both conditions (Hot and Cool). Previous research suggests that impairment associated with dehydration may stem from changes in mood, primarily driven by discomfort and distraction related symptoms (5). Hancock (10) suggests temperature exposure leading to a significant rise in core body temperature can drain attentional resources, affecting vigilance and leaving limited attention to complete required tasks. In the present study, no impact of mood-related changes on performance were apparent. Again, it is possible that the task employed may have been too short to observe any effects from changes in subjective mood or comfort and this warrants further investigation.

In the present study, driving performance was assessed using a simulated motor racing task. The use of a driving simulator allowed for repeat testing under safe and identical environmental conditions, making it a useful platform to test interventions (e.g. dehydration) on driving performance. However, the motorsport environment involves exposure to large gravitational forces and significant risk and danger derived directly from the driver's actions and from other vehicles travelling at high speeds. It is possible that dehydration may influence both muscle strength/fatigue (24) and risk-taking behavior (14). To assist translation of findings from driving performance simulation scenarios to motor racing, validation between simulations and on-track racing is required.

REFERENCES

1. Adam GE, Carter R, Chevront SN, Merullo DJ, Castellani JW, Lieberman HR, Sawka MN. Hydration effects on cognitive performance during military tasks in temperate and cold environments. *Physiol Behav* 93(4): 748-756, 2008.
2. Brearley MB, Finn JP. Responses of motor-sport athletes to v8 supercar racing in hot conditions. *Int J Sports Physiol Perform* 2(2): 182-191, 2007.
3. Castro-Sepulveda M, Ramirez-Campillo R, Astudillo S, Burgos C, Henriquez-Olguin C. Prevalence of dehydration and fluid intake practices in elite rally dakar drivers. *Sci Sport* 29(6): 327-330, 2014.
4. Chang YK, Labban JD, Gapin JL, Etnier JL. The effects of acute exercise on cognitive performance: A meta-analysis. *Brain Res* 1453: 87-101, 2012.
5. Chevront SN, Kenefick RW. Dehydration: Physiology, assessment, and performance effects. *Compr Physiol* 4(1): 257-285, 2014.
6. Cian C, Barraud PA, Melin B, Raphel C. Effects of fluid ingestion on cognitive function after heat stress or exercise-induced dehydration. *Int J Psychophysiol* 42(3): 243-251, 2001.
7. Cian C, Koulmann N, Barraud PA, Raphel C, Jimenez C, Melin B. Influence of variations in body hydration on cognitive function: Effect of hyperhydration, heat stress, and exercise-induced dehydration. *J Psychophysiol* 14(1): 29-36, 2000.
8. Gavin TP. Clothing and thermoregulation during exercise. *Sports Med* 33(13): 941-947, 2003.
9. Grandjean AC, Grandjean NR. Dehydration and cognitive performance. *J Am Coll Nutr* 26(5): 549-554, 2007.
10. Hancock PA. Sustained attention under thermal stress. *Psychol Bull* 99(2): 263-281, 1986.
11. Hocking C, Silberstein RB, Lau WM, Stough C, Roberts W. Evaluation of cognitive performance in the heat by functional brain imaging and psychometric testing. *Comp Biochem Physiol A Mol Integr Physiol* 128(4): 719-734, 2001.
12. Holt RIG, Hanley NA, Al-Lamki MA. Essential endocrinology and diabetes: Fifth edition. Sultan Qaboos Univ Med J 7(2): 97-98, 2007.
13. Irwin C, Campagnolo N, Iudakhina E, Cox GR, Desbrow B. Effects of acute exercise, dehydration and rehydration on cognitive function in well-trained athletes. *J Sports Sci* 36(3): 247-255, 2018.

14. Irwin C, Leveritt M, Shum D, Desbrow B. The effects of dehydration, moderate alcohol consumption, and rehydration on cognitive functions. *Alcohol* 47(3): 203-213, 2013.
15. Irwin C, Leveritt M, Shum DH, Desbrow B. Mild to moderate dehydration combined with moderate alcohol consumption has no influence on simulated driving performance. *Traffic Inj Prev* 15(6): 652-662, 2014.
16. Irwin C, Mollica J, Desbrow B. Sensitive and reliable measures of driver performance in simulated motor-racing. *Int J Ex Sci* X(X): X-X, 2019.
17. Leon GR, Koscheyev VS, Stone EA. Visual analog scales for assessment of thermal perception in different environments. *Aviat Space Environ Med* 79(8): 784-786, 2008.
18. Lieberman HR. Hydration and cognition: A critical review and recommendations for future research. *J Am Coll Nutr* 26(5): 555-561, 2007.
19. Lieberman HR. Hydration and human cognition. *Nutr Today* 45(6): 33-36, 2010.
20. Lieberman HR. Methods for assessing the effects of dehydration on cognitive function. *Nutr Rev* 70(2): 143-146, 2012.
21. Marsh-Richard DM, Hatzis ES, Mathias CW, Venditti N, Dougherty DM. Adaptive visual analog scales (AVAS): A modifiable software program for the creation, administration, and scoring of visual analog scales. *Behav Res Methods* 41(1): 99-106, 2009.
22. Piil JF, Lundbye-Jensen J, Christiansen L, Ioannou L, Tsoutsoubi L, Dallas CN, Mantzios K, Flouris AD, Nybo L. High prevalence of hypohydration in occupations with heat stress-perspectives for performance in combined cognitive and motor tasks. *PLoS One* 13(10): e0205321, 2018.
23. Potkanowicz ES, Mendel RW. The case for driver science in motorsport: A review and recommendations. *Sports Med* 43(7): 565-574, 2013.
24. Savoie FA, Kenefick RW, Ely BR, Chevront SN, Goulet ED. Effect of hypohydration on muscle endurance, strength, anaerobic power and capacity and vertical jumping ability: A meta-analysis. *Sports Med* 45(8): 1207-1227, 2015.
25. Shahid A, Wilkinson K, Marcu S, Shapiro CM. Stanford Sleepiness Scale (SSS). In: A Shahid, K Wilkinson, S Marcu and C M Shapiro editors. *Stop, that and one hundred other sleep scales*. New York, NY: Springer New York; 2012.
26. Walker S, Ackland T, Dawson B. The combined effect of heat and carbon monoxide on the performance of motorsport athletes. *Comp Biochem Physiol A Mol Integr Physiol* 128(4): 709-718, 2001.
27. Watson P, Whale A, Mears SA, Reyner LA, Maughan RJ. Mild hypohydration increases the frequency of driver errors during a prolonged, monotonous driving task. *Physiol Behav* 147: 313-318, 2015.
28. Williams-Bell FM, Aisbett B, Murphy BA, Larsen B. The effects of simulated wildland firefighting tasks on core temperature and cognitive function under very hot conditions. *Front Physiol* 8: 815-815, 2017.