

# Physiological measurements and analyses in motor sports: A preliminary study in racing kart athletes

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Physiological measurements and analyses in motor sports: a preliminary study in racing kart athletes.

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1 ***Abstract***

2

3 The aims of this study were, firstly, to assess methods for performing physiological  
4 measurements in motor sports and, secondly, to carry out a preliminary study in  
5 athletes participating in *Kart Racing*. The measurement of physiological variables in  
6 motor sports is practically challenging, largely due to the restricted space available for  
7 sensors and instrumentation and to movement artefacts from driver's operations and  
8 car vibration, hence the paucity of publications. We performed a preliminary study of  
9 amateur racing kart athletes to assess the performance of basic measurement apparatus  
10 and to collect preliminary data on the possible influences of  $G$  on cardiovascular  
11 activity. We measured the vector magnitude of acceleration,  $G$ , instantaneous heart rate,  
12 HR, from the ECG, blood pressure, BP, with a wrist sphygmomanometer, eardrum  
13 temperature as a core body temperature,  $T_{\text{eardrum}}$ , with a radiation thermometer, and lap  
14 time. The instrumentation functioned satisfactorily during karting on a racing circuit.  
15 In all participants during driving we found that HR was maintained at approximately  
16 150 beats/min. Time-frequency analysis of all HR data was performed to evaluate  
17 cardiac control mechanisms and this suggested that the observed rise in HR could be  
18 due to sympathetic acceleration. Furthermore, whilst we do not have sufficient data to  
19 draw firm conclusions, it is suggested that the rise in HR could be related to the  $G$   
20 stresses to which the drivers were subjected. Cross-correlation analysis of the  $G$  and  
21 HR signals was performed in one subject and this showed a statistically significant  
22 correlation. We also found a statistically significant decrease in BP ( $P<0.01$ ) and a rise  
23 in  $T_{\text{eardrum}}$  ( $P<0.01$ ) immediately after the driving period. We conclude that, whilst  
24 current sensors and instrumentation can allow basic monitoring of physiological  
25 variables in motor sport athletes, further developments are needed in order to allow  
26 more detailed investigations to be performed. Cardiovascular activity in response to  $G$   
27 stresses warrants particular detailed investigations in the future.

1

2

3 *Keywords*

4

5 blood pressure, core body temperature, acceleration, heart rate, kart racing.

6

## 1 Introduction

2  
3 We are concerned here with the investigation of physiological function in  
4 subjects driving motor vehicles. In its many forms motor vehicle driving  
5 challenges drivers in terms of physical strength and dexterity as well as  
6 mentally with respect to cognition, emotion and alertness. All of these facets  
7 interact to determine the overall performance of the driver and, in the  
8 general population, this performance is seen and judged in the road traffic  
9 accident statistics. There is considerable interest in identifying the major  
10 causes of road traffic accidents and to address these in order to reduce the  
11 associated mortality and morbidity. Physiological investigations have been a  
12 part of the overall effort in this area, looking at factors such as fatigue,  
13 drowsiness and alcohol consumption (Connor, 2002; Horne and Reyner,  
14 1995; Phillip, 2001).

15 It is also appropriate to consider the assessment of physiological function  
16 in motor sports, due to the potential for extreme levels of physical and  
17 mental stress being placed on the competitive drivers/riders. For example,  
18 rapid decisions and actions are needed to perform appropriate maneuvers  
19 safely under the significant levels of acceleration,  $G$ , that can occur with  
20 heavy braking and cornering. Despite this there have been only a few  
21 studies done to examine detailed physiological responses and motor sport  
22 driver performance, although potential benefits have been reported (Klarica,  
23 2001). This is in contrast to other popular sports, such as track and field  
24 athletics, water sports, cycling, wrestling and so on, which have been  
25 enthusiastically studied (Bird *et al.*, 2005; Chamari *et al.*, 2003; Cottin *et al.*,  
26 2004; Dranitsin, 2008; Du *et al.*, 2005; Neumayr *et al.*, 2003; Sullo *et al.*,  
27 2003).

1 It is reasonable to anticipate that cardiovascular, thermal, and respiratory  
2 systems will be influenced by the rigors of motor sport and indeed some  
3 studies have been aimed in these directions (Brearley & Finn, 2007; Jacobs  
4 *et al.*, 2002; Tsopanakis C & Tsopanakis A, 1998). The diverse abilities  
5 required of motor sports athletes include high dynamic visual acuity,  
6 responsiveness to the vehicle condition, and skills for rapid and precise  
7 vehicle control and decision-making. The reaction time of racing car drivers  
8 was reported to be significantly faster than controls, but no significant  
9 differences were found for postural stability, leg extensor strength, or arm  
10 strength and endurance (Baur *et al.*, 2006). Aerobic power, VO<sub>2</sub>, and heart  
11 rate response have been found to reach 45-81 % of values obtained in  
12 maximal graded exercise tests (Jacobs *et al.*, 2002; Tsopanakis C &  
13 Tsopanakis A, 1998). However, beat-by-beat heart rate changes/variability  
14 have not yet been thoroughly investigated.

15 For studying athletes in general, as well as persons engaged in exercise  
16 and fitness training, a variety of laboratory measurement techniques are  
17 already employed (Winter, 2007). Measurements include oxygen uptake to  
18 define the maximal value, blood lactate, muscle strength, and pulmonary  
19 function. Whilst these and other spot measurement techniques, usually  
20 performed, for example, in variants of graded exercise tests, are important  
21 tools for studying some aspects of motor sport athletes, they do not  
22 reproduce real driving and competitive conditions. In order to examine both  
23 methodological and physiological aspects of investigating motor sports  
24 athletes we consider here the sport of Kart Racing. This motor sport is  
25 generally accepted as being an accessible, relatively low cost, motor sport,  
26 under the regulation of La Commission Internationale de Karting and La  
27 Fédération Internationale de l'Automobile (CIK-FIA). It can be enjoyed by

1 males and females from the 8 years of age. In addition, it can offer a  
2 relatively safe stepping-stone for those aspiring to move into the higher  
3 ranks of motor sports. In fact, most of the recent F1 champions grew up in  
4 racing karts, prominent among them being Ayrton Senna, Michael  
5 Schumacher and Lewis Hamilton. This is a clear indication that the racing  
6 kart can indeed provide a very real experience and challenge closely allied  
7 to what exists in F1 and probably other motor sports.

