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REGULAR ARTICLE

Speed ratio but cabin temperature positively correlated with increased heart rates among professional drivers during car races

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Abstract
Objectives The present study measures heart rate (HR) on a number of professional race-car drivers during actual car races through annual seasons to test hypotheses that faster relative speed and higher cabin temperature would induce higher HR.
Methods Heart rates in fifteen male drivers (31.2 ± 5.5 years old) were obtained by chest-strap sensors during official-professional 13 races. Average HR was calculated while the driver was racing from the start to the end of each race.
Results The average HR during races was 164.5 ± 15.1 beats min^{-1} and the average amount of time each driver spent driving per race was 54.2 ± 13.7 min. Average HR significantly and positively correlated with mean speed ratio ($P < 0.001$), but not with the average cabin temperatures ($P = 0.533$, range 25.6–41.8 °C) by the multiple linear regression analysis. Both average HR and mean speed ratio were significantly lower under wet, than dry conditions (151.9 ± 16.5 vs. 168.3 ± 12.5 beats min^{-1}, 86.9 ± 4.4 vs. 93.4 ± 1.5 %).
Conclusions The cardiovascular system of drivers is considerably stressed at extremely high HR. This high average HR positively correlated with mean speed ratio, suggesting that faster driving speed would induce greater cardiovascular stress to professional drivers during actual races. However, contrary to our hypothesis, cabin temperature was not significantly correlated with average HR. It is speculated that direct body cooling systems used in this professional race category work well against increases in HR by thermal stress under the temperature range found herein.

Keywords Motorsport · Cardiovascular system · Gravitational loading · Thermal stress · Psycho-physiological influence

Introduction

Motorsports differ from other sports in that they do not depend solely on the strength and skill of athletes, but also on the quality of motor vehicles. Due to increases in automobile performance caused by advances in leading-edge technology, professional race-car drivers are enduring greater physiological stress than ever before [1]. Based on a few case reports and preliminary reports, heart rate (HR) increases during car races [2–6]. Gravitational loading, psycho-physiological influence [2–4, 7–9] and thermal stress [5, 10, 11] can be considered the main factors involved in increased HR. Therefore, it is hypothesized that driving at faster relative speeds and under hot condition would induce a higher average HR during professional car races. However, most of these studies measuring HR conducted during off-season tests, practice runs and amateur car races [2–4, 6] that may not have similar levels of influences during actual car races. On the other hand, investigations during actual professional car races have included only small cohorts (e.g. $n = 2$) [2, 5]. Moreover, in the recent professional car races under hot condition, countermeasures against thermal stress including

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direct human-body cooling systems have been usually used [5, 12]. Thus, to test hypothesis described above, it is necessary to measure HR on a number of professional race-car drivers during actual races and to examine correlations between the HR and driving speeds or cabin temperature. Therefore, we conducted this study measuring HR of 15 professional race-car drivers during actual races through annual seasons.

In addition, driving under wet conditions during rainy weather may also increase HR. During rain, drivers race under slippery conditions with low visibility. Thus, vigilant attention to driving would increase psycho-physiological influences under such conditions. However, there have been no reports comparing the HR during actual races under wet condition with dry condition. Therefore, we also compared the average HR between wet and dry conditions.

Materials and methods

Subjects

The institutional review board of Nihon University School of Medicine (Itabashi-ku, Tokyo, Japan) approved the present study and the protocols adhered to the tenets of the Declaration of Helsinki [13]. 15 healthy male, full-time, Super GT race car drivers (age 31.2 ± 5.5 years) provided written informed consent to participate in this study.

Design

All data were measured 13 times during the GT association's official Super GT races in 2011 and 2012 at Okayama international circuit (Okayama, Japan), Fuji speedway (Shizuoka, Japan), Sportsland Sugo (Miyagi, Japan), Suzuka circuit (Mie, Japan), Autopolis (Oita, Japan), Twin Ring Motegi (Tochigi, Japan) and the Sepang International Circuit (Selangor, Malaysia). Super GT is the most popular Japanese car-racing category and it comprises seven-circuit races. It is held from April to October (Table 1).

