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A Preliminary Study on Driver's Stress Index Using a New Method Based on Differential Skin Temperature Measurement

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Abstract— **Prolonged periods of driving in monotonous situations may lower a driver's activation state as well as increasing their stress level due to the compulsion to maintain safe driving , which may result in an increased risk of a traffic accident. There is therefore an opportunity for technological assessment of driver physiological status to be applied in-car, hopefully reducing the incidence of potentially dangerous situations. As part of our long-term aim to develop such a system, we describe here the investigation of differential skin temperature measurement as a possible marker of a driver's stress level. 10 healthy male subjects were studied, under environment-controlled conditions, whilst being subjected to simulated monotonous travel at constant speed on a test-course. We acquired measurements of relevant physiological variables, including truncal and peripheral skin temperatures (T_s), beat-by-beat blood pressure (BP), cardiac output (CO), total peripheral resistance (TPR), and normalized pulse volume (NPV) used as an indicator of local peripheral vascular tone. We then investigated the driver's reactivity in terms of cardiovascular haemodynamics and skin temperatures. We found that the simulated monotonous driving produced a gradual drop in peripheral T_s following the driving stress, which, through interpretation of the TPR and NPV recordings, could be explained by peripheral sympathetic activation. On the other hand, the truncal T_s was not influenced by the stress. These findings lead us to suggest that truncal-peripheral differential T_s might be used as a possible index indicative of the driver's stress. Such an index, if decisively validated, would be easy to apply in real driving situations by using radiation thermometer.**

I. INTRODUCTION

THE motor vehicle is regarded in most societies as an essential commodity, yet the considerable number of traffic accidents presents us with serious social problems. It is considered here that two significant causative factors in traffic accidents arise from the nature of the operational situation: one is driver overload, and the other is monotony. In the former, the driver is faced with too many decisions and driving tasks, such as right- or left turns at busy intersections, or traveling at high speed, or combinations of events demanding decisions and rapid actions. During such situations the driver has to raise his/her activation state and this might reach a level at which there is likely to be an increase in the risk of a traffic accident. This overload situation may well be beyond the driver's capability to handle safely. By contrast drivers are often faced with monotonous situations in which they are under significantly less pressure to make decisions and perform on-going driving tasks. This may arise, for example, driving repeatedly on a daily commuter route, or during motorway travel at constant-speed for long periods. During these monotonous situations, a driver's activation state may well be gradually lowered, and the driver could then have a lapse of attention, resulting in an increased risk of an accident. There are at least two possible ways that may be considered to address this problem in order to reduce the risk of a traffic accident, these being:

~Development of Biofeedback System in-car~

This system would detect 'physiological signals' from a driver predictive of their condition and warn him/her about the possible danger.

~Development of Biofeedforward System in-car~

This system would detect 'monotonous situations', for example from a car navigation system, and activate the driver by means of some form of stimulus so as to prevent their condition being reduced to a potentially dangerous level.

We have previously proposed a possible quantitative index of a driver's activation state using beat-by-beat blood pressure response patterns from an involuntary startle reflex [1]. We found that blowing relatively high O_2 concentrations around a driver's face could be effective in preventing his/her activation state being lowered. This could be useful for the development of an in-car *Biofeedforward System* [2].

By contrast, we have also been concerned with the development of an in-car *Biofeedback System* and to achieve this it has been necessary to find a definitive physiological parameter, that could be derived conveniently during driving, with which to assess practically any potential index. Such a parameter would need to be more convenient than approaches based on the use of heart rate variability [3], blinking [4] and so on.

Data from some of our earlier work have indicated that there appears to be a gradual increase in arterial blood pressure during monotonous situations in simulated driving [5]. The probable underlying mechanism of this phenomenon is peripheral vasoconstriction through acceleration of

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sympathetic activity. On the basis of these data, we conjectured that peripheral skin temperature might decrease due to the reduction of peripheral perfusion. We wished to explore this more thoroughly and so the aim of the study reported in the present paper was to analyze changes in skin temperature with this background of cardiovascular parameters under simulated monotonous driving. Further, we aimed to propose a new method that could feasibly reflect a driver's level of stress arising from the compulsion on them to maintain safe driving.

II. New Method for Assessing Driver's Stress

The peripheral parts of the body, such as the four limbs and the nose, which are rich in arterioles and arteriovenous anastomases, are sensitively vosoconstricted by stress. Therefore, the peripheral skin temperature, (T_{sp}), which is mainly adjusted by the blood volume, could be changed by stress ($\Delta T_{sp\text{-}stress}$). Additionally, the T_{sp} is also influenced by general disturbances ($\Delta T_{sp\text{-}d}$), especially environmental changes of ambient temperature, relative humidity, wind velocity and radiation temperature, as well as by metabolic changes and by clothing. So the T_{sp} is given by

$$T_{sp}=T_{sp\text{-}rest} \pm \Delta T_{sp\text{-}d} - \Delta T_{sp\text{-}stress} \qquad (1)$$

where $T_{sp\text{-}rest}$ is the peripheral skin temperature at rest.

