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Hemodynamic Responses during Simulated Automobile Driving in a Monotonous Situation

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Abstract---**Long hours of automobile driving under monotonous situations may cause the lowering of what we term a *Driver's Activation State (DAS)* or in other words the production of drowsiness, resulting in an increased risk of a traffic accident. There is therefore a need to create a newly advanced system focused on the DAS in-car, hopefully thus avoiding potentially dangerous situations. In order to develop such a system as a final goal, we have firstly set out to acquire such cardiovascular variables as beat-by-beat blood pressure (BP), RR interval from ECG and normalized pulse volume (NPV) used as a peripheral vascular tone of α-adrenergic sympathetic activity, during presentation to the driver of a screen movie simulating monotonous travel at constant speed on a test-course. Subsequently, we have investigated the reactivity in terms of the driver's cardiovascular hemodynamics. Through the successful monitoring of cardiovascular parameters during the movie presentation obtained in 11 healthy male subjects, the following results were obtained: The monotonous driving produces a statistically significant gradual rise in BP following drowsiness, which could be explained by enhancement of sympathetic activity using a time-frequency analysis of BP and RR. This finding strongly indicates that continuous driving in such monotonous situations can make a driver considerably stressful and thus may cause a gradual increase in BP, and that this gradual BP increase may be used as a possible index relevant to the DAS. This finding was also confirmed by the analysis of NPV, suggesting that the gradual increase in BP during the monotonous driving would be rather caused by a regulation of peripheral vasomotor constriction.**

Keywords---monotonous driving, driver's activation state, hemodynamic response, beat-by-beat blood pressure

I. Introduction

The expanding utilisation of motor vehicles in modern times has led to a considerable increase in traffic accidents. There is, nevertheless, a paradox in that, despite the increases in traffic density, drivers are often faced with monotonous situations in which they are under less pressure, or stress, to 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, what is termed the *'Driver's Activation State' (DAS)*, being a reflection of the driver's alertness, 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, thereby reducing 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 the DAS, e.g. ECG-RR interval or blinking etc, and warn him/her about possible danger.

~Development of Biofeedforward System in-car~
This system would detect 'monotonous situations', e.g. driving on a daily commuter route or monotonous driving in a motorway etc, from a car navigation system, and activate the driver by means of some stimulation so as to prevent the DAS being reduced to a potentially dangerous level.

In order to realize an advanced in-car system such as these, it is necessary to assess practically any potential index of the DAS (DASI). Any viable index would need to be derived and used more conveniently than that based on the analysis of conventional EEG recordings which have been widely used as an indication representing brain activity.

We have previously reported an experimental system in which physiological measurements can be made in subjects using a driving simulator [1]. Preliminary studies were performed in order to discover whether or not any measured physiological variables, or derivatives of these, could provide an indirect indication of brain activity. In this work an electrical test stimulus was also used to assess potential indicators. Responses in beat-by-beat BP were analysed and particular patterns were found, suggesting the use of these as a DASI.

In order to realize an in-car Biofeedforward system we hypothesized that administration of 30 % oxygen to a driver might raise or maintain the DAS [2]. The preliminary results of this study appeared to demonstrate that administration of such an O_2 stimulus might indeed be successful in achieving this.

Data from some of our earlier work has suggested that there might be a gradual increase in BP during monotonous situations in simulated driving [3]. We wished to explore this more thoroughly and so the aim of the study reported in the present paper was to further analyse the changes in BP on a beat-by-beat basis under simulated monotonous driving conditions. Further, we aimed to derive and evaluate a possible index derived from beat-by-beat BP that could effectively serve the DASI.