Methodology

Drivers were equipped with a HR monitor (RS800CX; Polar electro Oy, Kempele, Finland) before starting the races and HR data (R–R intervals) that were downloaded from the monitor after each race were processed using software (Protrainer5; Polar electro Oy, Kempele, Finland). The accuracy of the HR monitor is ±1 % or ±1 beats $\min^{-1}$, whichever larger [14]. The validity of the HR monitor has reported to be similar to electrocardiographic recordings [15]. Heart rates were averaged while the driver was racing from the start to the end of each race. The periods of stopping at the pit and of slow-driving for a safety-car were excluded for the average.

We calculated the mean speed ratio (%) from the course record and the average lap time of each driver as:

$$\frac{\text{Course record (per circuit)}}{\text{Average lap time (per driver)}} \times 100.$$

When the average lap time was similar to the course record of the circuit, meaning that the value was essentially 100, indicating that the driver drove the fastest.

We assessed thermal stress by recording cabin temperatures and humidity during races at one-minute intervals and averaging the values throughout each race using a small, temperature and humidity logger (SHTDL-2; Ymatic Co. Ltd, Tokyo, Japan). The cabin temperature and cabin humidity were averaged while the driver was racing from the start to the end of each race. The periods of stopping at the pit and of slow-driving for safety car were excluded for the average.

Statistical analysis

Values are shown as mean ± standard deviation. The relation between average HR as the dependent variable and the two factors (mean speed ratio and cabin temperature) as independent variables was investigated with multiple linear regression analysis. The selective criterion for the variables was a P value less than 0.05. For the selected variables, we obtained the Pearson's Product–Moment Correlation and the Spearman's Rank–Order Correlation to clarify what degree of correlation exists between average HR and the variable. Data from drivers who did not complete the race due to mechanical problems, a car accident, or physiological issues such as heatstroke were excluded from the statistical analysis. Data were also compared between wet and dry conditions using unpaired or paired t tests. Values of $P < 0.05$ were considered statically significant. Wet condition was defined as "there is water on a road surface due to rainfall during the race". The predicted maximal heart rate was defined as 220 minus age. Since the mean age of all drivers was about 30 years, the approximate predicted maximum heart rate = 190 beats $\min^{-1}$. So, the ratio of whose the highest HR reached ≥190 beats $\min^{-1}$ was calculated. All data were statistically analyzed using SigmaStat version 3.11 software (Systat Software Inc., San Jose, CA, USA). Precise P values are shown.

Results

Subjects characteristics were age, 31.2 ± 5.5 years-old; height, 170.1 ± 4.9 cm; weight, 63.9 ± 4.7 kg and with a 12.2 ± 3.2 years history of professional race-car driving.

Table 1 Values of measured parameters during all circuits and races

Race	HR (bpm)	Average driving time (min)	Highest HR ≥190 beat min^{-1} (n)	Mean speed ratio (%)	Cabin temperature (°C)	Cabin humidity (%)	Track condition
2011 (Jul) Rd.4 Sugo (9)	170.4 ± 13.1	47.8 ± 11.1	6 (67 %) of 9	91.1 ± 1.3	30.7 ± 4.1	54.0 ± 10.0	Dry
2011(Aug) Rd.5 Suzuka (9)	147.0 ± 16.9	59.1 ± 11.0	0 (0 %) of 9	81.6 ± 1.8	34.4 ± 3.2	61.6 ± 11.2	Wet
2011 (Sep) Rd.6 Fuji (10)	166.3 ± 19.6	43.5 ± 9.1	6 (60 %) of 10	93.4 ± 0.8	39.3 ± 3.1	42.6 ± 5.6	Dry
2011 (Oct) Rd.7 Autopolis (6)	165.3 ± 11.1	40.5 ± 11.9	1 (17 %) of 6	92.2 ± 1.0	NA	NA	Dry
2011 (Oct) Rd.8 Motegi (9)	171.7 ± 14.5	49.7 ± 6.6	5 (56 %) of 9	94.3 ± 0.5	38.6 ± 1.1	43.5 ± 3.0	Dry
2012 (Apr) Rd.1 Okayama (9)	169.2 ± 9.4	59.8 ± 11.0	4 (44 %) of 9	93.9 ± 0.6	26.5 ± 2.8	27.6 ± 3.5	Dry
2012 (May) Rd.2 Fuji (8)	165.4 ± 11.5	57.5 ± 17.2	3 (38 %) of 8	92.1 ± 1.7	30.6 ± 1.8	47.9 ± 3.7	Dry
2012 (Jun) Rd.3 Sepang (9)	170.2 ± 11.8	51.9 ± 7.3	8 (89 %) of 9	94.8 ± 0.6	40.8 ± 3.5	42.6 ± 4.9	Dry
2012 (Jul) Rd.4 Sugo (8)	177.6 ± 5.7	50.8 ± 7.1	8 (100 %) of 8	93.8 ± 1.1	41.3 ± 5.5	43.4 ± 8.9	Dry
2012 (Aug) Rd.5 Suzuka (11)	160.7 ± 11.9	72.4 ± 8.8	7 (64 %) of 11	93.9 ± 1.3	41.8 ± 4.0	45.1 ± 6.4	Dry
2012 (Sep) Rd.6 Fuji (10)	168.1 ± 7.4	51.6 ± 15.3	5 (50 %) of 10	93.3 ± 0.6	40.9 ± 2.0	39.2 ± 5.8	Dry
2012 (Oct) Rd.7 Autopolis (10)	154.2 ± 18.4	58.6 ± 15.4	3 (30 %) of 10	90.9 ± 2.3	NA	NA	Wet
2012 (Oct) Rd.8 Motegi (8)	154.5 ± 14.2	48.9 ± 9.8	1 (13 %) of 8	88.1 ± 1.1	25.6 ± 0.6	58.7 ± 0.3	Wet
Total (116)	164.5 ± 15.1	54.2 ± 13.7	57 (48 ± 29 %) of 116	91.9 ± 3.7	36.9 ± 6.2	45.3 ± 10.9	

