Estimation of Stress during Car Race with Factor Analysis

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Abstract:
Car race drivers are always in dangerous and harsh environments. In order to reduce risks due to mental stress, it is important to evaluate stress during a car race in real-time. The present study measured three physiological indices, heart rate variability, sweat rate, and electromyogram of massester from a professional racer during a car race. However, the relation between these indices, and the types of stress still remains unclear. In the present study, we examined the relations between the three indices and factors linked with these indices during car race with factor analysis. The results suggested that the three physiological indices related to two different factors. One factor scored high when driver saw other nearby car, and was influenced mainly by heart rate variability and sweat rate. We suggest that mental stress is probably high in such scenes, and named this factor as "mental stress". Furthermore, the other factor showed high values during urgent accelerations and decelerations, and was influenced mainly by electromyogram of massester. During urgent accelerations and decelerations, the driver probably suffered from large physical discomfort. Therefore, we named the second factor as "physical stress". In summary, we found the three physiological indices reflected two different types of stress during car race. Moreover, according to the results of factor analysis, we proposed a method of real-time estimation of both mental and physical stress with the three physiological indices during car race.

1. INTRODUCTION

Motor race is one of the most dangerous sports. Drivers compete with others at the speed over 200 km/h. High driving technique and quick decision are required, and slight mistake might result in serious accident. Therefore, drivers' stress during race is very high. Stress may cause decline in thinking, judgement, and muscle strain and thus it increases risk of accident. In order to reduce such a risk, it is important to measure and manage stress of driver during car races.

The mental state influence autonomic nerves including sympathetic and parasympathetic. Stress activates sympathetic and relaxed state activates parasympathetic. The balance of the activities of sympathetic and parasympathetic influences physiological indices. Previous studies used different physiological indices to measure stress. For example, Gross asked participants to watch sad, neutral and amusing films and measured heart rate, sweat rate, respiratory rate during the experiment [1]. Beside this, Chatterton measured salivary amylase response before and after skydiving [2]. However, it is still unclear whether the different physiological indices reflect the same stress. In other words, if we use multiple indices to measure stress, should we just add them up or give different indices with different weights to estimate a single type of stress? In order to answer this question and propose a method of real-time stress estimation during car race, we measured three different physiological indices synchronously from a professional racer during a car race. We analyze the relations between these indices and the stresses they reflect with a statistical analysis called factor analysis.

Prior research has used different physiological indices to examine stress, such as eye blink times [3], brain wave [3], heart rate variability [4][5][6][7], respiratory rate [1], sweat rate [8][9][10], electromyography of masticatory muscle [11], salivary amylase [2] and so on. We chose heart rate variability, sweat rate, and electromyogram of massester as target indices of stress, since they are possible to acquire without disruption of driving during a car race. The details of these indices is explained in the next section.

2. THE ESTIMATION BY PHYSIOLOGICAL INDICES

2.1 Heart rate variability (SDNN/RMSSD)

Heart rate was measured with a pair of electro cardiogram sensors which were attached on the chest of the driver (Fig. 1, 2). Heart rate has been reported to be influenced by the activity of sympathetic nervous, and the variability of heart rate has been used to examine stress [12]. Heart rate was led from R-R intervals (the interval from the peak to the peak of the next on electro cardiogram). In the present study, we calculated SDNN (Standard deviation of normal to normal R-R intervals) and RMSSD (Root mean squared successive differences) from the records of heat rate. SDNN indicates the activity of autonomic nerves including sympathetic nerve and parasympathetic nerve. RMSSD indicates the activity of parasympathetic nerve. Therefore SDNN/RMSSD is considered to be an index of sympathetic nerve, and influenced by stress condition.

2.2 Sweat rate (GSR)

Sweating rate was measured from the scruff of the driver with a pair of GSR sensors (Fig. 1, 2). Sweating activity is considerd to reflect autonomic nerves activity, and has been reported to be correlated with stress loading [8].

2.3 Electromyogram of massester (EMG)

Electromyogram of massester was measured with a pair of EMG sensors which were attached to the lower side of the jaw (Fig. 1, 2). Massester activity has been reported to be closely related with emotion and stress loading [11].