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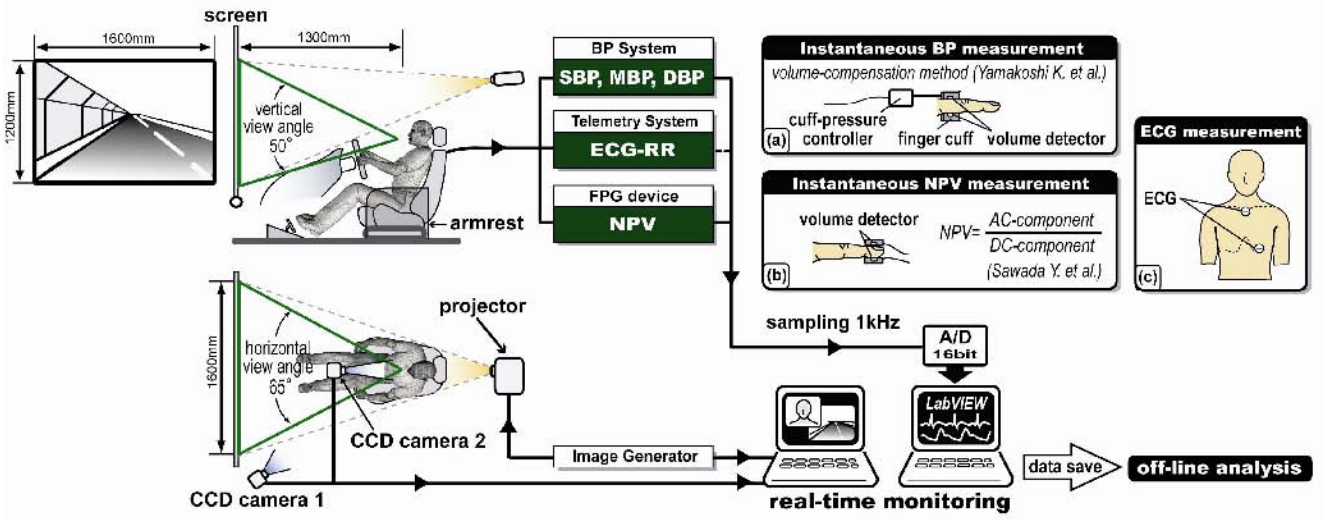

Fig. 1 Outline of experimental setup for physiological measurements during simulated monotonous driving. See text for explanation.

II. Materials & Methods

A. Experimental Setup

Fig.1 shows a schematic of the experimental setup. The details of this system are the same as previously described (see [3]).

The BP monitoring system was recently developed as an experimental instrument. This system, utilising the volume-compensation principle which is capable of measuring instantaneous BP in the finger (**Fig.1-(a)**), is essentially the same as our previously designed system [4]. The full details of this are described elsewhere [4-6].

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 third finger (**Fig.1-(b)**). 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 [7].

The electrocardiogram (ECG) was measured, as shown in **Fig.1-(c)**, from the chest leads and collected by a multi-telemetry system.

All of the output signals from these devices were stored in one of the two laptop 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: 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 normalized pulse volume (NPV), and RR interval of ECG (RR). In this experiment a level of drowsiness, estimated by the direct observation of event frequency (f_e; number of times/2min) of the subject's condition, i.e. yawn, facial drowsy expression, slow blinking, microsleep judged by body movement and blinking as monitored by the CCD cameras, was used as a reference of the driver's activation state, which is termed the "Objective Judgment Level" (OJL): "$f_e=0$; wakening [*Level-0* (normal level)]" , "$0<f_e\leq 2$; slightly drowsy [*Level-1* (attention level)]" , "$f_e>2$; very drowsy [*Level-2* (danger level)]", and "closed-eyelids more than 10-s; falling into sleep [*Level-3* (serious accident level)]".

C. Subjects & Procedures

11 healthy male subjects [33.8±13.9 (SD) yrs] without known cardiovascular disorders participated in the present experiment, after giving informed consent. They were studied in a quiet and dark room at a temperature of approximately 25 °C, the study beginning at 9:00 am. The subject was requested to sit down on the driver's seat where they could watch the monotonous screen movie of *autonomous travel* at constant-speed on a test-course. After resting for 5-min (baseline session; BLS) the movie was displayed on the screen, without operation, for a maximum of 120-min (simulated driving session; SDS) which was decided by appearance number of *Level-3*, and then the subject rested for 5-min (end session; ES). Additionally, in order to simulate a monotonous driving situation, each subject was previously informed that they had to continue watching the movie as though they had been driving, and also to refrain from sleeping as far as possible.

D. Data Analysis

To evaluate circulatory autonomic regulation, the following analyses were made using the collected data on a beat-by beat basis.

Time-frequency analysis: Spectral analysis was carried out using the BP and RR data by a maximum entropy method (MEM). It was applied to the data-set of 64 beats, which was updated every 16 beats (moving MEM). The spectral power of SBP in the middle-frequency band (0.07-0.14 Hz; PMF(BP)) and of RR in the high-frequency band (0.15-0.4 Hz; PHF(RR)) were calculated. It has been reported that PMF(BP) is expected to be an index of sympathetic activity

[8] and the PHF(RR) may be a marker of vagal activity [9]. In this study, these two spectral powers of SBP and RR were calculated by a logarithmic transformation (ln[PMF(BP)] and ln[PHF(RR)]) and then normalized by each averaged value as a reference during the BLS ($\ln[PMF(BP)|_{MBLS}]$ and $\ln[PHF(RR)|_{MBLS}]$), which we termed as NPMF(BP) and NPHF(RR). Then we defined a measure of RAAB (relative autonomic activity balance) which was obtained by subtracting NPHF(RR) from NPMF(BP), expecting to evaluate a relative balance between the sympathetic and the vagal activity.