Values are shown as means or means ± standard deviation of the mean. Number in parentheses represent number of the drivers with complete measurements for that race

Wet condition was defined as "there is water on a road surface due to rainfall"

HR heart rate, *Rd* round, *NA* not available (Due to the technical problem to manage the measuring device for the Autopolis circuit, we were not able to measure cabin temperature in 2011 Rd.7 and 2012 Rd.7)

No one used any medicines and had any cardiovascular/metabolic diseases. Their health conditions were checked by the official doctor of the GT association before each race.

The average HR during actual races was 164.5 ± 15.1 beats min^{-1}, and the average amount of time spent driving per race was 54.2 ± 13.7 min. The rate of drivers whose highest HR reached 190 beats min^{-1} was about 50 %. The average mean speed ratio was 91.9 ± 3.7 %. The average cabin temperature and humidity were 36.9 ± 6.2 °C (range 25.6–41.8 °C), 45.3 ± 10.9 %, respectively (Table 1). Peak cabin temperature reached 54.5 °C during a summer race (July).

The multiple correlation coefficient (r) was estimated to be 0.445 ($n = 85$). Mean speed ratio was found to be the significant independent contributing factor for average HR ($P < 0.001$). However, the cabin temperature was not found to be the significant independent contributing factor for average HR ($P = 0.533$).

Average HR significantly and positively correlated with mean speed ratio on all drivers during all 13 races (Pearson: $P < 0.001$, Spearman: $P < 0.001$) (Fig. 1). Moreover, average HR significantly and positively correlated with mean speed ratio on five drivers who completed all eight races in 2012 season (Pearson: $P < 0.001$, Spearman: $P < 0.001$) (Fig. 2).

Average HR and mean speed ratios were significantly lower in wet, than in dry conditions (Fig. 3). These results were consistent for all races (Fig. 3a), for the same three circuits and the same three drivers (Fig. 3b), and for four

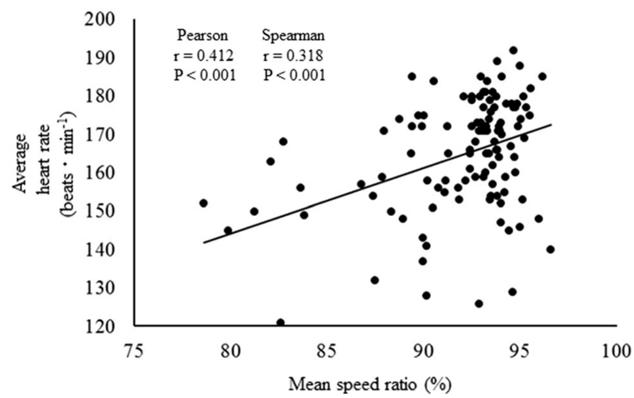

Fig. 1 Pearson's Product–Moment Correlation analysis and Spearman's Rank–Order Correlation analysis. Between average heart rate and mean speed ratio from all drivers during 13 races ($n = 116$)

