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Responses of Motor-Sport Athletes to V8 Supercar Racing in Hot Conditions

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Background: Despite the thermal challenge of demanding workloads performed in high cabin temperatures while wearing heavy heat-retardant clothing, information on physiological responses to racing V8 Supercars in hot conditions is not readily available. ***Purpose:*** To describe the thermal, cardiovascular, and perceptual strain on V8 Supercar drivers competing in hot conditions. ***Methods:*** Thermal strain was indicated by body-core temperature using an ingested thermosensitive pill. Cardiovascular strain was assessed from heart rate, hydration status, and sweat rate. Perceptual strain was estimated from self-rated thermal sensation, thermal discomfort (modified Gagge scales), perceived exertion (Borg scale), and perceptual strain index. ***Results:*** Prerace body-core temperatures were (mean ± SD) 37.7°C ± 0.4°C (range 37.0°C to 38.2°C), rising to 39.0°C ± 0.4°C (range 38.4°C to 39.7°C) postrace. Driver heart rates were >160 and >170 beats/min for 85.3% and 46.7% of racing, respectively. Sweat rates were 1.06 ± 0.12 L/h or 13.4 ± 1.2 $mL \cdot kg^{-1} \cdot h^{-1}$, and postrace dehydration was 0.6% ± 0.6% of prerace body mass. Drivers rated thermal sensation as hot (10.3 ± 0.9), thermal discomfort as uncomfortable (3.1 ± 1.0), and perceived exertion as very hard to very, very hard (8.7 ± 1.7) after the races. Overall physiological and perceptual strain were 7.4 ± 1.0 and 7.1 ± 1.2, respectively. ***Conclusions:*** Despite the use of cooling, V8 Supercar drivers endure thermal, cardiovascular, and perceptual strain during brief driving bouts in hot conditions.

Key Words: core temperature, heat, telemetry pill, thermal

The V8 Supercar Championship is the premier Australian motor-racing category, contested by 16 teams and up to 32 drivers racing Holden Commodore and Ford Falcon motorcars. The race-car versions are large enclosed 5-seat passenger vehicles that have been extensively modified rather than purpose-built for racing. The fact that the popularity of this category extends to those not otherwise interested in motor sport largely stems from the fact that standard versions of these vehicles are commonly owned by Australians as passenger cars, and the respective manufacturers rival one another for market share.

In contrast to NASCAR and some open-wheel-racing categories, V8 Supercars compete on racetrack and street circuits without the use of oval tracks. Race

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meets range from 2 to 3 sprint (<100 km) races over 2 days to 1-day endurance races (1000 km). Racing is typified by small margins between race cars, a factor that has contributed to the category's popularity and impetus for expansion to include 2 International Championship rounds, with the remaining 11 rounds contested throughout Australia. Races are therefore conducted across a range of environmental conditions, and unlike the passenger vehicles on which the race cars are based, cabin cooling via air conditioning is not readily available. The drivers can therefore experience high cabin temperatures, anecdotally reported to exceed 50°C.[1] Mandatory full-body ensembles with flame- and heat-retardant capabilities augment the potential for thermal stress because the overalls, gloves, boots, and helmet severely limit V8 motor-sport athletes' ability to dissipate heat, rendering conditions in the cabin uncompensable. Physical activity in such conditions results in body-heat storage, which if prolonged can induce hyperthermia and heat injury, conditions previously observed in motor-sport athletes.[2,3]

Despite the thermal challenge presented by these factors, information detailing the responses of V8 Supercar drivers is not readily available and consists mainly of anecdotal descriptions.[1] This investigation therefore sought to quantify selected physiological and perceptual responses to V8 Supercar racing in hot conditions.

Methods

Subjects

Four full-time V8 Supercar drivers provided written informed consent for the observational project approved by the human research ethics committee of Charles Darwin University. Table 1 describes the characteristics of the drivers.

