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Performance enhancement in rally car drivers via heat acclimation and race simulation ☆

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Abstract

To investigate the combined use of an interactive racecar simulator and heat acclimation on psychomotor (driving) performance, eight rally drivers underwent 4 days of repeated heat (50°C) exposure (1 $h \cdot day^{-1}$) during which they performed a simulated rally drive (3×12-min stages each separated by a 2-min break), after first cycling for 15 min at 125 W to induce some degree of fatigue and heat storage prior to beginning the rally. During the rally stages, a generic set of pace notes were read to the subject by a co-driver. In each simulation, sweat loss, heart rate, core (rectal) and skin temperatures were recorded and driving and psychomotor performance were assessed by recording stage times and time to complete a psychomotor test. Levels of physiological and perceived thermal strain were also recorded. Significant decreases in rally stage times (88 s; $P < 0.005$), psychomotor test time (18 s; $P < 0.01$), final core (0.25°C; $P < 0.001$) and skin (0.44°C; $P < 0.005$) temperatures, heart rate (16 $beats \cdot min^{-1}$; $P < 0.05$) and physiological (15 $W \cdot m^{-2}$; $P < 0.005$) and perceived thermal (3.7 units; $P < 0.01$) strain were evident by the end of the final simulation, and a significant ($P < 0.05$) increase in sweat sensitivity ($+0.33\ g \cdot h^{-1} \cdot °C^{-1}$) was also recorded. These results suggest that both heat acclimation and race simulation can improve the psychomotor performance of rally drivers, although the relative contribution of each factor was not determined here. However, in a practical setting, these factors would not be used in isolation. After performing the acclimation and simulation protocol prior to an actual rally, drivers subjectively reported improvements in tolerating a high thermal load and in their ability to control the rally vehicle.

Keywords: Motor sport; Heat acclimation; Sweat loss; Rectal temperature; Skin temperature; Psychomotor performance; Thermal strain; Race simulation

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1. Introduction

During the course of a motor sport race, the drivers(s) can experience a number of physical, environmental and psychomotor stressors. In combination, these stressors can lead to rapid fatigue and a resultant decrease in driving performance.

Physical stressors involve the oxygen consumption ($\dot{V}O_2$) and energy expenditure needed to control the car, particularly when dynamic steering actions are required. However, despite the measurement of high heart rates in drivers during races (Schwaberger, 1987; Lighthall et al., 1994), the level of $\dot{V}O_2$ likely to be required by drivers to control the car is less than 1.0 $l \cdot min^{-1}$ and, therefore, only 30–40% of $\dot{V}O_2$ max (Walker, 1999). A major stressor is the microenvironment experienced inside the race car. Especially in the summer season, high ambient temperatures are likely to be experienced within the confined space in the car. Pilot work for this study measured air temperatures within a rally car during a race of 50°C and greater. Many rally drivers also wear standard FIA safety suits (three-layer Nomex suit, gloves, boots and helmet) when racing (although these are not mandatory), which leaves virtually no skin surface area exposed to the environment, and, therefore, markedly reduces the opportunity for evaporative heat loss to occur. Wearing such a suit in a hot microclimate dramatically increases the chances of heat injury, and there have been reports of such problems being encountered in motor sports (Jareno et al., 1987).

In hot and/or humid environments, where heat storage is virtually unavoidable, there is likely to be a marked effect on psychomotor performance, and previous research has documented many such examples. Froom et al. (1993) reported that an increase in ambient temperature (especially above 35°C) produced a higher incidence of helicopter pilot error. Nunneley et al. (1987) have previously shown that fighter pilots scored lower on mental function tests in 47°C than in 35°C. Ramsey (1995), in a recent review, found that performance on tasks requiring perceptual motor skills were significantly reduced when performed in 30–33°C WBGT range. It is, therefore, apparent that the psychomotor performance of a motor sport driver could be seriously impaired by a hot microclimate, which is usually experienced within the car. We considered that there were two methods by which drivers could try to offset this potential problem. By both attempting to improve their heat tolerance via heat acclimation procedures, and their task familiarization by computer race simulation, we hypothesized that racing car drivers could improve their psychomotor performance and, therefore, their driving performance.