8 Here we describe the overall physiological measurements and responses of  
9 drivers in racing karts, anticipating that the results might be extrapolated  
10 to other motor sports. Furthermore, this study may have broader social  
11 relevance through its potential to contribute to decreasing road traffic  
12 accidents through a deeper understanding and use of physiological signals  
13 from drivers who are in so-called overload situations (Ho *et al.*, 2007;  
14 Yamakoshi *et al.*, 2009b).

15

16

## 17 **Methods**

18

### 19 *Experimental setup and apparatus*

20 **Figure 1** shows a schematic diagram of the experimental setup. For this  
21 study we used the “Ishino Circuit”, which was built in 2008, in the Toyota  
22 City, Japan. Careful attention had been given to the track design to include  
23 safety measures, including sufficient run-off areas and shock absorbers. The  
24 main parts of the experimental apparatus were two racing karts, devices for  
25 physiological measurement with a laptop PC (Vostro1200, DELL Inc., USA)  
26 and the appropriate interfaces. The karts were the BIESSE (B3-30/100,  
27 EIKO Co. Ltd., Japan) and the INTREPID (MT-01, SANTRAD Co. Ltd.,

1 Japan). The mounted two-stroke engines we used (KT100SD, YAMAHA  
2 Corp., Japan) are the most popular for racing karts worldwide.

3 The physiological measurements were made with a compact size heart rate  
4 recorder based on an electrocardiograph (ECG) and also containing a  
5 tri-axial sensor with which to measure accelerations ( $G$ ), a wrist type  
6 sphygmomanometer, and an ear-type body thermometer. To obtain a  
7 high-quality ECG and minimise movement artefacts three pre-gelled  
8 silver/silver chloride electrodes were used and attached firmly to the chest  
9 in Lead II. Care was also taken to strap down the ECG connecting wires.  
10 With this approach the instrument was able to measure the heart rate  
11 reliably even with a significant degree of artefacts caused by physical  
12 movements.

13

#### 14 *Measurement quantities*

15 Physiological monitoring during kart racing is made difficult by the strong  
16 vibrations from the road and the engine, as well as by the drivers' rapid  
17 movements. We were therefore limited in this study in the data that we  
18 could record and collect reliably. These measurement quantities were:  
19 beat-by-beat heart rate (HR beats/min) which was calculated from the ECG  
20 RR intervals sampled at 1 ms, vector magnitude of acceleration ( $G$  mG)  
21 (Active Tracer AC-301A, GMS Co. Ltd., Japan); systolic and diastolic blood  
22 pressure (SBP, DBP mmHg) in the subject's left wrist (HEM-6371T,  
23 OMRON Corp., Japan); eardrum temperature ( $T_{\text{eardrum}}$  °C) as core body  
24 temperature (MC-501, OMRON Corp., Japan); lap time (s). Instantaneous  
25 HR and  $G$  were recorded continuously during the experiments. However, BP,  
26 using the cuff-oscillometric method which could only be used reliably under  
27 rest conditions, and  $T_{\text{eardrum}}$  were measured before and after the driving



1 period. The environmental variables air temperature and relative humidity  
2 were also measured (TR-72U, A&D Co. Ltd., Japan). The lap time was  
3 measured by high accuracy instrumentation (PRO V2 A-105, ALFANO S.A.,  
4 Italy), based on magnetic strips buried under the circuit, to 1/100 s.

5

### 6 *Participants*

7 Eleven amateur racing drivers,  $34.4 \pm 7.7$  (S.D.) yrs, without known  
8 cardiovascular disorders participated in the present study. All subjects  
9 agreed to take part in the study voluntarily and signed an informed consent  
10 statement. The study was approved by the ethics commission of the faculty  
11 of medicine of Kanazawa University. All subjects had an SL kart license and  
12 were regularly involved in kart racing.

13

### 14 *Experimental conditions*

15 The experiment was conducted in fine weather, i.e. dry conditions, during  
16 the period between November and December in 2008. The duration of the  
17 driving period was set at 30 min, unless it was terminated earlier due to  
18 mechanical problems with the kart, or if the driver reached his physical  
19 limit. The test was conducted against the clock, by solo drive on the circuit.  
20 Before the experiment, we coached the subjects to drive with their  
21 maximum effort so as to record their best lap time during the experiment,  
22 and also to make a quick return to the main course if they spun out.

23

### 24 *Procedure*

25 After placing three electrodes on the chest for recording the ECG (Figure 1),  
26 the subjects were requested to sit down quietly on a chair in a

1 temperature-controlled room. After resting for 5 min (baseline period) the  
2 subjects got into the kart and drove for approximately 30 min (driving  
3 period). Then the subject got out of the kart and rested for 5 min (recovery  
4 period). Physiological monitoring was carried out during these three periods.  
5 The timing of measurements for HR,  $G$ , BP, and  $T_{\text{eardrum}}$  was beat-by-beat  
6 continuously, 1 s continuously, 0/2/4/35/40 min and 1/5/36/41 min,  
7 respectively. Additionally, air temperature and relative humidity  
8 measurement was done at 10 min intervals.