Design

Two drivers were observed during the respective 2002 and 2003 V8 Supercar championship rounds contested at the Hidden Valley Racetrack, Darwin, Australia. Drivers averaged ~150 km/h on the 2.87-km circuit containing 14 turns and a 1.1-km straight. Three sprint races were contested per round, one ~58-km (short) and

Table 1 Characteristics of the Drivers

	Subject					
Characteristic	**A**	**B**	**C**	**D**	**Mean**	**SD**
Age (y)	31	28	27	28	28.5	1.7
Height (m)	1.79	1.77	1.77	1.73	1.77	0.03
Mass (kg)	78.7	71.0	75.2	82.4	76.8	4.9
Body surface area (m^2)	1.97	1.87	1.92	1.96	1.93	0.05
Body surface area/mass (m^2/kg)	0.025	0.026	0.025	0.024	0.025	0.001
VO_2peak (mL · kg^{-1} · min^{-1})	47.3	60.0	—	—	—	—
Sum of 7 skinfolds (mm)	77.6	39.0	67.5	98.0	70.5	24.5
Body fat (%)	13.6	7.0	11.8	17.2	12.4	4.2

two ~100-km races (long). Figure 1 shows a V8 Supercar similar to those raced by the participants in this investigation.

Measures

Laboratory Testing. In 2002 drivers undertook treadmill running to volitional exhaustion to determine peak oxygen consumption (VO_2peak) using a Medgraphics CPX/D gas-analysis system (Medical Graphics Corp, St Paul, Minn). This was not possible for the 2003 round. Skinfold thickness was measured at 7 sites according to Norton et al[4] and summed for all drivers. Body-fat percentage was estimated according to Withers et al[5] and Siri.[6]

Core Temperature. A small silicon-encapsulated pill (CorTemp100, HTI Technologies, Palmetto, Fla) was used to provide a reliable[7] and valid[8] measure of gastrointestinal temperature (t_{gi}) to reflect body-core temperature. Drivers ingested a pill approximately 4 hours before racing to permit adequate time for it to pass the pyloric sphincter and enter the gastrointestinal tract. A receiver (BCTM, Fitsense Technology Inc, Southborough, Mass) was attached to the driver's seat after confirmation that the pill was within radio-transmission range. The receiver measured and recorded the pill temperature every 30 seconds. Data were downloaded to a personal computer after each race.

Driver Perception. Thermal sensation (13-point scale) and thermal discomfort (5-point scale) were rated prerace and postrace on the modified scales of Gagge et al.[9] Rating of perceived exertion was assessed for each driving bout according to the scale of Borg.[10]

Figure 1 — V8 Supercar similar to that raced by the drivers of this investigation.

Heart Rate. Cardiac frequency was measured and recorded at 5-second intervals by a band fitted across the driver's chest (Team System, Polar, Kempele, Finland) during the 2003 round. A system requiring transmission of heart-rate signals from the band to a watch had been used in 2002 (Vantage NV, Polar) but abandoned for 2003 because the strong electromagnetic field within the car prevented data storage. Safety-car periods were excluded from the heart-rate data analysis to provide racing-specific data.

Hydration Status. Prerace hydration status was estimated from urine specific gravity[11] determined by a refractometer (URC-NE, Atago, Tokyo, Japan). Sweat rate (factoring in fluid ingestion) and prerace-to-postrace dehydration were estimated from changes in body mass using calibrated scales accurate to 0.02 kg (CH-150KP, A&D Mercury, Adelaide, Australia). Body-mass loss was not corrected for respiratory losses or metabolic exchange. Sweat rates were ascertained for 6 driving bouts that comprised 45% racing, 28% in car but not racing, and 27% out of the race car.

Strain Indices. Rectal temperature was substituted with t_{gi} for input with heart rate (HR) into the modified physiological strain index of Moran et al[12] as follows: 5(t_{gi} postrace – t_{gi} prerace)/(39.5 – t_{gi} prerace) + 5(HR postrace – HR prerace)/(180 – HR prerace). The perceptual strain index was calculated according to Tikuisis et al.[13]

Environmental Conditions. Pit-lane environmental conditions were continuously measured and recorded at 1-minute intervals and averaged for the duration of racing (QuesTemp 36, Quest Technologies, Oconomowoc, Wisc). The temperature of a naturally ventilated wet-bulb thermometer (t_{nwb}), a black globe (t_g), and ambient air temperature (t_a) were weighted ($0.7t_{nwb} + 0.2t_g + 0.1t_a$) to calculate the wet-bulb-globe temperature.[14] Cabin temperatures were recorded by team telemetry (MOTEC, Croydon South, Australia) and averaged over race duration. Each race car had ambient air cooled through a cold block and interfaced with the driver's helmet to provide head cooling. Three of the subjects also used torso cooling via a reticulation of tubes in a T-shirt perfused with cold water (Cool Shirt, Shafer Enterprises, Jonesboro, Stockbridge, Ga).