We did not attempt to partition the effects of these two factors on any performance improvement, as in 'real life' a racing car driver would use both procedures. Previous work from our laboratory has demonstrated that performing race simulations in cool ambient conditions were not effective, as without a hot microenvironment, drivers did not perceive the situation as being representative of 'real' race conditions, and, therefore, their arousal levels were lowered (Walker, 1999).

Therefore, the aim of this study was to assess the effectiveness of the combined use of both heat acclimation and race simulation on the driving and psychomotor performance of rally drivers in a laboratory setting. If successful, then these procedures were planned to be used as part of driver preparation for actual races, as they could improve driving performance (and possibly driver safety as well).

2. Materials and methods

2.1. Subjects

Eight male Australian Rally Championship level drivers, who had had at least 2 years experience in competing at National or International level, volunteered to act as subjects. Their mean (±S.D.) physical characteristics were age 24 ± 4 years, height 180 ± 6 cm, body mass 77 ± 12 kg and body surface area 1.96 ± 0.16 m^2. The experimental protocol for the study was approved by the Human Rights Committee of the University of Western Australia and all subjects gave their informed consent to participate prior to the commencement of testing.

2.2. Equipment

A race car simulator was designed and built for the study to closely replicate the physical environment of an actual racing car. The exterior comprised a steel roll cage and steel panels (painted matt black) which provided a source of radiant heat to the driver, similar to the transmission tunnel and firewall of a race car. The roof was made of poly-carbonate sheeting, which allowed light to enter the simulator. The interior of the simulator had a standard FIA plastic seat (with shoulder and waist straps), typical racing car steering wheel and foot pedals, all of which could be adjusted to suit the driver. The steering and pedal system was manufactured by Hyperstimulator (Melbourne, Australia) and a sequential gear shift was located on either the steering column or transmission tunnel (either left or right), depending on driver preference. The steering column was fitted with a torque resistance device, which simulated the physical effort required in turning the steering wheel.

The race simulation was provided through a software package (Rally Q Championship, Europress/Magnetic Fields) which was operated by a Pentium 166 MH_z computer and fed to a monitor located approximately 60 cm in front of the driver's head, where the windscreen of the car would normally be positioned. The design of the screen in the software simulated the view that the driver would have if looking through the windscreen of a rally car. By using the simulator driving controls (steering, gears, accelerator and brake pedals) the driver then utilized similar psychomotor skills to 'drive the car', as would be the case in a normal rally. However, the simulator could not replicate the g-forces, which a driver would experience in a real race. The simulator was also made large enough to accommodate a co-driver who sat next to the driver and viewed the race course through a second monitor. The co-driver called the pace notes for each stage, communicating with the driver via a Terraphone rally communication (headset) system.

2.3. Experimental procedures

The subjects were firstly fully familiarized with the simulator and test protocol, by taking a 'test run' on one or two occasions, in the week prior to the commencement of testing. For these familiarization sessions the subjects wore only light clothing and the ambient temperature was only 25°C. After familiarization, the subjects then had four 1-h acclimation/simulation sessions over 4 consecutive days, with each session occurring at the same time of the day for each subject, to control for any effect of circadian variation. The simulator was placed inside a climate chamber where the ambient air temperature was maintained at 50 ± 2°C and the same 'race' was performed by all subjects on all 4 days. A different 'race' was not used at the start and finish of the acclimation/simulation protocol, as this would not occur in actual rally competition. If permitted, drivers would practice on the competition course or use a computer simulation of the actual course, to gain specific exposure to the race terrain.

On arrival at the laboratory, the subjects consumed 300 ml of water. Nude body mass (± 10 g) was then recorded, before a YSI model 401 rectal probe (inserted 10 cm beyond the anal sphincter), YSI model 408 skin thermistors (taped on to the sternum, anterior mid forearm and posterior mid-calf) and a heart rate monitor (Polar Electro PE 4000) were fitted. The subjects dressed in a FIA approved three-layer Nomex race suit and helmet, boots and gloves, before entering the climate chamber. The first part of the test protocol required them to cycle (Monark model 808) for 15 min at 125 W. This was designed to induce some degree of pre-fatigue and heat storage within the subjects so that the race simulation would better replicate the latter stages of an actual race, when drivers would be tired and hot. After completing the pre-fatigue/heat storage phase the subjects then moved into the simulator and had a 2-min rest period, in which 200 ml of water was consumed. A mental fatigue task, where a course had to be drawn as fast as possible on a map grid to match 30 typical rally commands was then performed, to add to the fatigue of the driver just prior to starting the first stage of the simulated race. These commands were called, at the rate of 1 every 2 s, by the co-driver. Ten variations of this mental fatigue task were developed, and these were varied for each subject by stage and day, so that the same map grid was never used twice during an acclimation/simulation session.