### 9 10 *Data analysis*

11 To evaluate circulatory autonomic regulation, time-frequency analysis was  
12 carried out using the collected data. Spectral analysis was carried out using  
13 the RR data by a maximum entropy method. It was applied to a dataset of  
14 64 beats, which was updated every 16 beats. The spectral powers of RR in  
15 the low-frequency band (0.04-0.12 Hz; LF) and in the high-frequency band  
16 (0.15-0.4 Hz; HF) were calculated. It has been reported that HF power may  
17 be a marker of vagal activity (Pomeranz *et al.*, 1985; Berger *et al.*, 1989).  
18 The ratio of LF power to HF power (LF/HF) is expected to be an index of  
19 sympathetic activity (Pagani *et al.*, 1986). This spectral analysis was  
20 conducted using the special software named BIMUTUS II.

21 Descriptive statistical analysis was performed with means  $\pm$  S.D. or  $\pm$   
22 S.E.M. Between-period differences, i.e. baseline vs. driving, were assessed  
23 by the *Wilcoxon* signed-rank test. In addition, to evaluate the correlation  
24 between HR and  $G$ , cross-correlation analysis was conducted. These two  
25 analyses were performed with the software of Statistical Package for Social  
26 Sciences (SPSS version 17.0).

1

## 2 **Results**

3

4 **Table I** shows basic information of individuals and events during the  
5 experiments. As shown in Table I, three subjects, Sub.01~03, spun out and  
6 then immediately returned back into the course, and Sub.06 stopped after  
7 20 min (drove 15 min) due to mechanical trouble, and Sub.10 stopped at 26  
8 min (drove 21 min) due to reaching his physical limit. We have successfully  
9 measured the variables listed above in these subjects as well as the other  
10 drivers during the active periods of their racing kart driving. **Figure 2** shows  
11 a typical recording of a 40 min trend-chart of the physiological variables  
12 obtained in Sub.09. This includes the  $G$  power, HR, HF power as an  
13 indication of vagal activity, LF/HF power as an indication of sympathetic  
14 activity, and lap time.

15 It can be seen in Figure 2 that the  $G$  vector magnitude periodically  
16 changed according to the layout of the course. The mean values of maximum,  
17 minimum, and mean  $G$  during the driving period were  $2374 \pm 349$  mG,  $175 \pm$   
18  $20$  mG and  $681 \pm 69$  mG, respectively.

19 It is clearly shown in Figure 2 that there was a rapid increase in HR at the  
20 start of the driving period, and this then stabilized during driving. It is of  
21 note that the HR variability during driving was very low as compared to  
22 that in the baseline period. **Figure 3** shows a summary HR profile (means  $\pm$   
23 SDs) for subjects in whom full data is available ( $n = 9$ ) over the period of the  
24 experiment. Each data point was calculated from 1 minute HR averages. It is  
25 clearly shown that the HR during driving remained at a high level around  
26 150 beats/min.

27 The analysis of HF and LF/HF data clearly showed that the vagal activity

1 was suppressed and the sympathetic activity was accelerated during the  
2 driving period as compared to the baseline period. **Figure 4** presents these  
3 data as the change (means  $\pm$  SEMs) of the sympatho-vagal activity balance from  
4 baseline, during driving and recovery period. The sympatho-vagal balance was  
5 analyzed by HF and LF/HF, which were normalized using the peak value as 1.0  
6 together with the minimum value as 0. As shown in Figure 4, it is apparently  
7 demonstrated that the suppression of vagal activity and acceleration of sympathetic  
8 activity during driving were statistically significant ( $P < 0.01$ ).

9 Concerning the lap time, the results indicate that the best lap tended to appear in the  
10 first half period. Also due to the demands of severe machine control, the lap time was  
11 fluctuated within approximately 0.5 s during driving.

12 **Figure 5** shows the means  $\pm$  SEMs of the SBP, DBP, and  $T_{\text{eardrum}}$  changes from  
13 baseline at immediately after driving and 5 min after driving. Immediately after driving,  
14 SBP and DBP were significantly decreased ( $P < 0.01$ ) as compared to the baseline  
15 period, and  $T_{\text{eardrum}}$  was significantly raised ( $P < 0.01$ ). Moreover, significant decreases  
16 in SBP ( $P < 0.01$ ) and DBP ( $P < 0.05$ ), and increases in  $T_{\text{eardrum}}$  ( $P < 0.05$ ) were  
17 confirmed in the measurements 5 min after driving.

18 **Figure 6** shows a correlation between HR and  $G$ , HR and lap time. This  
19 data was derived from lap 10 to the end of driving in all subjects ( $n = 11$ ),  
20 and  $G$  and HR data were averaged during each lap over this period. Due to  
21 the narrow range of HR,  $G$ , and lap time levels in this experiment, each  
22 variable is shown as a normalized value using z-score method. It is  
23 demonstrated that the HR has a significant association with  $G$  and lap time  
24 ( $r = 0.743$ ,  $P < 0.01$ ,  $r = -0.639$ ,  $P < 0.01$ ) according to *Spearman* test. This  
25 analysis was based on mean values, but to discover more detail a  
26 cross-correlation analysis was performed between HR and  $G$ . **Figure 7**  
27 shows the time course of  $G$  and HR changes during the time period from 20

1 to 25 min in Sub.09 as shown in Fig.2. The HR was re-sampled at a  
2 frequency of 1 Hz, that is the same sampling rate as  $G$ , to produce the  
3 trend-chart shown, The numbers shown along the top of each chart indicate  
4 the corner in the circuit (see Fig.1). Looking at this section of recordings,  
5 there appears clearly some kind of correlation. Accordingly, the  
6 cross-correlation analysis was conducted for this section of data indicated in  
7 Fig.7, that is 300 paired-data set, and shifting 20 times. The result is shown  
8 in **Figure 8**. The two lines of  $r = \pm 0.117$  (df = 279) indicate the limit value of  
9 5% significance level. It is clearly demonstrated that there is a statistically  
10 significant correlation between HR and  $G$  for time shifts between 5~15 s,  
11 although not at 10 s.

