A NEW PROPOSAL OF DRIVER'S ACTIVATION STATE INDEX BASED ON PHYSIOLOGICAL MONITORING UNDER SIMULATED MONOTONOUS DRIVING

T.Yamakoshi*, K.Yamakoshi**, S.Tanaka**, M.Nogawa**, Y.Sawada***, P.Rolfe****, M.Kusakabe*

* Graduate School of Eng., Fukui University, Fukui, Japan
** Dept. of Human & Mechanical Systems Eng., Kanazawa University, Kanazawa, Japan
*** Faculty of Medicine, Sapporo Medical University, Sapporo, Japan
**** Dept. of Communication, Computer & System Sciences, Genova University, Genova, Italy

takehiro@m3.dion.ne.jp

Abstract: Automobile driving under monotonous situations may cause the lowering of what we term a driver's *Activation State (AS)* resulting in an increased risk of an accident. There is therefore a need to create a more suitable environment in-car so as to allow active driving, hopefully thus avoiding potentially dangerous situations. In order to develop such an activation method supported by substantive evidence of effectiveness as a final goal, we have firstly set out to acquire physiological variables, including cardiovascular parameters, during presentation to the driver of a screen image simulating monotonous travel of constant speed on a test-course. Subsequently, we investigated the derivation of a suitable driver's AS index. During the image presentation, a momentary electrical test stimulus of 0.5-s duration was randomly applied to the subject's shoulder to obtain physiological responses. In 11 normal subjects monitoring of physiological variables during the image presentation revealed particular patterns in the beat-by-beat changes of blood pressure in response to the electrical test stimulus. This finding, which could be explained by autonomic activity balance, suggests that the patterns may used as be an appropriate and practicable index relevant to the AS.

Introduction

In the present era of the increasingly motorised society, there has been a considerable increase in traffic accidents. It would appear that there are two main causative factors of traffic accidents related to a driver's operational situation; one is an overload situation, and the other a monotonous situation. In the former, the driving tasks are too demanding, such as right- or left-turns at busy intersections, or travelling at too high a speed, or combinations of tasks requiring decisions and actions. In these situations the driver has to raise his/her activation state or alertness to reduce the increased in the risk of a traffic accident. Besides this individual effort of the driver to raise the activation level, several trials to improve the operational performance of cars have been developed, e.g. Intelligent Speed Adaptation (ISA).

In the monotonous situation, a driver is under considerably less pressure to perform on-going driving tasks. This may arise, for example, driving on a daily commuter route, or during motorway travel with constant-speed. During these situations, what is termed the driver's *'Activation State'* (AS), being a reflection of the driver's alertness, would be gradually lowered, the driver could then have a lapse of attention, resulting in an increased risk of an accident. There are at least possibly two ways to address this problem, thereby reducing the risk of a traffic accident, as follows:

Development of Biofeedback System in-car

This system would detect physiological signals from a driver predictive of the AS, e.g. ECG-RR interval or blinking etc, and warn him about possible danger. However, this is a complicated system and practically difficult to implement within a car.

Development of Biofeedforward System in-car

This system would detect 'monotonous situations', e.g. driving on a daily commuter route or motorway etc, from a car navigation system and activate the driver by means of some stimulation so as to prevent the AS being reduced to a potentially dangerous level. This is the subject of our present study.

In order to realize an in-car *Biofeedforward System* it has been necessary to develop a definitive validation method with which to assess practically any potential "Driver's AS" Index. Such validation method would need to be more convenient than approaches based on the use of conventional EEG recording which clearly can provide an indication of one aspect of brain activity. We therefore considered, as a first step, the development of a new definitive index of the AS from a cardiovascular viewpoint which could provide an indirect reflection of brain function. Following this, we proposed to develop an activation technique that could be validated using the index during defined monotonous situations. The final goal is, of course, to produce safer driving.

