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Development of a Novel Tympanic Temperature Monitoring System for GT Car Racing Athletes

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Motor racing athletes, especially Grand Touring (GT) car racing drivers in the closed-cockpit category, can face life-threatening situations caused by heat stroke. In this paper, a novel continuous tympanic temperature monitoring system, that could help to reduce this risk, is presented. The system consists of an earpiece containing an infrared-radiation-type tympanic thermometer and a micro-speaker. We validated the reliability of the system for tympanic temperature monitoring in 10 healthy volunteers (21.8 ± 1.0 S.D. years) using a temperature-controlled water bath. In addition, we evaluated the usefulness of the system with 2 professional drivers under real racing conditions in the 2010 SUPER GT International Series. The results showed strong correlation between the infrared-radiation tympanic temperature obtained by the present system and both the direct tympanic temperature (r = 0.994, n = 1119, P < 0.001) and the sublingual temperature (r = 0.972, n = 1119, P < 0.001) as a reference temperature. The mean difference between these temperatures was +0.09 °C, and -0.08 °C, and 95 % confidence interval (equal to 1.96 S.D.) was 0.21 °C, and 0.44 °C, respectively. In the field test, involving real competitive racing under severe conditions on a racing circuit, the system functioned well. These results suggest that our novel system has an acceptable performance in a race setting as a reliable tympanic temperature monitor and could help to improve safety of motor sports.

Keywords—**body core temperature, continuous monitoring, heat stroke, motor sport, thermal stress**

I. Introduction

Motor racing athletes are not only fighting against their rival competitors, but are also facing the invisible enemy of intense high-level thermal stress during racing. Actually, it has recently been reported that in current motor racing the risk of heat stroke by elevated body temperature is increasing [1-3]. There are two main factors contributing to the occurrence of heat stroke in motor racing. The first comes from the environment surrounding the driver. Generally in motor racing the cabin-air conditioner is removed in order to reduce weight and maximise speed. As a result, it has been reported that the temperature in the cockpit can rise to about 70 °C in unusually hot conditions [4]. Despite this abnormal environment, for reasons of safety, drivers are also obliged to wear a special racing suit with a full-face helmet. The last factor is simply the very high level of physical effort demanded of the racing athletes [1,5,6]. Motor racing is a recognised isometric challenge [6] as a result of the intense *g*-forces generated [1,5,7], which can increase the athletes' body temperature considerably [7].

An elevated body core temperature can adversely affect concentration and decision-making thereby increasing the risks of accidents [2]. Therefore, the monitoring of body core temperature during racing could bring significant safety benefits to motor sports.

With regard to body core temperature, there are several anatomical sites that indirectly reflect core temperature, examples including the axilla, the oral cavity, the eardrum, and highly-insulated skin temperature. However, considering the need to make measurements continuously and conveniently without undue encumbrance to the athlete, the measurement of tympanic temperature would appear to be the most appropriate technique in practice. In addition, it has been reported that tympanic temperature is the most reliable non-invasive index of core temperature, due to the fact that the eardrum reflects the temperature of the internal carotid artery, which feeds the hypothalamus [9,10]. Therefore, the purpose of the present study was to examine the reliability of the developed system for continuous tympanic temperature monitoring. Firstly, we compared measurements from a novel infrared-radiation tympanic thermometer to direct tympanic and sublingual temperatures. Secondly, we evaluated the usefulness of the new device under real GT racing conditions.

II. MATERIALS & METHODS

A. System Description

Fig. 1 shows an outline of the whole system for the measurement of tympanic temperature. The key points of the system are two newly developed ear-pieces, one with a micro-speaker for communication and the other custom-made to incorporate a temperature sensor with a second micro-speaker. In addition, a warning light located in the corner of the car front window flashes when the measured tympanic temperature exceeds a set threshold.