Analysis of baroreceptor cardiac reflex (BCR) function: In order to estimate vagal activity of BP regulation, the baroreceptor cardiac reflex sensitivity (BRS) was derived using the Bertinieri's method [10]: The BCR function is assessed by identifying the spontaneous sequences of three or more consecutive beats, in which SBPs progressively increase (or decrease) and the corresponding RRs progressively lengthen (or shorten) in a linear fashion ($\gamma^2>0.85$). A regression coefficient or slope between these consecutive beats of SBP and RR represents a measure of BRS.

III. Results & Discussion

Fig.2 shows a typical example of a 120-min trend-charts of cardiovascular variables together with those of the reference of activation state (OJL), BRS, NPMF(BP), NPHF(RR), and RAAB 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.

As for the trend-charts of NPMF(BP) and NPHF(RR), it is clearly shown that the sympathetic activity is relatively accelerated (*NPMF(BP)>0*) and the vagal activity is suppressed (*NPHF(RR)<0*) during the simulated driving session (SDS) as compared to the baseline session (BLS). As a result, RAAB shows a tendency towards the relative sympathetic acceleration side (*RAAB>0*), and this tendency was observed in most of the subjects tested. From the recording of the BRS, it is demonstrated that regulation of BP through a cardiac-related baroreflex tends to be gradually suppressed in accordance with the gradual lowering of OJL (*Level-0 → Level-3*), taking the reduction of the BCR appearance into consideration. With regard to the normalized pulse volume, NPV, as a possible maker of the peripheral sympathetic activity, it is shown that the sympathetic activity (vasomotor constriction) gradually accelerates as compared to that in the BLS. Consequently, the gradual increase in BP was obtained as a reflection of accerelation of the sympathetic activity, and this tendency was observed in most of the subjects tested.

Fig.3 shows the time course of the means±SDs (n=11) of the percentage change of the MBP, RR, and NPV reactions in the SDS period as compared to the BLS. Because of the different SDS periods for each subject, the horizontal axis is normalized as %-age by each SDS period (%-SDS time). In the right part of Fig.3 are shown the means±SDs of these physiological variables during the whole SDS. Additionally, asterisks (**p<0.05, **p<0.01*) indicate the level of statistical significance as analyzed by the *Wilcoxon* test.

As shown in Fig.3, it is clearly demonstrated that the BP gradually increases during the SDS and this increase is statistically significant (*p<0.01*). Furthermore, taking the statistically significant decrease (*p<0.05*) in NPV into account this increase in BP is likely to have been caused by constrictive peripheral vasomotor regulation.