In order to pursue this important objective we firstly acquired particular cardiovascular parameters on a beat-by-beat basis under simulated monotonous driving conditions using a screen image presented to the driver. Then, we attempted to derive and evaluate a possible index that could effectively indicate the driver's AS. We particularly focused our investigation on the beat-by-beat change of cardiovascular parameters in response to

 ISSN: 1727-1983

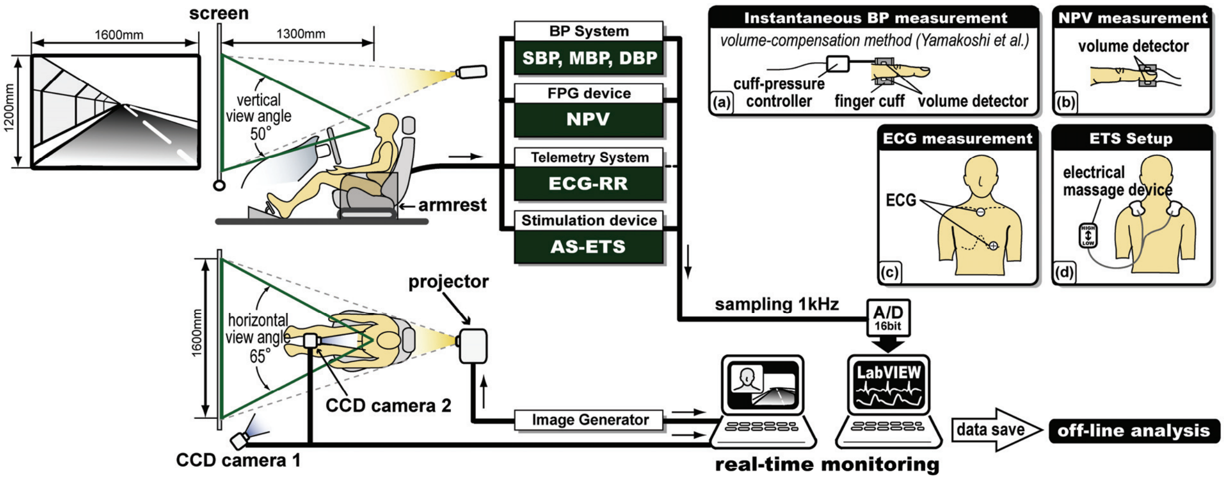


Figure 1: Outline of experimental system for physiological measurements during simulated monotonous driving. See text for explanation.

a randomly applied, momentary, electrical test stimulus during the image presentation to the driver in order to search for a novel AS index.

Materials and Methods

Experimental System

Figure 1 shows a schematic of the experimental system. It consists 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, two CCD cameras to monitor the subject, a newly developed blood pressure (BP) monitoring system, a finger photo-plethysmograph (FPG) device, an electrical stimulation device (Low Frequency Treatment Device HV-F05, Omron Co., Ltd., Japan), a multi-telemetry system (WEB-5000, Nihon Kohden Co., Ltd., Japan), and two conventional laptop PCs. To conduct the experiment, the subject is asked to sit down quietly on the seat, with their left hand held horizontally on an armrest at heart level, and to look at the screen as though they were in a car.

The BP monitoring system has been recently developed as an experimental instrument. This system, utilising the volume-compensation principle which is capable of measuring instantaneous BP in the finger (Figure 1-(a)), is essentially the same as our previously designed system [1]. The full details of this are described elsewhere [1-3].

The finger photo-plethysmograph consists of a near-infrared light-emitting diode (810 nm; L810-40K00, Ebisu Denshi Co., Ltd., Japan) as the light source and a photodiode (HPI-2464R5, Kodenshi Co., Ltd., Japan) as the photo-sensor. They were placed on opposite sides of the distal part of the basal phalanx of the left third finger (Figure 1-(b)). Normalized pulse volume (NPV) was obtained from the DC and AC (pulsatile) components of the photoelectric signal. This measure has been recently proposed as a more valid index of alpha-adrenergic sympathetic activity to the finger arteriolar vessels [4].

The ECG was measured, as shown in Figure 1-(c), from chest electrodes and collected by the multi-telemetry system.