B. Comparative evaluation test

A test was conducted in healthy volunteers to compare the tympanic temperature measured by the infrared-radiation-type thermometer in the present system, with direct tympanic and sublingual temperatures using high accuracy contact sensors. 10 healthy male participants, with a mean age of 21.8 ± 1.0 S.D. years, without known cardiovascular disorders participated in the present study. All subjects agreed to take part in the study voluntarily and signed an informed consent statement. The study was approved by the ethics commission of the faculty of medicine of Kanazawa University.

We used two electronic thermometers (DS103, TECHNOL SEVEN Co., Ltd.: accuracy ± 0.02 °C, resolution 0.001 °C) with two highly sensitive thermistor probes (SXK-67, TECHNOL SEVEN Co., Ltd.: 3φ), which were properly calibrated at fixed temperatures specified in the International Temperature Scale of 1990 (ITS-90) by the manufacturer who provided a test chart just before our experiment. The measured temperatures were recorded at 30 s intervals. We positioned the tailor-made ear-piece with the implanted thermo-pile sensor in the right ear. In the left ear we carefully placed the thermistor probe so as to softly contact the eardrum, and then fixed it by infusing an impression material. The same type of thermistor probes were used for the measurement of sublingual and water temperatures, being fixed beneath the tongue and the inside wall of the bathtub respectively.

After ensuring that the participants had adequate hydration with appropriate fluid intake, they were requested to sit down in a quiet, temperature-controlled, healthcare laboratory having a built-in bathroom, in Kanazawa University. The four stages of the experiment were carried out in the following order: (a) volunteer wearing a bathing suit and the temperature sensors attached in the appropriate positions; (b) a rest period of 10 min; (c) a bathing period of 30 min, with the water preset to 42 °C; (d) a 30 min period during which the water temperature was reduced gradually by pouring in cold water. We used correlation analysis and *Bland-Altman* plots for assessing the differences between the two measuring methods [11].

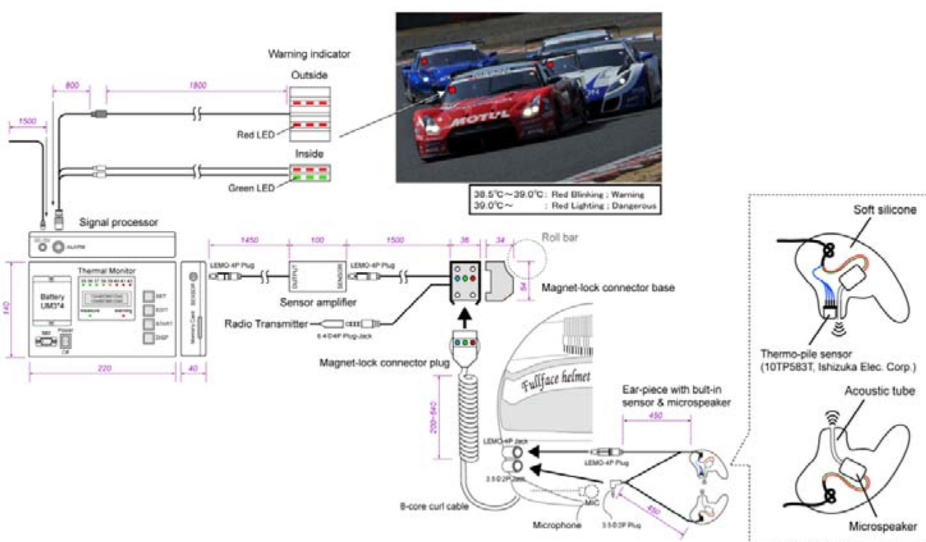

Fig. 1 Outline of the complete system for the measurement of tympanic temperature using an ear-piece with a built-in microspeaker. The inserted photo in the upper right part is provided by GTA Co., Ltd.

C. Test during real racing

An evaluation test was conducted to determine the operational performance of our system under real racing conditions. This test was performed during the 2010 SUPER GT (S-GT) International Series that was held at the Twin Ring Motegi in Japan. Two healthy male professional athletes (#01/#02), who were regular drivers of *Autobacs Racing Team Aguri*, together with their associated team, participated in the present study.