12

## 13 **Discussion**

14

### 15 *Acceleration, G*

16 The results show that during driving the kart drivers experienced an  
17 average acceleration of about 0.7  $G$ , and a maximum acceleration of about  
18 2.4  $G$ . This compares with a F1 car, which can achieve a lateral acceleration  
19 of about 4.5  $G$  on cornering, whilst a high-performance road car is said to  
20 achieve a maximum of 1  $G$  (Lippi *et al.*, 2007; Watkins, 2006). Although the  
21  $G$ s during kart driving are approximately twice as small as those during F1  
22 driving, it could be considered that the physical load during motor sports  
23 can be quite high. During this situation, it is worth investigating the  
24 measurement of BP, although it is speculated that the body fluid including  
25 blood is also under the influence of these high  $G$  forces.

26 Investigation of the physical and physiological implications of exposure of  
27 motor sport athletes to various modes of acceleration could be performed in

1 complex test-rigs, but reproducing the actual changes in  $G$  that occur under  
2 live driving conditions is by no means straightforward. Thus on-track  
3 monitoring is preferred, even though this approach has its own challenges.  
4 The study of the effects of  $G$  on the human body has mostly been conducted  
5 within the context of aerospace medicine (Balldin, 2002). In this field the  
6 concern is that acceleration along the axis of the spine,  $G_{\pm z}$ , can impede  
7 blood flow to the brain, leading to ‘greyout’ or ‘blackout’ of pilots or  
8 astronauts. The study of  $G$  is also important in vehicle crash testing (Huang,  
9 2002). Here, both forward-reverse accelerations,  $G_{\pm x}$ , and lateral  
10 accelerations,  $G_{\pm y}$ , are important in terms of blood volume shifts and  
11 impact injury. A similar situation pertains in the study of contact sport head  
12 injury (Manoogian *et al.*, 2006), where crash helmet design is of interest.

13 In the present study the athletes experienced high levels of lateral  
14 accelerations,  $G_{\pm y}$ . This is discussed further below in relation to the  
15 changes found in HR.

16

### 17 *Blood pressure*

18 The BP responses investigated in this study were for two conditions,  
19 namely, immediately after driving and five minutes after driving. It is  
20 widely known that the BP can act as a physiological stress marker (Sawada  
21 *et al.*, 2002). Therefore, it might be anticipated that BP would be  
22 significantly raised during motor sports. However, we found that both  
23 systolic and diastolic pressures were statistically significantly decreased  
24 immediately after driving ( $P < 0.01$ ) as compared to the pre-driving baseline. This  
25 finding differs from the results of reported studies where BP was raised  
26 immediately after exercise (Du *et al.*, 2005; Laukkanen *et al.*, 2004; Molina  
27 *et al.*, 1999). We suggest that after driving the relief and sense of safety

1 could be dominant. Our results could suggest a rebound reaction.

2 It would be valuable to measure BP continuously during motor sports but  
3 this is technically difficult with current instruments. However, we have  
4 recently developed a BP system utilizing the volume-compensation principle  
5 (Nakagawara & Yamakoshi, 2000; Tanaka *et al.*, 2007; Yamakoshi, 2003;  
6 Yamakoshi *et al.*, 2000), which is capable of measuring instantaneous BP  
7 (Yamakoshi, 1991; Yamakoshi *et al.*, 1980). Instantaneous BP response  
8 during simulated monotonous driving has already been measured with this  
9 method (Yamakoshi *et al.*, 2009a & 2009b). We will now consider the  
10 feasibility of using this method during motor sports.

#### 11 12 *Core body temperature*

13 It was confirmed that the core body temperature,  $T_{\text{cardrum}}$ , was significantly  
14 increased ( $P < 0.01$ ) at the end of the driving session by approximately 0.5 °C.  
15 Although this temperature is not really reflected as a steady-state one, as mentioned  
16 below, it could be suggested that motor sports can have considerably increased the core  
17 temperature. The mechanism for this rise during exercise was reported by Nielsen to be  
18 physiological thermoregulation (Nielsen, 1938), and it was also found that the  
19 steady-state core body temperature is reached after 40-50 min from the beginning of  
20 exercise. This steady-state temperature has been reported to be proportional to the  
21 magnitude of exercise intensity (Saltin & Hermansen, 1966). These authors also found  
22 that the core temperature is not influenced by the ambient temperature over the range  
23 5-36 °C for the same level of exercise intensity. It is therefore likely in our own study  
24 that the core temperature obtained was little influenced by air temperature during the  
25 experiment since this was relatively constant, at  $16.2 \pm 3.9$  (S.D.) °C (Table I). In fact,  
26 there was a large difference between the ambient temperatures in our study. Comparing  
27 the cloudy weather group (ambient temperature=  $13.1 \pm 1.0$  S.D.,  $T_{\text{cardrum}}$ =  $36.3 \pm 0.3$

1 S.D. °C:  $n = 6$ ) to the fine weather group (ambient temperature=  $20.4 \pm 1.6$  S.D.,  
2  $T_{\text{cardrum}} = 36.6 \pm 0.6$  S.D. °C:  $n = 5$ ), the averaged core temperature at the immediately  
3 after driving shows no statistically significant differences. Nevertheless, it is possible  
4 that core temperature could be increased by large environmental temperatures higher  
5 than  $36$  °C. In fact, the temperature in a closed cockpit can rise to about  $70$  °C in  
6 unusually hot conditions (Jareno *et al.*, 1987), or about  $50$  °C in hot conditions  
7 (Brearley & Finn, 2007). Furthermore, it should be noted that the driver must wear a  
8 racing suit, gloves, high-cut shoes and a full-face helmet for safety. Evaporation of  
9 sweat from the driver's skin is therefore prevented, seriously impairing evaporative  
10 heat dissipation, which is the only mechanism for losing excess body heat when  
11 environmental temperature rises above body temperature, that is beyond  $36$  °C. In fact,  
12 it has been reported that the core body temperature during supercar racing was rising to  
13 about  $39$  °C in hot conditions (Brearley & Finn, 2007). Monitoring of continuous core  
14 temperature during motor sports must therefore be regarded as an important aspect of  
15 driver protection. In addition, although there was no evidence of correlation between  
16 core body temperature and lap time, monitoring of core temperature could possibly be  
17 useful in assessing driver's performance.