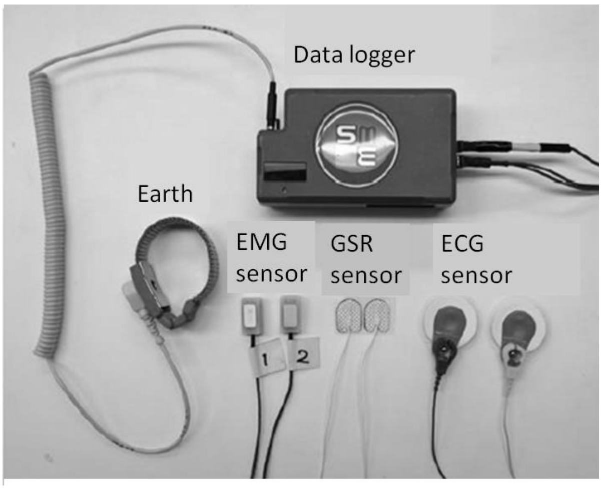

Fig.1 The biological sensors

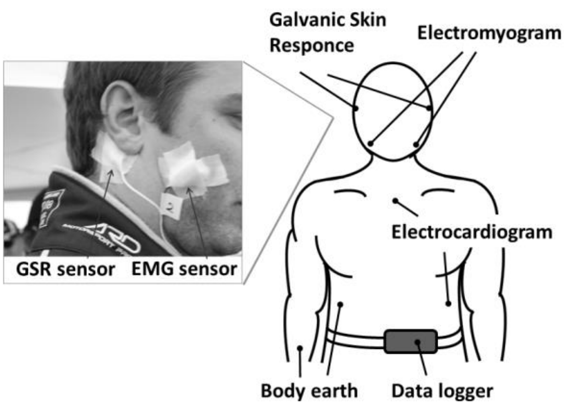

Fig.2 The position of the sensors.

3. Factor analysis

Factor analysis is a statistical method used to describe relations and variability among multiple observed indices, and detect lower number of variables which mainly reflect the variations of observed indices. The detected variables are called “factors”. In the present study, we examined the relations between the three measured indices, and aimed to find the number of main factors influencing these indices. If there is only one factor, the different physiological indices could be considered to reflect the same type of stress. If there are more than one factor, the different physiological indices would probably reflect different type of stress during car race. Factor analysis derive eigenvalues and factor coefficient of main factors. The reference determining the number of main factors is the max number of factors that the eigenvalue is over 1.0. Factor score that explains the level of main factor during race is derived from factor coefficient and physiological indices.

4. Experiment

4.1 Measurement environment and equipments

The measurement was conducted in Super GT 4th race practice session on July 2013. Figure 3 shows the layout of the racing course. A professional driver (male, age 27) participated in the experiment.

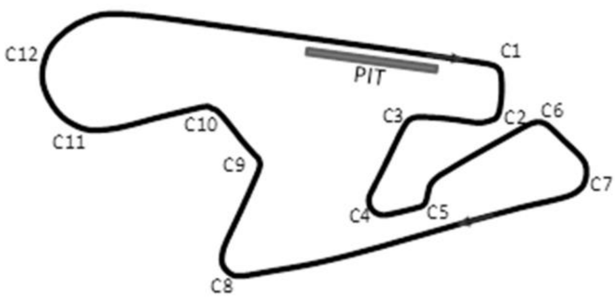

Fig.3 Course layout (C1~C12: corner position number).

Physiological indices were recorded from ECG heart rate sensors (DL-310), sweating sensors (DL-340) and myoelectric sensors (DL-41) and were stored in a data logger (S&ME DL-3100, Fig. 1). The data logger and peripheral devices were placed in the waist pouch on the lumbar. Figure 2 shows the position of the sensors.

4.2 Results

We used the data from the third to the sixth laps for analysis because the driver told that the first two laps were for warming up and the mental condition differed from that in the latter laps. According to the factor analysis, we found two factors (eigenvalue above 1.0). The factor coefficients of each indices are showed in Table 1. SDNN/RMSSD and GSR were mainly influenced by factor 1, and in contrast, EMG was mainly influenced by factor 2.

Table 1 Factor coefficient

	Factor 1	Factor 2
SDNN/RMSSD	0.362	0.154
GSR	0.346	-0.207
EMG	0.015	0.355

Furthermore, factor scores indicated the quantitative relationship between indices and factors. Formula (1) and (2) show factor score calculated from the three physiological indics. S1, S2 are the score of factor 1 and factor 2, respectively. x_1, x_2, x_3 are the standardized value of SDNN/RMSSD, GSR, EMG. According to the formulas of factor scores, it is possible to estimate different types of stresses (factors) from the measured physiological indices in real-time.

$$S_1 = 0.362x_1 + 0.346x_2 + 0.015x_3 \quad (1)$$

$$S_2 = 0.154x_1 - 0.207x_2 + 0.355x_3 \quad (2)$$

5. DISCUSSION

In the present study, in order to examine stresses during car race, we measured three different physiological indices from a professional driver during a car race, and analyzed the results with factor analysis. According to the result of the analysis, we found that the three indices were influenced by two different factors. The two different factors were considered to involve two different types of stress. In order to determine the types of stresses during car race, we examined the situation in which factor scores were relatively high.