The subjects then 'drove' the first stage of the simulated race, which took approximately 12 min to complete. Their time for the stage and their perceived level of thermal strain (an arbitrary numbered scale, ranging from 3 = normal to 17 = extremely hot) were recorded, while they had a 2-min rest period and consumed 200 ml of water. During this time a small fan was used to blow ambient air across their faces to simulate them exiting the rally car at the end of a stage, as would occur in a normal race. The mental fatigue task was again performed, prior to starting the second stage of the simulated race. This again took approximately 12 min to complete, before the same procedures as described after stage 1 were repeated. A third stage (≈ 12 min) of the simulated race was then performed and recordings made of the time to complete the stage and perceived thermal strain. Then, before leaving the simulator, the subjects attempted a psychomotor test, which required them to perform simple mental arithmetic in order to calculate a map coordinate, which then had to be plotted onto a grid (e.g. x axis $= 11 + 8$, y axis $= R$, so 19 R had to be plotted). They were instructed to do this as fast as possible and the time taken to complete the test was recorded as an index of psychomotor performance. Each error (in either the arithmetic or plotting) resulted in a 3-s time penalty being added to the recorded time. Three variations of this psychomotor test, each containing 22 items, were developed, and as for the mental fatigue tests, were varied between subjects and days (this test was only done on days 1 and 4). On completing this test the subjects left the climate chamber and undressed, removed all measuring equipment and were then wiped dry with a towel before having nude body mass measured again, in order to provide an estimate of sweat loss (corrected for water intake) over the acclimation/simulation session.

Rectal (T_{re}) and sternum (T_{st}), forearm (T_{fa}) and calf (T_c) temperatures were measured to the nearest 0.05°C on a YSI Model 46 TUC tele-thermometer. Mean skin temperature (T_{sk}) was calculated by the formula $0.5T_{st} + 0.14T_{fa} + 0.36T_c$ and mean body temperature (T_b) by $(0.65 \times T_{re}) + (0.35 \times T_{sk})$ (Burton, 1935). The equations of Hall and Polte (1960) were then used to calculate heat storage and a physiological index of heat strain from the temperature and sweat loss data:

$$\Delta S = \frac{0.83 \times \Delta T_{body} \times W}{Ad}$$

where ΔS = heat storage ($W \cdot m^{-2}$); ΔT_{body} = change in body temp. (°C); W = body mass (kg); and Ad = body surface area (m^2)

$$I_s = (\Delta HR/100) + \Delta T_{re} + SR$$

where ΔHR = change in heart rate ($beats \cdot min^{-1}$); ΔT_{re} = change in rectal temp. (°C); SR = sweat rate ($kg \cdot h^{-1}$).

These measurements were made on days 1 and 4 only; on days 2 and 3 rectal temperature was checked before and after the session by a Zeal clinical thermometer.

All temperature probes and thermistors used here were calibrated against a NATA certified thermometer in a water bath before testing commenced to verify their accuracy.

2.4. Statistics

A one-way ANOVA was used to determine any significant differences in the variables measured in the first and the fourth acclimation/simulation session. For perceived level of thermal strain, a Wilcoxon Signed Ranks test was used, due to the non-parametric nature of the scale. Significance was accepted at $P < 0.05$.

3. Results

Table 1 presents data on the variables measured on each of the 4 days of the acclimation/simulation protocol. All eight subjects recorded a faster total race time on day 4 compared with day 1, and for six of the eight subjects, this was their best time recorded over the 4 days. As a group, their driving performance was 88 s faster ($P < 0.003$) on day 4 than on day 1. Their perceived level of thermal strain also significantly improved over the 4-day treatment, decreasing from ($\bar{x} \pm$ S.D.) 12.3 ± 2.4 to 8.6 ± 2.4 (day 4), ($P < 0.012$), with all drivers individually recording a lower score on the last day from the first day.

The group heart rate results also decreased day by day, for both the peak values recorded during the 15 min of cycling which preceded the race simulation, and also for the values recorded during the race.