18

### 19 *Heart rate*

20 It is well known that the beat-by-beat HR data contains information on  
21 circulatory autonomic regulation (Berger *et al.*, 1989; Pagani *et al.*, 1986;  
22 Pomeranz *et al.*, 1985) and so we conducted spectral analysis of RR data to  
23 explore this. We found significant suppression of vagal nerve activity ( $P < 0.01$ ) and  
24 acceleration of sympathetic nerve activity ( $P < 0.01$ ) during driving. It seems highly  
25 likely that this is beta-adrenergic sympathetic acceleration and is the underlying  
26 mechanism of the rise in HR.

27 As shown in Figure 3, HR increased rapidly and then stabilized at about



1 150 beats/min (approximately twice the baseline value) for the first half of  
2 the driving period. There was a small but steady decrease in HR from  
3 around the middle of the driving period until the end. From the HR  
4 variability point of view, analysis of the CVs (coefficients of variation)  
5 showed that this was statistically higher in the baseline period than in the  
6 driving period (driving = 0.062; baseline = 0.119:  $P < 0.01$ ). It could be  
7 speculated that during driving the cardiac performance in terms of cardiac  
8 reserve or margin, was decreasing in our amateur participants, as  
9 influenced by vagal suppression (Berger *et al.*, 1989; Pomeranz *et al.*, 1985).  
10 However, it has been reported that physically trained athletes are  
11 strengthened in terms of this vagal activity (Levy *et al.*, 1993), so the  
12 extremely hard-trained racing driver, such as those in F1, might not exhibit  
13 this decreasing cardiac performance.

14 The correlation between  $G$  and HR, shown in Figs. 6-8, is of interest. It has  
15 been reported that the vagal activity for the heart has a relatively quick  
16 response of approximately 1 s as compared with that of sympathetic activity,  
17 which is approximately 10 s (Berntson *et al.*, 1997). In motor sports athletes,  
18 we have demonstrated, by using the time frequency analysis, that  
19 sympathetic acceleration is dominant. So, we can speculate that the HR  
20 phase shift of 5~15 s is mainly due to the sympathetic nerve control. Taking  
21 these results into consideration, whilst we do not have sufficient data to  
22 draw firm conclusions, it could therefore be suggested that the HR is  
23 influenced by the accelerations,  $G$ , to which the driver is subjected, and  
24 possibly also it will be related to the lap time.

25 A consideration of muscle behaviour appears to support this hypothesis  
26 further. Key muscle groups used in motor sport may be considered to  
27 require a mostly reactive role, as they maintain posture in the face of the

1 rapidly changing  $G$  forces, whereas other sports generally require muscles  
2 to perform in a proactive way. Therefore, once again, this suggests that the  
3 HR levels and changes that we have observed in our study are closely  
4 related to the drivers' responses to the  $G$  forces to which they were subjected.  
5 Further investigation of this finding of the relationship between HR and  $G$   
6 will be required.

7 Although our findings were obtained in amateur racing drivers, HR trends  
8 obtained in F1 drivers by Ceccarelli, who was a doctor in the TOYOTA F1  
9 Racing Team, and Watkins tend to be similar (f1.panasonic.com, 2009;  
10 Watkins, 2006). It could therefore be argued that our results are  
11 representative of the general physiological responses in motor sports.

12 The HR was found in our study to be raised and maintained at about 150  
13 beats/min, due to sympathetic nerve activity and adrenergic sympathetic  
14 activity simultaneously. Although, bearing in mind the finding that HR is  
15 closely related to core body temperature (Ladell & Watkins, 1956), HR  
16 during motor sports could be elevated even more in hot condition, this HR  
17 response being similar to that seen in the long-distance runner (Du *et al.*,  
18 2005). The physiological purpose of this rise in HR is of course to meet the  
19 oxygen requirements of the muscles but also of the brain. Cerebral  
20 oxygenation is especially important in motor sport, where perception,  
21 judgment and rapid decision-making are arguably more important than in  
22 many other sports. Overall, it could be said that the motor racing driver  
23 must be a super athlete, needing to face tough competition with a clear and  
24 cool head, under extreme physiological conditions.

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27 **Conclusion**

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A physiological measurement study in racing kart drivers has found clear BP, core body temperature and HR responses, related in part to the imposed *G* forces experienced by the drivers. Our results clearly confirm the heavy physiological burden that must be tolerated by participants in motor sports. The muscle dynamism and the bodily conflict clearly visible in many other popular sports, may not easily be perceived by observers, as the racing driver is completely obscured by the racing suit and full-face helmet with a mirrored shield. We emphasise the importance of physiological measurement during motor sports and conclude that more research is needed to pursue further the detailed physiological aspects under full competitive racing conditions.

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1 *Figure captions*

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3 Figure 1. Outline of experimental setup for physiological measurements  
4 during racing kart driving.

5  
6 Figure 2. Typical examples of 40 min trend-charts of Acceleration, HR, HF,  
7 LF/MF and Lap Time obtained in one subject.

8  
9 Figure 3. Time course of heart rate changes (means  $\pm$  SDs) throughout the  
10 study period.

11  
12 Figure 4. Means  $\pm$  SEMs of the sympatho-vagal activity balance from  
13 baseline during driving and recovery period analyzed by the normalized HF  
14 & LF/HF trend-charts. Asterisks indicate significant deviation according to  
15 the *Wilcoxon* test (\* $P < 0.05$ , \*\* $P < 0.01$ ). See text for details.