Statistical Analysis

Because of the limited size of the cohort, statistical analysis was limited to descriptors, means, and standard deviations.

Results

Core Temperature

Two data sets were excluded as a result of mechanical difficulties, leaving 10 data sets generated by 4 drivers from 3 races. A peak t_{gi} of 39.7°C was observed after a long race by the only driver not using torso cooling. Average postrace t_{gi} (mean ± SD) was 39.0°C ± 0.4°C (range 38.4°C to 39.7°C), which increased from 37.7°C ± 0.2°C (range 37.0°C to 38.2°C) prerace. Postrace t_{gi} was similar between race formats because of a higher rate of t_{gi} increase during the short (0.042°C ± 0.012°C) than during the long (0.029°C ± 0.006°C) races.

Driver Perception

After the races, drivers perceived their thermal sensation as hot (10.3 ± 0.9), causing them to feel uncomfortable (3.1 ± 1.0). The highest average thermal sensation and thermal discomfort were reported after race 3. The rating of perceived exertion was very hard to very, very hard for the racing periods. Table 2 summarizes the physiological and perceptual responses to racing.

Heart Rate

From the 2 drivers analyzed during the 2003 round, average cardiac frequencies of 167 and 169 beats/min were observed during the short and long races, respectively. Overall, driver heart rates were >160 and >170 beats/min for 85.3% and 46.7% of racing, respectively.

Hydration Status

There was a trend for cumulative dehydration with each race (urine specific gravity: 1.010, 1.011, and 1.015). Sweat rates were 1.06 ± 0.12 L/h, or 13.4 ± 1.2 $mL \cdot kg^{-1} \cdot h^{-1}$, and postrace dehydration was 0.6% ± 0.6% of prerace body mass.

Environmental Conditions

Race-car cabin temperatures peaked at 52.1°C during the long races, with average cabin temperature exceeding average ambient temperature by ~13°C to 15°C (Table 3).

Table 2 Core-Temperature (t_{gi}) and Perceptual Responses to V8 Supercar Driving in Hot Conditions, Mean (SD)*

	Race Format		
Descriptors	**Short**	**Long**	**Overall**
Analysis period, min:s	70:00 (3:40)	108:21 (22:14)	93:00 (25:54)
Race time, min:s	20:25 (3:48)	39:10 (6:24)	31:32 (7:26)
Postrace t_{gi}, °C	38.8 (0.5)	39.1 (0.4)	39.0 (0.4)
Δ t_{gi}, °C/min	0.042 (0.012)	0.029 (0.006)	0.034 (0.011)
Postrace thermal sensation†	10.1 (0.9)	10.4 (0.9)	10.3 (0.9)
Postrace thermal discomfort‡	2.8 (0.9)	3.3 (1.1)	3.1 (1.0)
Rating of perceived exertion	8.3 (1.2)	9.0 (1.5)	8.7 (1.7)
Prerace USG	1.010 (0.009)	1.014 (0.008)	1.013 (0.008)
Sweat loss, kg	1.29 (0.19)	1.66 (0.12)	1.48 (0.25)
Sweat rate, kg/h	1.08 (0.16)	1.04 (0.09)	1.06 (0.12)
Dehydration, % body mass	0.5 (0.5)	0.6 (0.6)	0.6 (0.6)
Physiological strain index	6.5 (0.7)	8.0 (0.6)	7.4 (1.0)
Perceptual strain index	6.7 (1.1)	7.3 (1.3)	7.1 (1.2)

*USG indicates urine specific gravity.
†Thermal-sensation scale: 7 = *neutral,* 10 = *hot,* 13 = *unbearably hot*.
‡Thermal-discomfort scale: 1 = *comfortable,* 3 = *uncomfortable,* 5 = *unbearably uncomfortable*.

Table 3 Racetrack and Race-Car Environmental Conditions*

	Thermal Measure (°C)				
	t_{nwb}	t_g	t_a	WBGT	Cabin
Race format					
short	23.9	41.9	33.3	28.4	46.2
long	23.7	45.0	34.8	29.1	50.1
Weighted mean	23.8	44.4	34.5	28.9	48.6

*t_{nwb} indicates wet-bulb thermometer; t_g, black-globe thermometer; t_a, ambient air temperature; and WBGT, wet-bulb-globe thermometer.