The electrical test stimulus (ETS) was delivered as a 0.5-s duration pulse of approximately 2.0 V in magnitude applied *via* two conducting rubber electrodes attached to the shoulder (Figure 1-(d)). All of the output signals from these devices were stored in one of the 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).

Measurement Quantities

We acquired the following parameters during the experiment: beat-by-beat systolic (SBP), mean (MBP) and diastolic (DBP) blood pressure in the subject's left forefinger at the proximal phalanx; beat-by-beat normalized pulse volume (NPV); 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 camera, was used as a reference of the AS, which is termed as the "Objective Judgment Level": "$f_e=0$; wakening [Level-0 (normal level)]", "$0<f_e \leqq 2$; slightly drowsy [Level-1 (attention level)]", "$f_e>2$; very drowsy [Level-2 (danger level)]", and "*closed-eyelids more than 15-s;* falling into sleep [Level-3 (serious accident level)]".

Procedures

11 normal 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℃ and requested to sit down on the driver's seat where they could watch the monotonous screen image of autonomous travel at constant-speed on a test-course. After resting for 5-min (baseline session; BLS) the image was displayed on the screen for a maximum of 120-min (simulated driving session; SDS), and then the subject rested for 5-min (end session; ES), beginning at 9:00 am. During the BLS and the ES at least one ETS was applied, and during the SDS the ETS was applied randomly at about once per 10-min. The timing was randomly decided by the experimenter. As explained above the intension was to use a stimulus that ideally would not be consciously perceived by the subject. Additionally, in order to simulate a monotonous

ISSN: 1727-1983

driving situation, each subject was previously informed that they had to continue watching the image as they had been driving, and also to refrain from sleeping as far as possible.

Data Analysis

To evaluate circulatory autonomic regulation, the following analyses were made using the collected data.

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 [5] and PHF(RR) may be a marker of vagal activity [6].

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 Bertinieri's method [7]: 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.

Results & Discussion

Figure 2 shows a typical example of 100-min trend-charts of physiological variables together with those of Objective Judgment Level (OJL), derived indices of BRS, normalized PMF(BP) (NPMF(BP)) and PHF(RR) (NPHF(RR)), and relative autonomic activity balance (RAAB) obtained in one subject. The arrows shown along the top of each chart indicate the delivery of the ETS. Spectral power of SBP and RR are shown as NPMF(BP) and NPHF(RR) which actually represent the normalized variation of ln[PMF(BP)] and ln[PHF(RR)] from each average value as a reference during the baseline session, BLS ($\ln[PMF(BP)|_{MBLS}]$ and $\ln[PHF(RR)|_{MBLS}]$). RAAB is derived by subtracting NPHF(RR) from NPMF(BP). 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 SDS as compared to the BLS. As a result, RAAB shows a tendency to lean towards the relative sympathetic acceleration side (RAAB>0), and this tendency was observed in most of the subjects tested. The frequent decrease in NPV also supports this suggestion. Consequently, a gradual increase in BP was observed. It is considered that during monotonous driving several influences on *stress of monotonous driving*, such as demand to keep eye on surroundings and the driver shaking off his/her drowsiness, may be combined.

The arrows shown in the top of Figure 2 indicate the delivery of the electrical test stimulus (ETS), and the resulting physiological responses were successfully obtained in all the subjects. Of particular note the beat-by-beat BP is seen to change in a specific pattern following the ETS in accordance with the subject's activation state. Figure 3 shows typical examples of detailed trend-charts of BP (BP curve), RR and NPV by expanding in time just before and after the ETS. In Figure 3, the indications of ETS-I~-IV correspond to those inserted in the