On the other hand, the truncal skin temperature (T_{st}) is almost entirely determined by the influence of disturbances ($\Delta T_{st\text{-}d}$).

$$T_{st}=T_{st\text{-}rest} \pm \Delta T_{st\text{-}d} \qquad (2)$$

where $T_{st\text{-}rest}$ is the truncal skin temperature at rest.

If there exists a body part for which

$$\Delta T_{sp\text{-}d} \approx \Delta T_{st\text{-}d} \qquad (3)$$

then, by subtracting (2) from (1) we can obtain the almost stress-dependant differential temperature, as:

$$T_{st} - T_{sp}=\Delta T_{sp\text{-}stress} + \alpha \qquad (4)$$

where α is the difference between trunk and peripheral temperatures at rest.

On the basis of anatomical considerations the body parts meeting the condition of (3), used in the present study, are the nose as the peripheral site and the cheek as the truncal site.

III. Materials and Method

A. Experimental Setup

Fig. 1 shows a schematic of the experimental setup. The main part of this comprises of a video projector (LV-5210, Canon Co., Ltd., Japan) and an 80-inch screen for displaying an image to the subject, a driver's seat, and two CCD cameras to monitor the subject. The physiological and environmental measurements were made with three thermistors (DS103, Techno Seven Co., Ltd., Japan), a newly developed blood pressure (BP) & cardiac output (CO) monitoring system, a finger photo-plethysmograph (FPG) device (MPN1001, Medisens Co. Ltd., Japan), a temperature recorder (TR-72U, A&D Co., Ltd., Japan), a radiation thermometer recorder (PGT-01, Prede Co., Ltd., Japan), an anemometer (V-01-AND2, Sato Shouji Inc., Japan) and three conventional PCs with appropriate interfaces.

To conduct the experiment, the subject was asked to sit down quietly on the driver's seat with their left hand held horizontally on an armrest at heart level and to drive a car with their right-handed.

In practical situation of driving, a radiation thermometer is applicable for the non-contact and unrestrained measurement

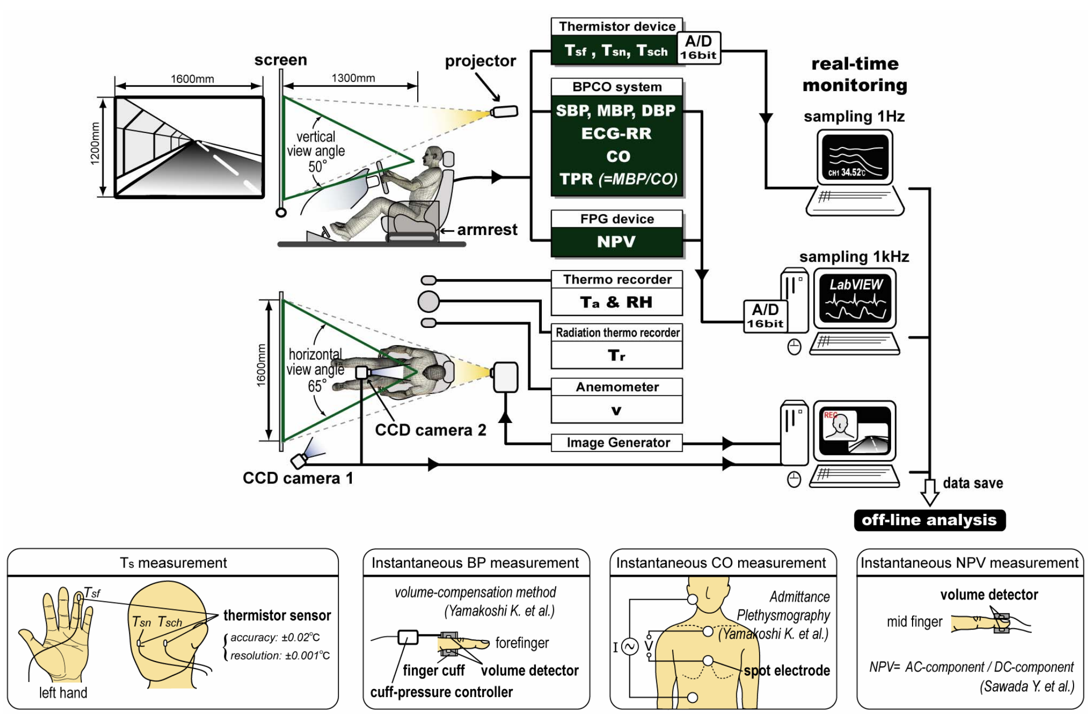

Fig. 1. Outline of experimental setup for physiological measurement during simulated monotonous driving. See text for explanation.

of skin temperature. For the preliminary experiment, however, we used thermistors for the skin temperature measurement: The thermistors used had an accuracy of ±0.02 ºC and temperatures at the finger tip (T_{sf}), the nose tip (T_{sn}) and the cheek (T_{sch}), were obtained as shown in Fig.1-(a).