Table 2 presents data on the variables measured only on day 1 and day 4 of the acclimation/simulation protocol. As for driving performance, all eight subjects recorded faster completion times for the psychomotor test on the final day of the 4 day treatment; as a group they were 18 s faster ($P < 0.001$) on day 4 than on day 1. For the thermoregulatory variables, all except sweat loss were significantly improved on day 4 from the values measured on day 1. Absolute

Table 1
Summary of data ($\bar{x} \pm$ S.D.) recorded on each day of the 4-day acclimation/simulation protocol: simulated race times, perceived thermal strain and heart rates[a]

	Day 1	Day 2	Day 3	Day 4	*P*-value
Total race time (s)	2258 ± 120	2224 ± 121	2190 ± 105	2170 ± 78	< 0.003
Perceived thermal strain	12.3 ± 2.4	10.5 ± 2.7	9.8 ± 2.1	8.6 ± 2.4	< 0.012
(Rating)	(Very hot)	(Hot)	(Very warm)	(Very warm)	
Heart rate (beats · min^{-1})					
(a) 15-min peak	163 ± 22	159 ± 17	158 ± 8	151 ± 16	< 0.022
(b) Race — average	134 ± 20	131 ± 17	124 ± 16	119 ± 14	< 0.003
(c) Race — final	137 ± 21	134 ± 17	136 ± 16	121 ± 17	< 0.011

[a] *P*-values are for day 1 vs. day 4 values. For heart rates, 15-min peak is the peak value recorded during 15 min of cycling at 125 W completed prior to starting the race; race — average is the average value calculated for the three simulated race stages combined; race — final is the average value calculated for the last stage of the simulated race.

final T_{re} and T_{sk} values, as well as the change (Δ) from pre- to post-simulation temperatures were all significantly lower on day 4, as were the calculated variables of heat storage and heat strain index. Sweat sensitivity (sweat per °C rise in T_{re}) was significantly higher ($P < 0.031$) on day 4, even though sweat loss was unchanged. Seven out of the eight drivers demonstrated this response.

4. Discussion

This study was conducted to investigate whether the combined use of both heat acclimation and task familiarization (via race simulation) could improve the driving and psychomotor performance of rally drivers in a laboratory setting. The rationale for the study was that if these procedures proved successful, then performing a daily acclimation/simulation protocol in the week prior to competing in a race might be a practical way of optimizing the psychomotor skills of drivers, which could help to improve driving performance (and possibly driver safety as well).

In terms of performance, all drivers recorded individual improvement in total race time over the 4 treatment days, and a similar result was found for the psychomotor test time. For both of these variables, the group recorded significantly faster times on day 4 than on day 1, demonstrating that driving and psychomotor performance were enhanced by the acclimation/simulation protocol. While, for reasons of practicality (as explained earlier), the race simulation was the same on each day, the psychomotor test had three variations. These psychomotor tests were ran-

Table 2
Summary of data ($\bar{x} \pm$ S.D.) recorded on day 1 and day 4 of the 4-day acclimation/simulation protocol: psychomotor test time and thermo-regulatory variables[a]

	Day 1	Day 4	*P*-value
Psychomotor test time (s)	140 ± 20	122 ± 21	< 0.001
Sweat loss (g)	1350 ± 320	1330 ± 140	NS
Sweat sensitivity (g h^{-1} · °C^{-1})	1.20 ± 0.42	1.53 ± 0.33	< 0.031
15 min ΔT_{re} (°C)	0.53 ± 0.13	0.29 ± 0.07	< 0.001
Final rally T_{re} (°C)	38.98 ± 0.21	38.73 ± 0.22	< 0.020
Overall ΔT_{re} (°C)	1.18 ± 0.23	0.90 ± 0.19	< 0.001
15 min ΔT_{sk} (°C)	3.26 ± 0.45	2.83 ± 0.46	NS
Final T_{sk} (°C)	37.92 ± 0.30	37.48 ± 0.36	< 0.040
Overall ΔT_{sk} (°C)	3.89 ± 0.31	3.03 ± 0.36	< 0.005
Heat storage (W · m^{-2})	68.5 ± 6.8	53.4 ± 4.7	< 0.001
Heat strain index	1.71 ± 0.30	1.33 ± 0.21	< 0.003

[a] *P*-values are for day 1 vs. day 4 values. T_{re}, rectal temperature; T_{sk}, mean skin temperature; Δ, change; overall Δ, = pre − post total acclimation/simulation session; 15 min, value recorded over 15 min of cycling at 125 W completed prior to starting the rally; heat storage and heat strain index were calculated as per Hall and Polte (1960) and sweat sensitivity was calculated as sweat loss/ΔT_{re}.

domly assigned, therefore, there was less opportunity for specific (exact) task learning day by day.