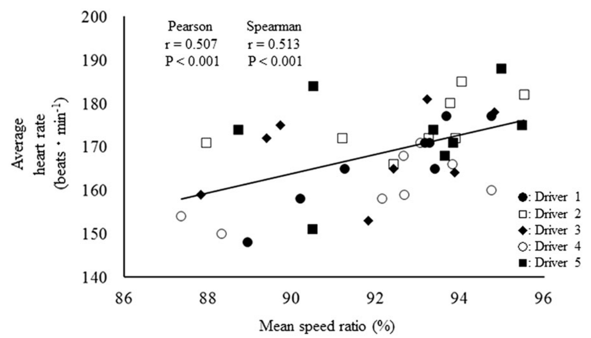

Fig. 2 Pearson's Product–Moment Correlation analysis and Spearman's Rank–Order Correlation analysis. Between average heart rate and mean speed ratio from five drivers during eight races in 2012 season ($n = 40$)

races under low outside air temperatures (14–17 °C) (Fig. 3c).

Discussion

Few studies have investigated the effects of speed and thermal stress on the cardiovascular system in a large group of professional race-car drivers during actual races. The present study found that the cardiovascular systems of many professional drivers are considerably stressed during actual races, furthermore, significant positive correlations between average HR and mean speed ratio. However, average HR did not significantly correlate with the cabin temperatures. In addition, the mean speed ratio and average HR were significantly lower under wet than dry conditions.

Heart rates during actual races

Physiological data are difficult to obtain during motorsport competitions because of factors such as powerful electromagnetic disturbances in the race-car cabin as well as the weight, size and positioning of measurement devices. Therefore, race-car drivers have typically been investigated during off-season tests, practice runs, and amateur car races, or in small study cohorts [2–6]. However, that may not have similar levels of influences during actual professional car races. Therefore, we obtained data from a larger group of professional race-car drivers during actual races through the annual season. The average HR during actual races was high in the present study and the average amount of time spent driving per race was about 1 h. Moreover, the rate of drivers whose the highest HR reached ≥190 beats min^{-1} was about 50 %. These results indicate that the cardiovascular systems of race-car drivers are considerably stressed during actual races.

Significant positive correlations between this high average HR and mean speed ratio suggest that faster driving speed would induce greater cardiovascular stress to professional drivers during actual races. A faster relative speed might induce greater gravitational loading, vibration stress, and psycho-physiological influence increasing HR [2].

Gravitational loading

Drivers maintain driving positions and the position of the head and helmet against high gravitational loading [1] primarily by isometric contraction of the neck, abdomen and legs. Therefore, increased energy requirements might be associated with increases in HR. Drivers must also maintain circulation against high gravitational loading. For example, body fluids might be pulled towards the legs during deceleration, since most race-car seats recline deeply. This gravitational loading would augment venous pooling in the lower body and reduce central blood volume and stroke volume, resulting in a reflex increase in HR similar to gravitational loading by centrifugation [16, 17].

Vibration stress

Since whole-body vibration increases HR [18], vibration from the car seat during high-speed driving may be one of the important factors to increase HR. Driving at faster speeds would induce a greater vibration and higher HR. However, we were not able to measure the levels of vibration from the car seat by technical limitations in the present study. Further study is needed to reveal this point.

Psycho-physiological influences

Psycho-physiological influences can also be involved in increasing HR. Fear can be experienced while driving at high speeds and during sudden braking. Fear, anxiety, anticipation and the competitive nature of the sport might