Discussion

The data from this investigation were collected during annual competition rounds held in Darwin during 2002 and 2003. Although this setting provided the opportunity to assess responses to racing in hot conditions, the uncontrolled environment resulted in some incomplete data sets and limited the size of our cohort. Therefore, this investigation is considered preliminary, providing descriptive information on selected physiological and perceptual responses to V8 Supercar racing in hot conditions.

The drivers' physical characteristics are similar to Australian national team-sport representatives.[15] High aerobic power, low adiposity, and high body-surface-area/mass values are generally considered advantageous for thermoregulation.[16] Nonetheless, the combination of the 3-layer protective full-body ensemble that inhibits evaporative heat exchange with high cabin temperatures (42°C to 52°C) and causes heat gain via radiation creates uncompensable conditions in which heat storage is inevitable.[17] Assuming similar absolute workloads among drivers, the uncompensable conditions would act to nullify the advantage of the heat-dissipation potential conferred by high aerobic power and negate the positive correlation of body surface area/mass and core temperature observed in temperate conditions[18] by radiation gain through the skin surfaces.[19]

To our knowledge there are no published reports describing the body-core temperature response to V8 Supercar racing in compensable or uncompensable heat stress. Because core temperature is the single best physiologic predictor for heat exhaustion,[20] the lack of data prevents assessment of the performance and thermal-injury risk, impeding development of evidence-based strategies to maximize performance and minimize thermal strain of V8 Supercar drivers. The results of this investigation demonstrate that V8 Supercar drivers might approach hyperthermic core temperatures from driving bouts in hot conditions. There were several instances when t_{gi} exceeded 39°C at the conclusion of racing, which surpasses the proposed tolerable core-temperature limit for physical activity in severe environments of duration comparable to the longer races.[21] Although physical exhaustion in compensable environments tends to occur at an esophageal temperature of ~40°C,[22,23] internal temperatures analogous to those reported by this investigation (rectal temperature 38.5°C to 39.2°C) have been associated with exhaustion during protective-clothing-uncompensable heat stress in the laboratory.[20,24,25] Because full protective clothing lowers tolerance to uncompensable heat stress,[26] the core temperatures of the V8 Supercar drivers suggest that they were operating in a near-exhaustive state. Subjects from field investigations, however, have greater physiological tolerance to uncompensable heat stress than their laboratory-based counterparts.[27] It is possible that the motivation of subjects in the field permits them to tolerate greater thermal strain before succumbing to exhaustion. Although the drivers reported high levels of thermal sensation, thermal discomfort, and perceived exertion during the short and long races, no complaints of exhaustion during or postrace were noted. The V8 Supercar drivers might have suppressed the afferent perception from warm thermoreceptors to tolerate higher core temperatures before exhaustion than subjects in laboratory studies.

High core temperatures were observed despite the use of cooling by all drivers. The head cooling was subjectively rated as producing a minor benefit for thermal sensation, likely related to the small surface area cooled and the limited capacity of air for heat storage. Torso cooling was achieved for 3 drivers by cold-water reticulation through tubes in a T-shirt. The "cool shirt" has been used by motor-sport athletes for the past 4 decades to reduce driver heat stress[2] and is commonly used by V8 Supercar drivers during races in warm to hot conditions. The ice volume of the cooler carrying the ice limited the heat-storage capacity of the cool shirt so that it was perfused intermittently throughout the races. Intermittent use of the cool shirt not only prolongs its cooling capacity but also increases its effectiveness by augmenting the cutaneous blood volume available to cool,[28] thereby attenuating the rise in core temperature.[25,29,30] Although the small, unmatched sample of V8 Supercar drivers does not permit definitive cross-sectional analysis, those using the cool shirt exhibited a rise in t_{gi} of 0.030°C/min to attain 38.8°C at the conclusion of racing. The sole driver without torso cooling (subject A) averaged a postrace t_{gi} of 39.4°C that increased at a rate of 0.043°C/min. Although data contrasting responses of motor-sport athletes to racing with and without torso cooling are lacking, it is likely that such cooling systems blunt the rise of core temperature and limit the other physiological and perceptual responses reported by this investigation.