Factor scores above 2.5 times standard deviation and the corresponding scenes were examined. The scene were recorded with a video camera in the driver's perspective, and conditions of acceleration or deceleration, which were recorded by GPS. The situation with high factor scores could be categorized to three types; scenes with other cars in the visual field, acceleration or deceleration, and others. Proportions of each situation with high factor scores are given in Table 2. For factor 1, most of the situations (92%) with high factor scores contained scenes in which competitors' cars were visible. In such condition, the driver would feel more mental stress from the competition. Therefore, factor 1 is suggested to refer to mental stress.

Furthermore, for factor 2, acceleration or deceleration were the most often situations. During abrupt acceleration or deceleration in the car race, the driver suffered from large physical discomfort, resulting in unconscious chewing (i.e., activities in massester). We named this condition as physical stress, to differ from the mental stress which was mainly reflected by SDNN/RMSSD and GSR.

Table 2 Proportion of each situation with factor scores above 2.5 times standard deviation

Situation	Factor 1	Factor 2
Other car	92%	37%
Acceleration (Deceleration)	54%	63%
No car, Not acceleration	4%	8%

According to the results of factor analysis, we found that SDNN/RMSSD, GSR, and EMG reflected two different types of stress (the mental and physical stress). Because factor scores reflect the quantitative relations between observed indices and factors, they could be used for the estimation of the influence of factors. Especially during the car race, SDNN/RMSSD, GSR, and EMG are able to be measured in real-time, it is possible to give quantitative estimation for both mental and physical estimation from the three indices. Figure 4 and 5 show factor scores for mental stress (factor 1) and physical stress (factor 2), respectively. Durations when other cars were visible were overlaid with gray bar in Fig. 4. Most of these durations correspond with high scores of mental stress. Furthermore, durations of acceleration and deceleration were overlaid with gray bar in Fig. 5. The conditions with highest scores of physical stress also correspond with the period of acceleration and deceleration. The proposed estimation of both mental and physical stress fitted well with the observed situations, and it could be used to measure real-time stress of racers for other races in future.

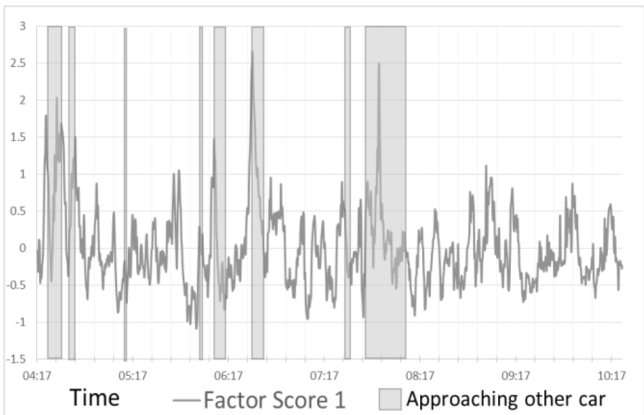

Fig. 4 Physiological stress and the durations when other cars were visible.

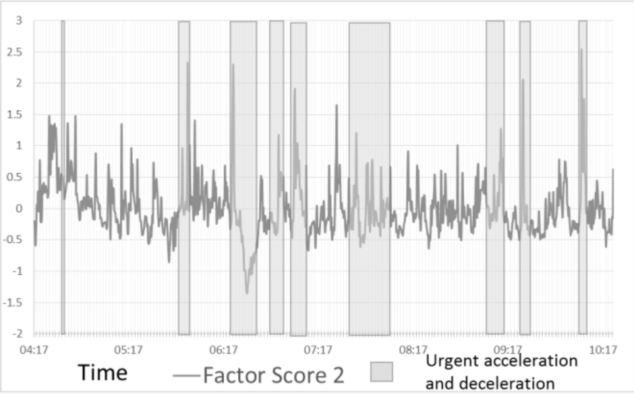

Fig. 5 Physical stress and the durations of accelerations or decelerations

6. CONCLUSION

In the present study, we measured three physiological indices (activity of massester, sweat rate, heart rate variability) from a professional racer, and analyzed the relations between these indices and types of stresses the indices reflected with factor analysis. As a result, we found two different main factors. The first factor was named as mental stress, and mainly influenced sweat rate and heart rate variability. The second factor was named as physical stress, and mainly influenced activities of massester. Although the three physiological indices have been used to examine stress in a number of previous studies, we first found that the three indices actually reflect different types of stress. In addition, we also proposed a quantitative estimation of both mental and physical stress from the three physiological indices during car race. Our research would be useful for the mental management of racers.

ACKNOWLEDGEMENTS

This work was in part supported by JST RISTEX Service Science, Solutions and Foundation Integrated Research Program and JSPS KAKENHI Grant Number 26120005.

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