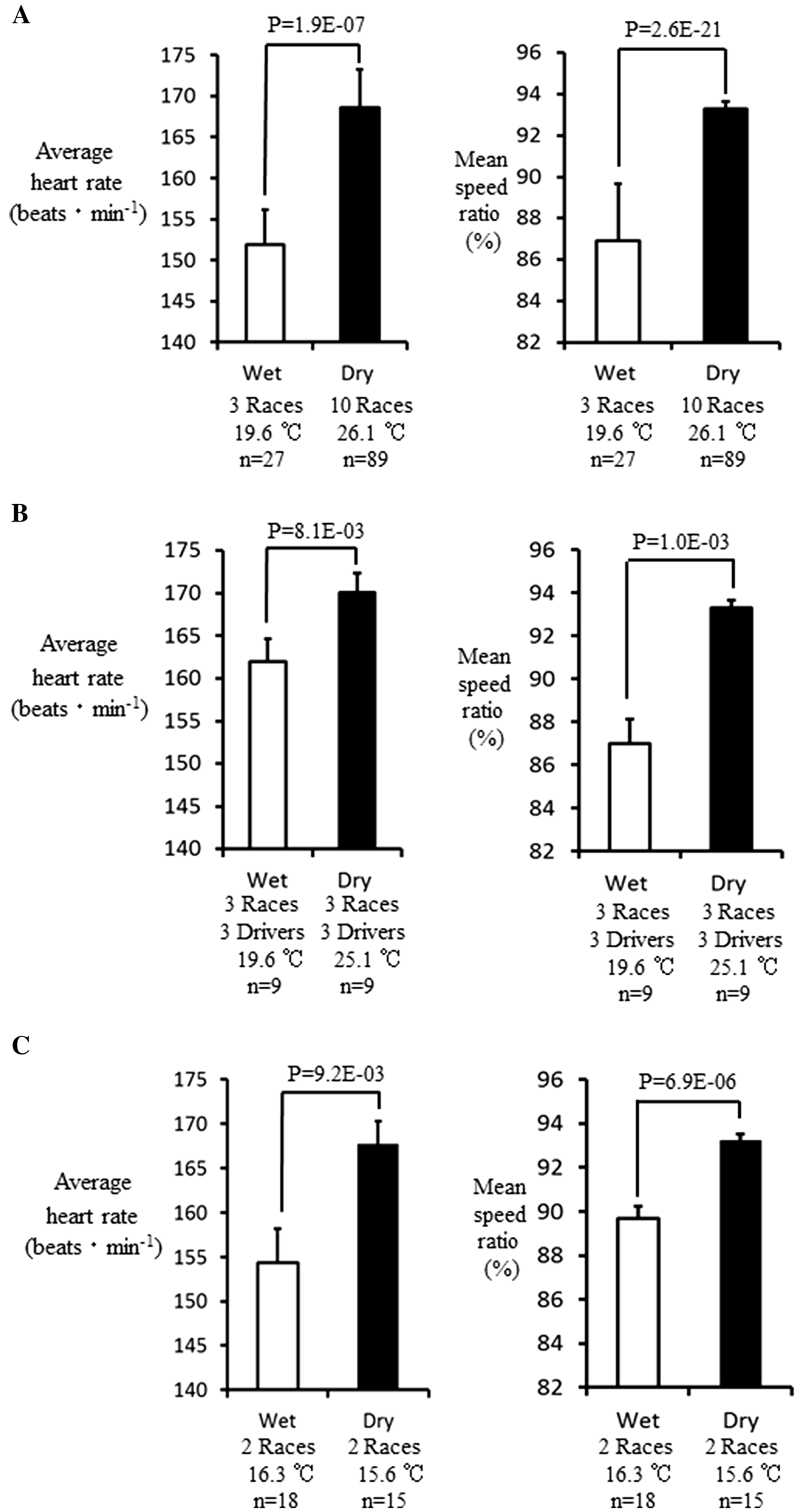

Fig. 3 Average heart rate and mean speed ratio under wet and dry conditions. Data from all races were compared wet (3 races, $n = 27$) and dry (10 races, $n = 89$) conditions using unpaired t test (**a**). Data from same three circuits and same three drivers were compared wet (3 races, $n = 9$) and dry (3 races, $n = 9$) conditions using paired t test (**b**). Data from outside air temperatures ranging from 14 to 17 °C were compared wet (2012 Round.7 and 2012 Round.8, $n = 18$) and dry (2011 Round.7 and 2012 Round.1, $n = 15$) conditions using unpaired t test (**c**). Unit of standard deviation a whisker bar represent 1 SD

increase sympathetic nervous activity and hormone release [3, 4, 8, 9]. Thus, faster speed driving may also induce greater psycho-physiological influences.

We postulated that psycho-physiological influences would increase HR more under wet, than in dry conditions due to extremely low visibility and slippery conditions. However, the results contradicted this notion. The mean speed ratio was significantly lower under wet, than dry conditions. This would suggest that the psycho-physiological influence of low visibility and slippery conditions would be weaker than the effect of relative speed on average HR under wet conditions. However, all drivers in the present study were experienced professionals, and this phenomenon might not be evident in amateur drivers.