We measured the following temperature data during racing: the tympanic temperature (T_{ty}) obtained by the newly developed system; the air temperatures ($T_{a(cabin)}$ and T_a) and relative humidities (RH_{cabin} and RH) in the cabin and the pit, respectively; and the ambient temperatures ($T_{a(suit)}$ and $T_{a(met)}$) and relative humidities (RH_{suit} and RH_{met}) in the racing suit and the helmet using a thermo-hygrometer (DS1923, Maxim Integrated Products, Inc.: 17φ*6H mm, 3.3 g). Tympanic temperature and environmental variables were recorded every 10 s and 30 s respectively. These data were automatically recorded in every session, that is Practice, Qualifier, Freerun, and Final. S-GT is an endurance race, so every team (about 40 teams) is obliged to engage 2 or more drivers, and is required to change the driver at least once in the final race.

III. Result

A. Comparative test

Fig. 2 shows clearly that the tympanic temperature obtained by the present system corresponded well with the direct tympanic temperature and sublingual temperature.

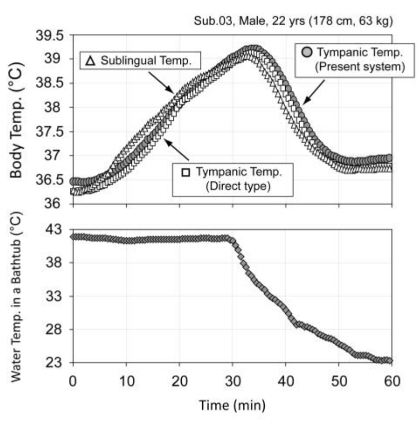

Fig. 2 Typical trend-charts showing simultaneous recordings of the body temperatures and the water temperature in a bathtub.

Fig. 3 shows the relationships, firstly, between the direct tympanic temperature ($T_{ty\text{-}direct}$) and the tympanic temperature measured by the present system (T_{ty}) and, secondly, between the sublingual temperature (T_{subl}) and T_{ty} (Fig 3a). Their corresponding *Bland-Altman* plots are shown in Fig 3b. These results demonstrate a strong correlation between the T_{ty} and both the $T_{ty\text{-}direct}$ (r = 0.994, n = 1119, P < 0.001) and the T_{subl} (r = 0.972, n = 1119, P < 0.001). According to the *Bland-Altman* analysis, the mean difference between these temperatures ($T_{ty} - T_{ty\text{-}direct}$, $T_{ty} - T_{subl}$) was +0.09 °C, -0.08 °C, and 1.96 S.D. was 0.21 °C, 0.44 °C, respectively.

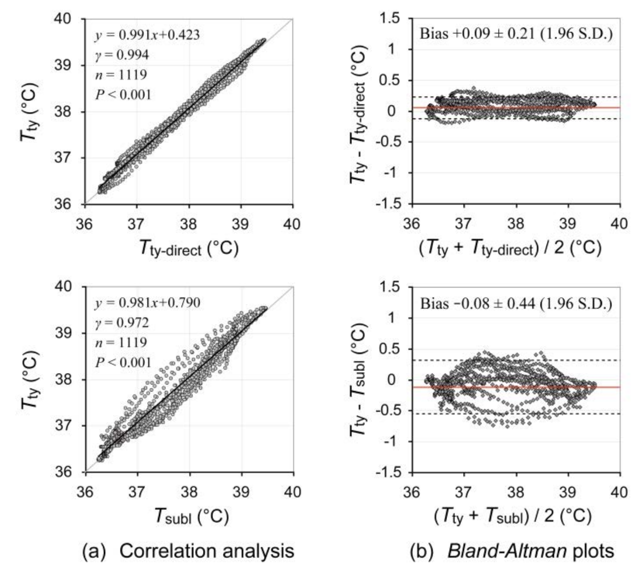

Fig. 3 Analytical results of comparative evaluation test. (a) Relationship between the direct tympanic temperature ($T_{ty\text{-}direct}$) and the tympanic temperature measured by the present system (T_{ty}), and that between the sublingual temperature (T_{subl}) and T_{ty}, and (b) their *Bland-Altman* plots.