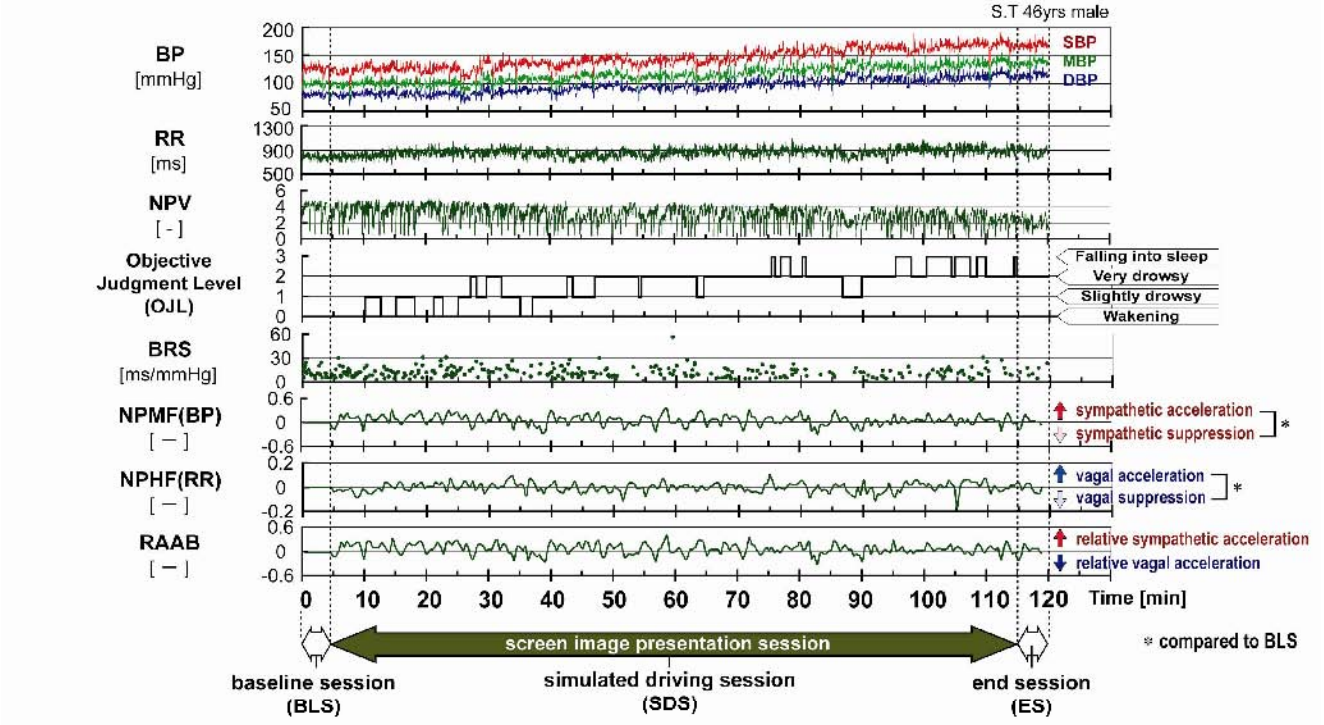

Fig. 2 Typical example of 120-min trend-charts of cardiovascular variables together with those of OJL, BRS, NPMF(BP), NPHF(RR) and RAAB obtained in one subject. See text for symbols and explanation.

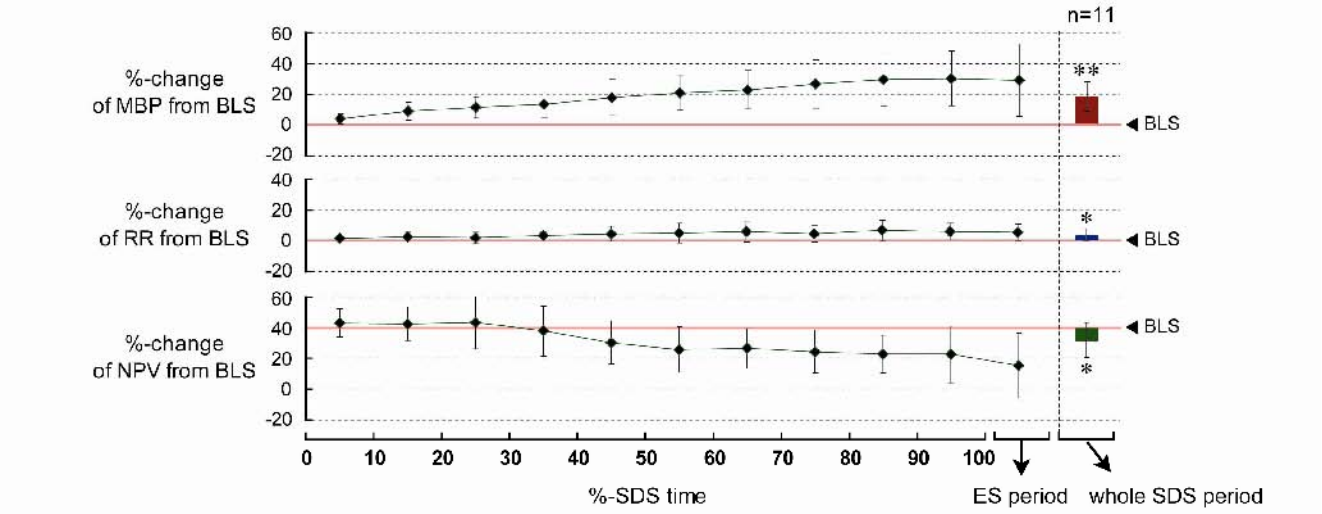

*Fig. 3 Means±SDs of time course percent changes from baseline session (BLS) in hemodynamic reactions to monotonous driving situation. Right bars indicate means±SDs of average value during simulated driving session (SDS). Asterisks indicate significant deviation according to the Wilcoxon test (*p<0.05, **p<0.01). See text for details.*

The measurement of this gradual increase in BP during monotonous driving could be useful for assessing one important aspect of a driver's activation state. 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 shaking 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 but significant increase in BP caused by an increase in vasoconstriction through acceleration of sympathetic activity.

IV. Conclusion

Under laboratory conditions, during the presentation to healthy volunteers screen movie simulating monotonous driving, we have successfully measured cardiovascular hemodynamic variables and their responses to the monotonous driving situation. It was clearly demonstrated that sympathetic activity was increased relatively, whilst vagal tone appeared to be suppressed during the monotonous situation. Consequently, a statistically significant gradual rise in BP was observed. This leads us to hypothesise that monotonous driving situations can actually make drivers considerably stressful. Although the BP change appears to be the basis of an appropriate and feasible index capable of reflecting the driver's activation state, further experiments are needed to test this hypothesis under actual driving conditions.

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