The BP & CO monitoring systems were developed as experimental instruments and have been described fully elsewhere [6]-[8]. The BP system, utilizing the volume-compensation principle, is capable of measuring instantaneous BP in the finger (Fig.1-(b)), and the admittance cardiograph, provides an instantaneous indication of CO (Fig.1-(c)).

The finger photo-plethysmograph (FPG) consists of a near-infrared light source and a photosensor which were placed on opposite sides of the distal part of the basal phalanx of the left mid finger (Fig.1-(d)). Normalized pulse volume (NPV) was obtained from the DC and AC (pulsatile) components of the FPG signal. This measure has been recently proposed as a more valid index of α-adrenergic sympathetic activity to the finger arteriolar vessels [9].

The skin temperature signals were stored in one laptop PC, and the rest of the output signals from these devices were stored in one of the two desktop PCs *via* a 16-bit A/D converter with 1-ms sampling interval for the purpose of real-time display using LabVIEW 7 Express (National Instruments Co., Ltd., USA).

B. Measurement Quantities

We acquired the following parameters during the experiment: a finger tip temperature (T_{sf}) in the subject's left ring finger, the nose tip temperature (T_{sn}) and the cheek temperature (T_{sch}), beat-by-beat systolic (SBP), mean (MBP) and diastolic blood pressure (DBP) in the subject's left forefinger at the proximal phalanx, beat-by-beat cardiac output (CO) with RR interval of ECG (RR), beat-by-beat total peripheral resistance (TPR ($=MBP/CO$)), beat-by-beat normalized pulse volume (NPV) as an indication of local peripheral resistance, and air temperature (T_a), relative humidity (RH), radiation temperature (T_r), and wind velocity (v) as an indication of environmental factors. In this experiment the level of stress as estimated from the answers given in a questionnaire every 10-min, was used as a reference, termed the "Subjective rating of stress" (SRS). Although the sensation of stress is difficult to report because it is purely subjective, we used the reporting from a 9-level scale by selecting any number between *Level-1* (not stressful at all) and *Level-9* (extremely stressful) to indicate their feeling; this is referred to as *Kakizaki's* method [10].

C. Subjects and Procedures

10 healthy male subjects [22.9 ± 1.1SD yrs] without known cardiovascular disorders participated in the present preliminary experiment, after giving informed consent. They were studied in a temperature-controlled quiet room held at 25 °C, the study beginning at 9:00 am. The subjects were requested to sit down on the driver's seat where they could drive on an oval test-course. After resting for 10-min (baseline session; BLS) the subjects drove for a maximum of 120-min (simulated driving session; SDS) by which time driving was deemed to have been seriously uncontrolled, and then the subject rested for 5-min (end session; ES). In order to simulate a real monotonous driving situation, each subject was previously informed that they had to continue driving safely as though they had actually been driving, and maintaining a speed of 80~120 km/h.

IV. RESULTS AND DISCUSSION

Fig.2 shows a typical example of a 135-min trend-chart of the physiological variables together with the differential skin temperature (T_{sch} - T_{sn}) and the reference stress level (SRS) obtained in one subject. Less than 1-2 % of the total number of data-sets were classified as artifacts and these were omitted by manual editing.

Considering the normalized pulse volume, NPV, as a possible marker of the peripheral sympathetic activity, it is seen that the sympathetic activity (vasomotor constriction) gradually accelerates during the simulated driving session (SDS) as compared to that in the baseline session (BLS). Correspondingly, from the recording of the total peripheral resistance, TPR, it is clearly demonstrated that the vascular resistance is gradually increased. The cardiac output, CO, tends to fall. Consequently, the gradual increase in BP appears to have occurred as a reflection of the acceleration of sympathetic activity. With regard to the skin temperature, the T_{sn} and T_{sf}, as peripheral parts, gradually fell in accordance with the gradual increase of SRS. In particular, it is shown that a very significant fall occurs during the period of high stress (>*Level-5*). On the other hand, the T_{sch} as a truncal part is constant despite the gradual rise of SRS. The calculated differential temperature, T_{sch} -T_{sn}, is well associated with the SRS. These tendencies were observed in most of the subjects tested.