B. Real racing test

As shown in Fig. 4, the system functioned well under real competitive racing conditions. It was verbally reported from both drivers that the radio contact with the pit-crew was also loud and clear during racing, and fitting of the device to the ear was also comfortable. The T_{ty} gradually increased to the threshold levels, and it can be seen that this activated the flashing warning light a few times (the period from 45 to 72 min in Fig. 4a, and from 25 to 40 min and 60 to 85 min in Fig. 4b) in the race.

As for the local environment around the body, although the variables were changing according to the situations, the maximum value of $T_{a(cabin)}$, $T_{a(suit)}$, $T_{a(met)}$, RH_{cabin}, RH_{suit}, and RH_{met} were 33.0 °C, 35.3 °C, 37.9 °C, 22.0 % (minimum), 94.8 %, and 95.8 % respectively.

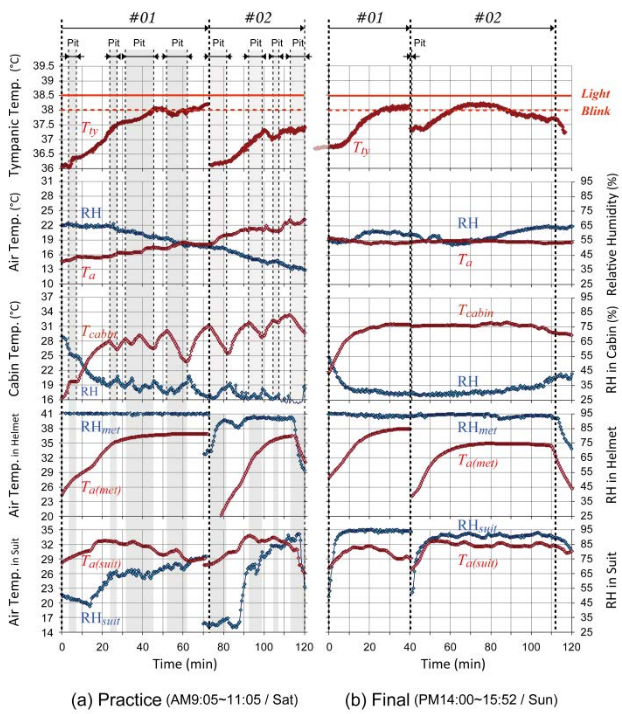

Fig. 4 Results of real racing test. (a) Practice and (b) Final session of SUPER GT International Series.

IV. Discussion

We have developed a novel system for the continuous monitoring of tympanic temperature suitable for use with GT car racing athletes. The device allows tympanic temperature monitoring using an infrared-radiation sensor, with a micro-speaker in order to maintain the unique communication system that is vital for motor sports. The performance of the system was evaluated, firstly, to determine the validity using a temperature-controlled water bath, secondly, to evaluate the practical use under real racing conditions. The results clearly showed a strong correlation between the tympanic temperature measured with the newly developed system and both the direct tympanic temperature and the sublingual temperature. As for the field test during racing, the system functioned well, and verified its usefulness in warning of potentially hazardous high tympanic temperature. These results suggest that our novel system can be used in a race setting as a reliable tympanic temperature monitor and could help to improve safety of motor sports.

Despite these positive findings our tympanic temperature system for use in racing car athletes may well have important limitations. It is still not known whether or not tympanic temperature can accurately reflect the racing car driver's core temperature under the extremely severe and unique conditions in motor sports, *i.e.* exercising under intensive *g*-force, under the severe mental and physical stress, and under the influence of cooling underwear. In addition, further studies are needed to examine fully the operational performance of the present system using a more acceptable "gold-standard reference" of body core temperature, examples including the temperature of an intra-pulmonary artery, the esophagus, the rectum, or the gastrointestinal tract [8].

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