16  
17 Figure 5. Means  $\pm$  SEMs of the SBP, DBP, and  $T_{\text{eardrum}}$  changes from  
18 baseline at immediately after driving and 5 min after driving. Asterisks  
19 indicate significant deviation according to the *Wilcoxon* test (\* $P < 0.05$ , \*\* $P$   
20  $< 0.01$ ). See text for details.

21  
22 Figure 6. Correlation between HR and  $G$ , HR and Lap Time. Each variable  
23 are shown as normalized value.

24  
25 Figure 7. Time course of acceleration ( $G$ ) and re-sampled heart rate changes  
26 during 20 to 25 min in the Sub.09 as shown in Figure 2. Re-sampling of HR  
27 was 1 s, which was the same as  $G$  sampling rate. The numbers shown along

1 the top of each chart indicate the corner in the circuit.

2

3 Figure 8. Results of cross-correlation analysis. The two lines of  $r = \pm 0.117$   
4 indicates the limit value of 5% significance level.

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6 ***Table captions***

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8 Table I. Basic information of the volunteer racing kart drivers.

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11 *Ethical standards*: The study was approved by the ethics commission of the  
12 faculty of medicine of Kanazawa University.

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14 *Competing Interest*: The authors declare that they have no conflict of  
15 interest.

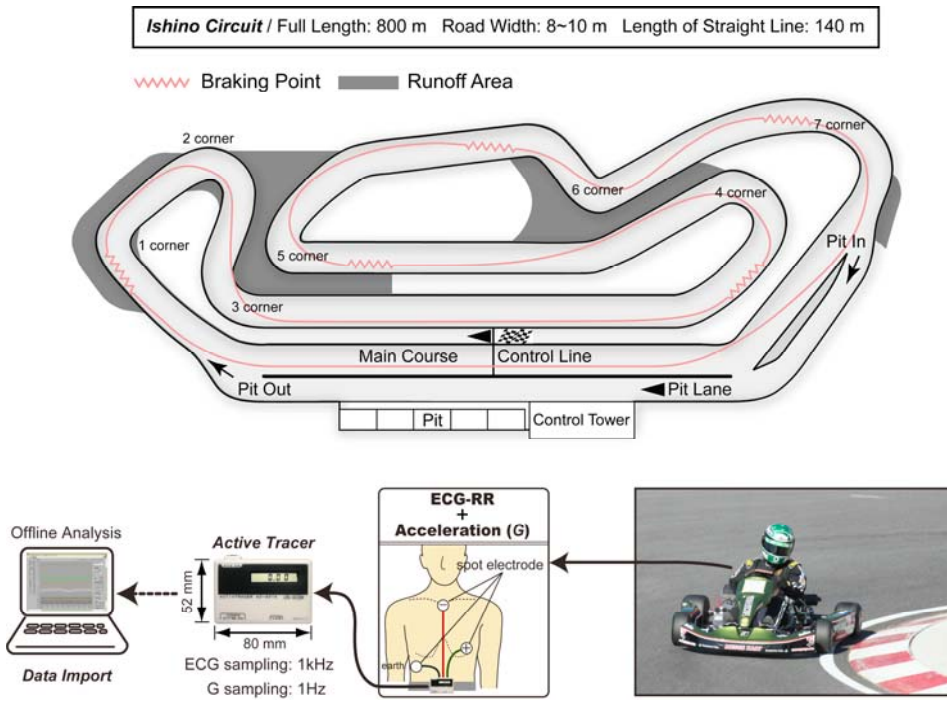
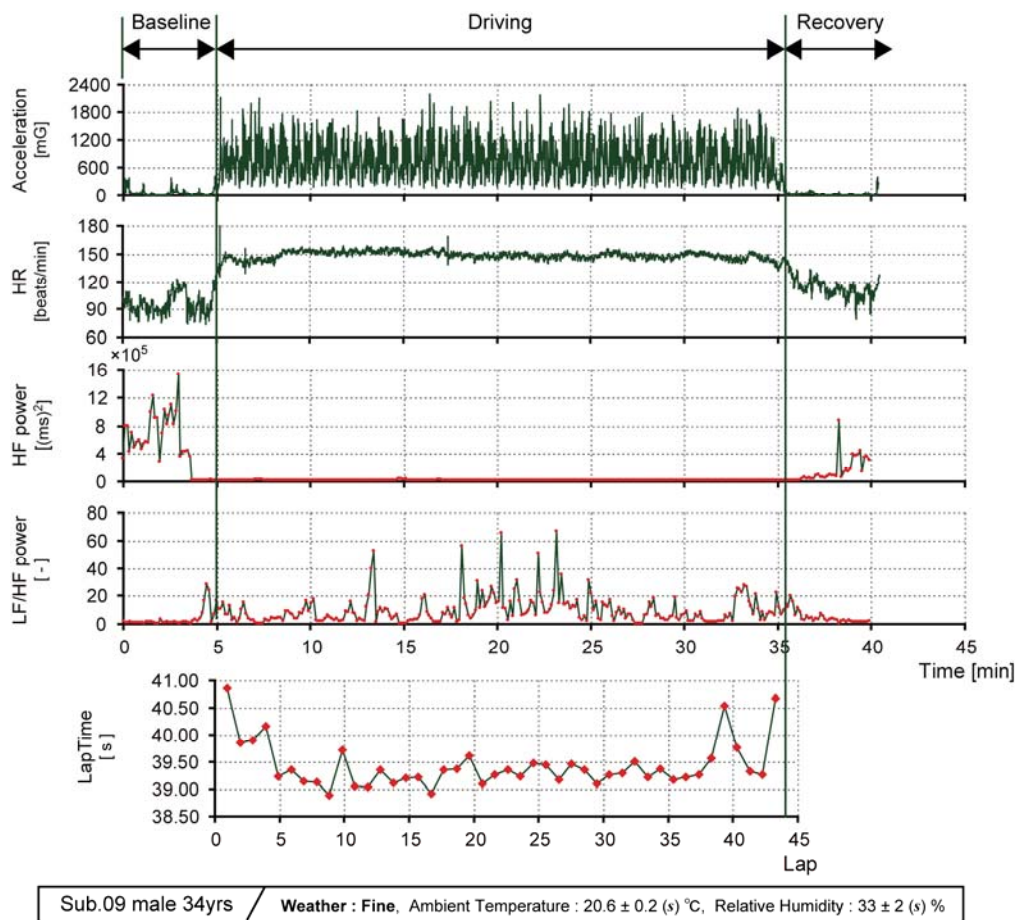


Figure 1. Outline of experimental setup for physiological measurements during racing kart driving.