As predicted, it is clearly demonstrated that the peripheral skin temperature gradually falls during simulated monotonous driving, and this fall is likely to have been caused by constrictive peripheral vasomotor regulation, taking the decrease in NPV and the increase in TPR recordings into account. Furthermore, we have confirmed that the cheek skin temperature as a truncal part is independent of the SRS. As a result, the differential skin temperature shows good correspondence with the SRS.

The measurement of this differential skin temperature, T_{sch} -T_{sn}, during monotonous driving could be useful for assessing one important aspect of a driver's stress. It appears that, despite being in monotonous situations, drivers must still face demands, such as 'to keep an eye on surroundings', 'to perform on-going monotonous tasks under constrained situations', 'to shake off their drowsiness' and so on. The results obtained here strongly indicate that long hours of driving under such monotonous situations can actually makes a driver considerably stressful, resulting in a gradual drop in peripheral skin temperature caused by an increase in vasoconstriction through acceleration of sympathetic activity.

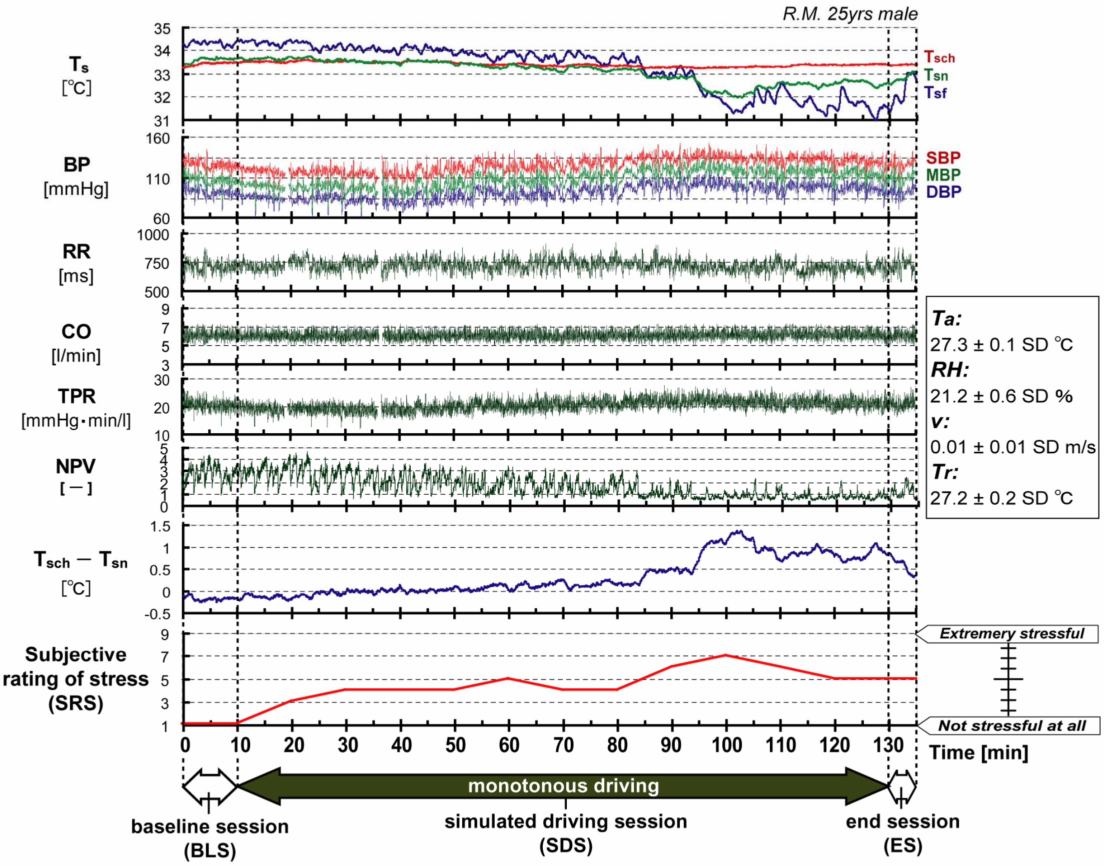

Fig. 2. Example of 135-min trend-charts of physiological variables together with those of diferential skin temperature (T_{sch}-T_{sn}) and reference of stress level (subjective rating of stress; SRS) obtained in one subject. See text for symbols and explanation.

V. Conclusions

Under laboratory conditions, in healthy volunteers during simulated monotonous driving, we have successfully measured truncal and peripheral skin temperatures as well as cardiovascular haemodynamic variables. It was clearly demonstrated that the sympathetic activity, peripheral vasoconstriction, was increased during the monotonous situation. Consequently, a significant gradual drop in peripheral skin temperature was observed, and the calculated differential skin temperature between a peripheral and truncal part could be useful for assessing an index of driver's stress. Although the change of differential skin temperature appears to be the basis of an appropriate and feasible index capable of reflecting the driver's stress, further experiments are needed to test this under varying environmental conditions like actual in-car surroundings.

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