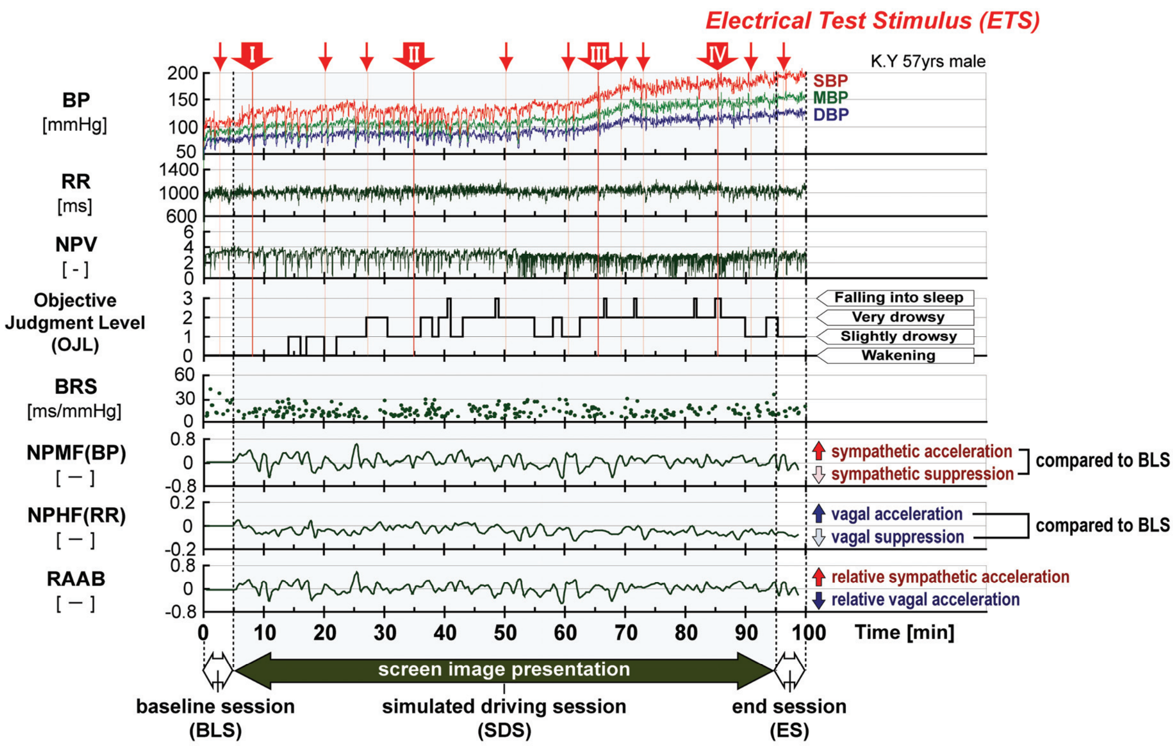
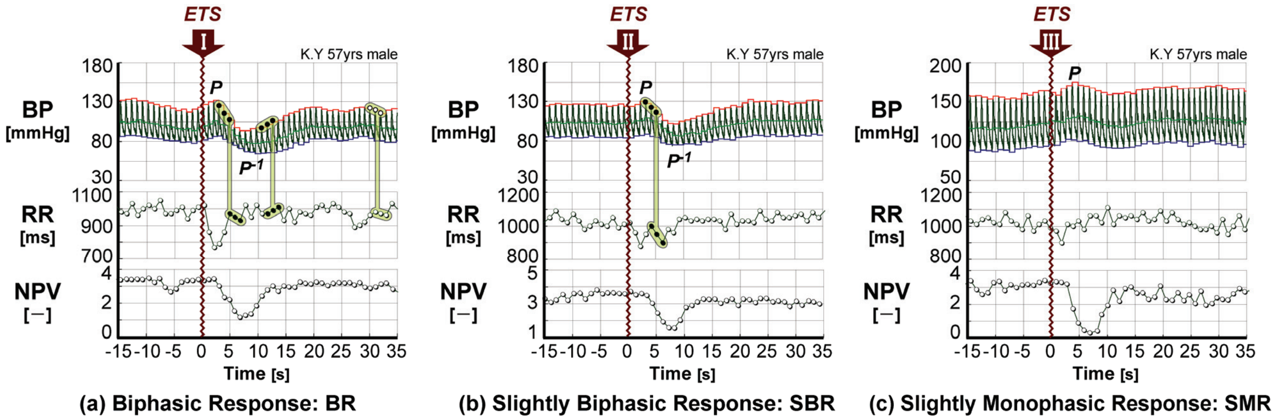


Figure 2: Typical example of 100-min trend-charts of physiological variables together with those of OJL, BRS, NPMF(BP), NPHF(RR) and RAAB obtained in one subject. See text for symbols and explanation.