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HR, heart rate; HF, spectral power of high frequency band; LF/HF, ratio of low frequency power to HF power.

Figure 2. Typical examples of 40 min trend-charts of Acceleration, HR, HF, LF/HF and Lap Time obtained in one subject.

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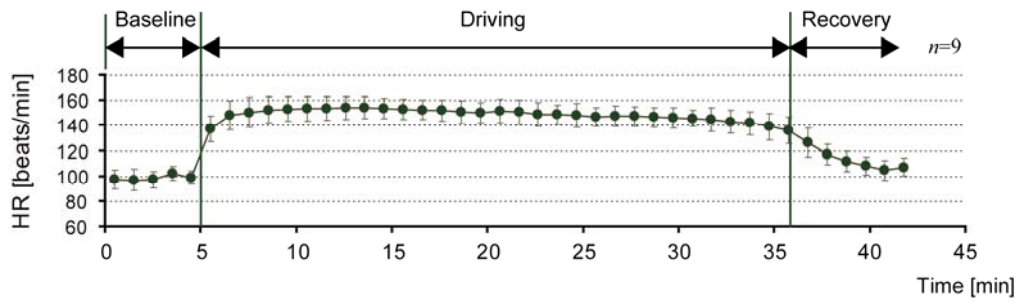
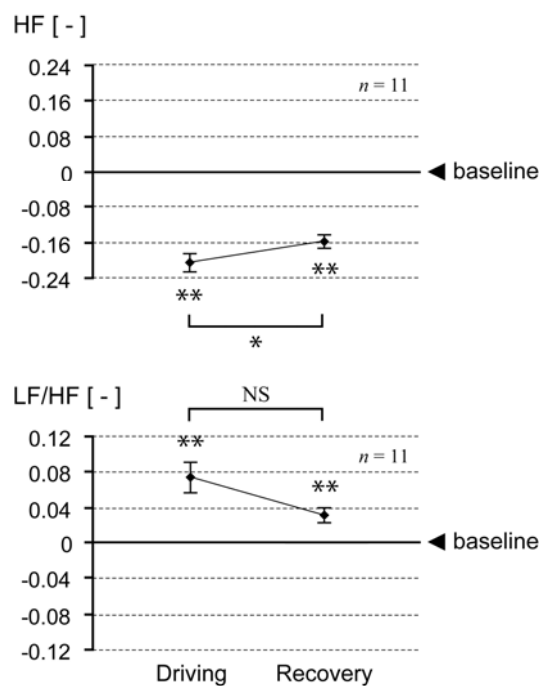


Figure 3. Time course of heart rate changes (means  $\pm$  SDs) throughout the study period.

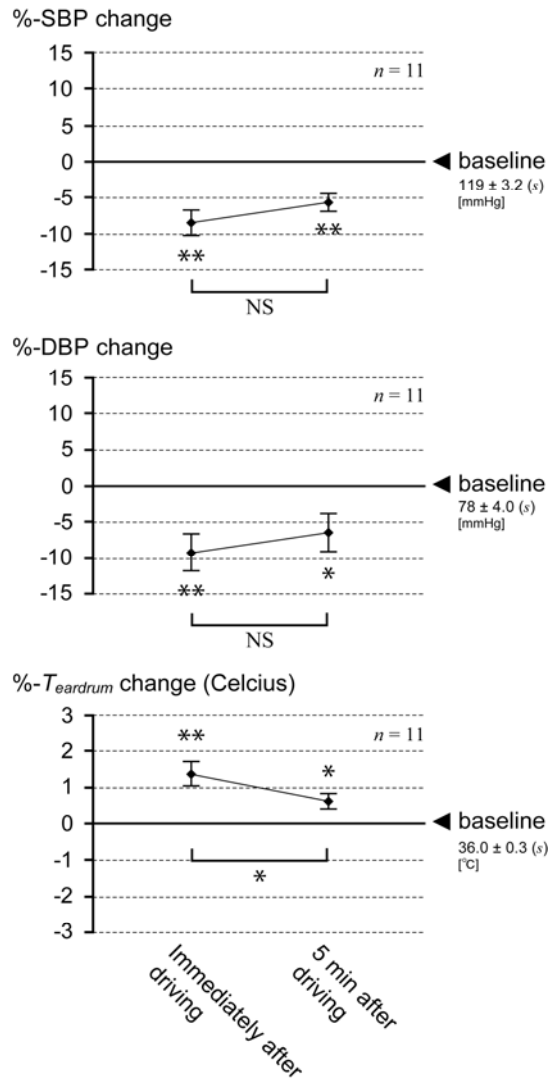
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HF, spectral power of high frequency band; LF/HF, ratio of low frequency power to HF power.

Figure 4. Means  $\pm$  SEMs of the sympatho-vagal activity balance from baseline during driving and recovery period analyzed by the normalized HF & LF/HF trend-charts. Asterisks indicate significant deviation according to the *Wilcoxon* test (\* $P < 0.05$ , \*\* $P < 0.01$ ). See text for details.