Thermal stress and heatstroke

Drivers often experience thermal stress because safety regulations require them to wear full-face helmets, racing suits, inner wear, shoes and gloves, all of which are fire-resistant [1] and impede heat diffusion by sweat. Core temperature might increase during summer races [5, 10, 11]. We postulated that the average HR would increase with increasing cabin temperatures. Even if the thermal stress was moderate and the core temperature did not increase, hot conditions would induce greater perspiration, dehydration and peripheral vascular dilation [19]. We supposed that even moderate thermal stress would cause an increase in HR. However, we did not find a significant correlation between average HR and cabin temperatures. This finding may suggest that the effects of direct human-body cooling system (e.g. cooling suits or GT cooling systems) used in the recent professional races are satisfactory against increases in HR induced by thermal stress across the range of cabin temperatures found in the present study. In fact, one driver in the present study developed heatstroke due to a malfunctioning cooling suit during a race. His HR reached 211 beats min^{-1} (Fig. 4). Also, a case was reported that the core temperature reached about 39 °C after racing in hot environments without cooling tools [5]. Although cabin temperatures can reach about 75 °C [10], the highest cabin temperature in the present study was 54.5 °C. The results might have differed if the cabin temperatures had been higher in the present study.

Practical applications

The findings of high average HR for about 1 h and the positive correlation to driving speed indicate the greater cardiovascular stress of race-car drivers during the faster speed races. Judgment capability will decline if the limits of the physical strength of a driver are reached during a

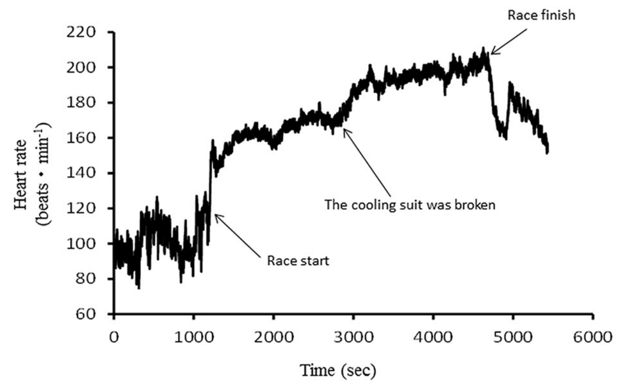

Fig. 4 Heart rate of driver who developed heatstroke

race. Judgment errors during motorsport races can lead to disasters [20, 21]. Therefore, professional drivers who participate in faster speed races should regularly participate in physical training to endure the greater stress during a race. The present HR findings during actual professional races would be useful for designing training programs. Considering that the average HR remains high for about 1 h during actual races, race-car drivers might consider endurance training such as running or cycling for about 1 h at HR between 140 and 160 beats min^{-1}. Moreover, considering the number of drivers whose highest HR reached 190 beats min^{-1} during the race, interval training might also be needed to acclimatize their hearts to such rates (for example, alternating full-speed running and walking for 5 min each). Of course, training programs would need to be individualized based on HR determined during actual races.

Limitations

A limitation of the present study is that multiple confounding factors may exit. For example, differences in gravitational loading, vibration, and psycho-physiological influences at same speed ratio among the circuit or the race-car setting were not able to be evaluated in the present study. The Clo value or insulation of the cloths may also be one of the confounding factors that we could not examine in the present study. The racing suits that drivers wore were different among the racing teams and might induce different levels of the thermal stress. We were not able to obtain these values.

The other limitation is that we did not measure the core temperature of the drivers to determine the effects of thermal stress. Although technically possible [5, 11], the regulations of this race category in Japan do not permit such measurements during races. Only permissible parameters during an actual Japanese GT race were measured in the present study.

Conclusions

The present study examined the work environment and HR of 15 professional race-car drivers during 13 races throughout two annual seasons. Considerable stress on the cardiovascular systems of professional race-car drivers induces extremely high heart rates during actual races. This high average HR positively correlated with the mean speed ratio as an index of relative speed. This finding suggests that faster driving speed would induce greater cardiovascular stress to professional race-car driver during actual races. Contrary to our hypothesis, cabin temperature and average HR were not significantly correlated. It is speculated that direct body cooling systems work well against increases in HR induced by thermal stress under the temperature range found herein. The data presented herein might be useful for designing training programs and for improving the occupational health and safety of professional drivers during car races.

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Compliance with ethical standards

Conflict of interest The authors have no conflicts of interest to declare.

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