As we considered it impractical to use a control (cool) condition here, it is impossible to partition the noted improvements in driving and psychomotor performance which are due to heat acclimation or task familiarization. While it is likely that both factors played a part in improving performance, it is difficult to suggest which one may have been the more important. A 1-h heat treatment on 4 consecutive days is not a large amount of heat exposure, but research has indicated that up to 75% of the total acclimation to heat can occur in 4–5 days (Pandolf, 1998).

Certainly the subjects here displayed the classical indicators of heat acclimation within the 4-day treatment; namely decreased heart rate, T_{re} and T_{sk}, and while sweat loss (rate) did not increase, sweat sensitivity was increased and these responses are again quite typical of heat acclimation (Dawson, 1994). The low energy expenditure of the drivers during the race simulation, coupled with the very hot (50°C) ambient temperature experienced within the simulator, may have helped produce a rapid acclimation to these conditions. The 15-min of cycling performed in 50°C, prior to the race simulation, may have also helped in this regard, by initially raising T_{re} and T_{sk}, which were then maintained for the duration of the simulation. The magnitude of the reductions seen here in final heart rate (≈ 15 beats·min^{-1}), T_{re} (≈ 0.25°C) and T_{sk} (≈ 0.45°C) are similar to those measured in several studies where the period of acclimation has been longer and the $\dot{V}O_2$ or energy expenditure higher during the daily acclimation sessions (Dawson, 1994; Pandolf, 1998). Therefore, acclimating to the thermal stress imposed by the simulator microclimate would have helped driver performance here as Grether (1973), Hancock (1982, 1986) and Ramsey (1995) have all demonstrated that increases in bodily thermal strain will cause decreases in psychomotor performance. The reductions seen here over the 4-day treatment in T_{re}, T_{sk}, heat storage and heat strain index should have assisted the drivers to function with a higher degree of psychomotor skill on day 4 than was evident on day 1. Likewise, their lower level of perceived thermal strain on day 4 should have produced a more comfortable feeling, translating to a better mental performance, as the driver is able to focus more on the psychomotor skills necessary to control the car.

With regard to the factor of task familiarization, although the improved performance measured here was seen in a race simulation rather than an actual race, the psychomotor skills required in the simulation are essentially the same as required when driving in a rally. The subjects had to perform cognitive functions in determining when and how to steer, change gears and accelerate or brake according to the terrain of the race simulation, as would be the case in a real race. Also, the drivers had to interpret the pace notes from the co-driver into a mental image, and then into a motor action, within the same time frame as would normally apply in a rally. Therefore, the simulation still produced a very specific practice for an actual rally drive, as the driver had to use the same psychomotor skills. As a result, while it is difficult to quantify the degree, the task familiarization created by the four trials of the race simulation would certainly have helped, along with the heat acclimation, to produce the improvements noted on day 4 in driving and psychomotor test performance.

A psychological review of racing car drivers by Johnsgard (1977) determined that mental confidence was a very important factor in successful performance. The acclimation/simulation treatment used here showed that the drivers were more skilled in psychomotor tasks on day 4, which would promote feelings of confidence going into a race, as their competency in things such as vigilance, tracking and reactive tasks had been improved over the 4-day period.

Based on the results presented here, we propose that an acclimation/simulation protocol similar to the one used in this study, can improve the driving and psychomotor performance of rally drivers, and should be used as a pre-event preparation routine in the week leading up to a race, especially if the driver is not acclimated to heat. Similar procedures to those described here were used prior to a round of the FIA World Rally Championship in November, 1998 and the Australian Junior Rally Championship in 1999. Subjectively, the drivers all commented that they felt an improved ability to interpret pace notes quickly into an action and had a better mental tolerance to heat, suggesting that the psychomotor skills practised in a rally simulator can be transferred to an actual rally situation. Further research is needed to attempt to quantify any performance improvements in actual races, which may have been produced by pre-event acclimation/simulation protocols.

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