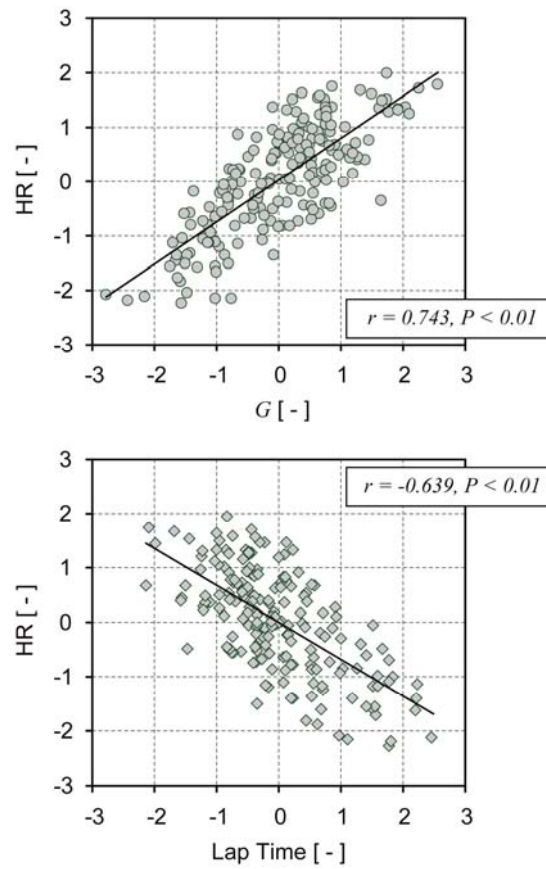
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SBP, systolic blood pressure; DBP, diastolic blood pressure;  $T_{\text{eardrum}}$ , eardrum temperature.

Figure 5. Means  $\pm$  SEMs of the SBP, DBP, and  $T_{\text{eardrum}}$  changes from baseline at immediately after driving and 5 min after driving. Asterisks indicate significant deviation according to the *Wilcoxon* test (\* $P < 0.05$ , \*\* $P < 0.01$ ). See text for details.

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N-HR, normalized heart rate; N-G, normalized G force power, N-Lap time, normalized Lap Time.

Figure 6. Correlation between HR and G, HR and Lap Time. Each variable are shown as normalized value.

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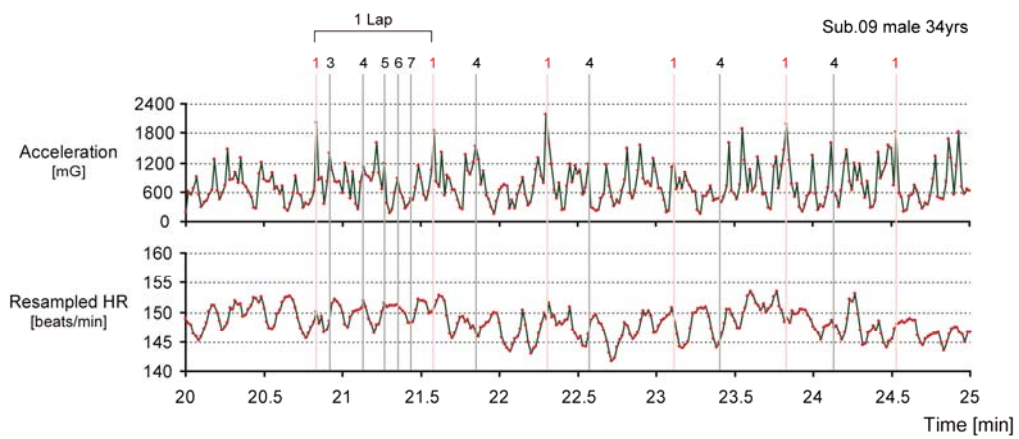


Figure 7. Time course of acceleration ( $G$ ) and re-sampled heart rate changes during 20 to 25 min in the Sub. 09 as shown in Figure 2. Re-sampling of HR was 1 s, which was the same as  $G$  sampling rate. The numbers shown along the top of each chart indicate the corner in the circuit.

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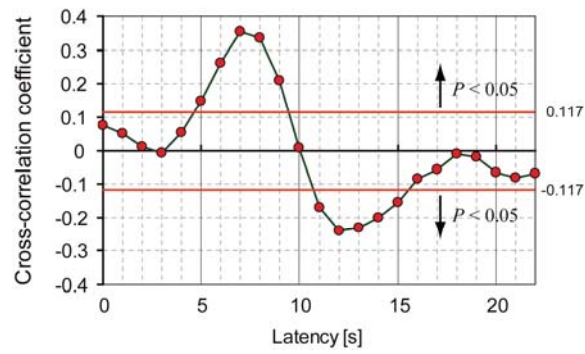


Figure 8. Results of cross-correlation analysis. The two lines of  $r = \pm 0.117$  indicates the limit value of 5% significance level.

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Table I. Basic information of the volunteer racing kart drivers.

Subject No.	Age	Kart Experience	Weather	Mean (S.D.) of Ambient Temp.	Mean (S.D.) of Relative Humidity	Events
	[yrs]	[yrs]		[°C]	[%]	
01	34	3	Cloudy	13.1 (0.2)	66 (4)	Spinout at 24 min
02	30	3	Cloudy	14.0 (0.5)	62 (1)	Spinout at 20 min
03	26	2	Cloudy	13.9 (0.2)	66 (5)	Spinout at 26 & 31 min
04	31	4	Cloudy	13.7 (0.4)	70 (2)	–
05	34	5	Cloudy	12.1 (0.2)	82 (1)	–
06	30	6	Cloudy	11.5 (0.3)	84 (2)	Machine trouble at 20 min
07	33	4	Fine	18.0 (0.1)	40 (2)	–
08	28	2	Fine	18.8 (0.4)	39 (1)	–
09	34	5	Fine	20.6 (0.2)	33 (2)	–
10	58	18	Fine	21.5 (0.6)	31 (1)	Reach the end of his Lether at 26 min
11	30	1	Fine	21.3 (0.3)	34 (1)	–
Mean	33.46	4.82		16.2	49	
S.D.	8.15	4.41		3.9	20	