Similar rates of core-temperature rise (0.036°C/min) while wearing protective clothing have been induced by 2 minutes of jogging followed by 4 minutes of walking and 4 minutes of seated rest.[31] In that study, an average rectal temperature of 39.2°C coincided with volitional exhaustion after 65 minutes. Subject A commenced racing with a substantially higher core temperature and sustained a higher rate of heat storage and postrace core temperature than those in the aforementioned study, completing the race in a competitive position. His thermal sensation was hot to extremely hot postracing, but he did not complain of heat exhaustion. Core temperatures in this investigation were lower than the hyperthermic reports for endurance (>2 hours) in stock-car and open-wheel racers.[2,3] It appears that the warm to hot conditions and duration of racing interacted to produce hyperthermia in those studies. Heat illness was a risk for the V8 Supercar drivers, but the rate of heat storage during the longer races (0.029°C/min) was substantially lower than during the short races (0.042°C/min), implying lower work intensity concomitant with pacing to ensure longevity of the driver and/or car. The similarly high average heart rates and ratings of perceived exertion from the short and long sprint races are not consistent with this hypothesis, however.

High driver heart rates are a common observation during touring-car, NASCAR, and open-wheel automobile racing.[32-34] Psychoemotional stress is thought to contribute to the high cardiac frequencies,[34] making it difficult to classify driver physical strain. The sole motor-sport study reporting metabolic data found that open-wheel racers practicing on a road course consumed oxygen at the rate of ~2.8 L/min, equivalent to 79% VO_2max, with average cardiac frequency of 152 beats/min.[35] This evidence supports a major role for physical stress in determining physiological responses during race-car practice sessions, when psychoemotional factors are less prevalent.[34] The higher heart rates for V8 Supercar drivers might result from the additional psychoemotional stress of racing and high core temperatures. High internal temperatures contribute to cardiovascular stress through intrinsic regulation of heart rate[35] and reduced stroke volume and mean arterial pressure caused by augmented cutaneous blood flow and volume.[36]

Although not measured in the present study, skin temperatures would likely have been cooler than cabin conditions, because skin temperatures at exhaustion in full protective clothing approximate 38°C.[26] Evaporation of sweat is therefore the sole method of heat transfer, yet the mandatory racing ensemble limits drivers' maximal evaporative capacity, for which the body attempts to compensate with an increased sweat rate.[31] The moderate sweat rates of 1.06 L/h reported by our study appear counterintuitive but are considered conservative estimates because less than half the analysis period was racing, with the remainder evenly divided between idle time in and out of the race car.

The trend for deteriorating hydration status before the races could be associated with team schedules' limiting the opportunity for rehydration. Briefings, meetings, and media commitments are common for drivers between races. Drivers need to prioritize fluid consumption to achieve rehydration before the next race. The minimal dehydration reported in this study is not consistent with anecdotal reports.[1] Factors contributing to this discrepancy are the sprint format, which limits race duration, and the track layout. Fluids are usually consumed on straight sections of the track, because cornering requires isometric contractions that increase intra-abdominal pressure, limiting one's ability to drink. The straight section of track used in this study accounted for 38% of the distance, with an ~7-second period without gear changes, thereby providing opportunity for fluid consumption via the motorized fluid-delivery system in the race car. It remains possible that endurance races would result in substantial dehydration.[1]

Practical Applications

This study demonstrates that V8 Supercar drivers competing in hot conditions are likely to endure high core temperatures, cardiac frequencies, and perceptual strain. These motor-sport athletes should therefore prepare for such conditions by maximizing their aerobic fitness and using evidence-based strategies to enhance performance. Precooling, hyperhydration, and heat acclimation/acclimatization are such strategies worthy of consideration by V8 Supercar drivers. The effect of thermal strain on physical and motor-skill proficiency of V8 Supercar drivers should also be examined to determine whether the responses reported by this investigation negatively affect racing performance in hot conditions. Such analysis would help bridge the research gap between the laboratory and the field.

Conclusions

Despite the provision of cooling to head and torso, V8 Supercar drivers endure high body-core temperatures, thermal strain, and heart rates during sprint-racing bouts in hot conditions. Based on the current understanding of core temperatures at exhaustion during full-protective-clothing-uncompensable heat stress, the drivers are at high risk of thermal injury.

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