ISSN: 1727-1983 © 2005 IFMBE



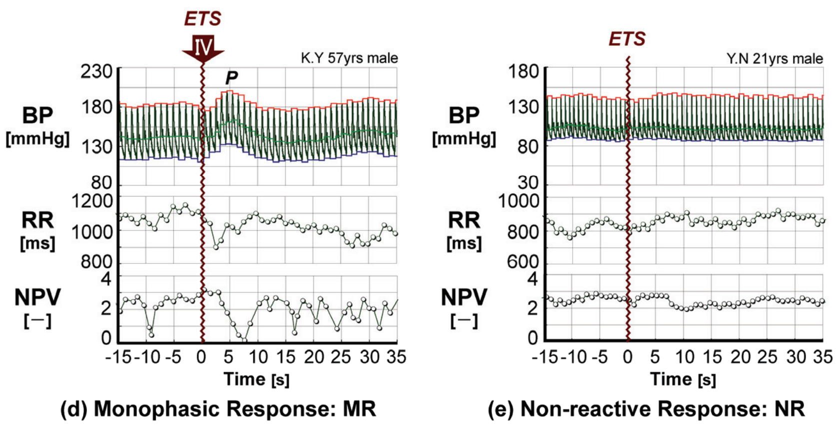


Figure 3: Typical examples of detailed trend-charts of BP, RR and NPV by expanding in time just before and after the electrical test stimulus (ETS). Situations I -IV correspond to those symbols inserted in the top of Fig. 2. The BCR sequence in the SBPs and the corresponding RRs appearing in the records is indicated by an elliptical area. See text for further explanation.

top of Figure 2. Also, the BCR sequence in the SBPs and the corresponding RRs appearing in the records is indicated by an elliptical area.

As shown in Figure 3, mainly five types of response patterns in BP were observed: the first is an increase followed by a decrease in BP [Figure 3(a)], termed a biphasic response (BR) pattern (i.e., convex <*P*> and then concave curve <P^{-1}> indicated in the BP record): the second is an increase followed by a slight decrease in BP [Figure 3(b)], termed a slight biphasic response (SBR) pattern: the third is a slight increase in BP [Figure 3(c)], termed a slight monophasic response (SMR) pattern (i.e., convex curve <*P*>): the fourth is a temporary increase in BP [Figure 3(d)], termed a monophasic response (MR) pattern: the fifth is where there is no significant response in BP, RR and NPV [Figure 3(e)], termed a non-reactive response (NR) pattern. In all the subjects, these patterns (a)→(e) were usually observed in accordance with a lowering of activation state criteria (Level-0 ~ -3). It is noted that in the case of the BR response, the RR response to the momentary stimulation was very similar to that seen in the '*startle reflex*' reported by Codispoti et al [8].

These BP responses could be explained on the basis of a balance between vagal and sympathetic activity. As shown, in the biphasic BP response (in Figure 3(a)/(b)), the decrease in RR would cause the increase in BP (phase <*P*> region), which means relative suppression of vagal activity, while in the phase <P^{-1}> region the decrease in BP would be due to acceleration of vagal activity, taking the emergence of BCR regulation into consideration. The biphasic response could therefore be explained on the basis of vagal control.

The findings of the monophasic BP responses [Figure 3(c)/(d)] are strongly suggestive of a degree of low activation state, since these responses occurred only around the Level-2/-3. Although the reason for these responses is at present unclear, it is speculated that, following the stimulation, the vagal activity would be firstly suppressed and then dampening or slowing down in the vagal activity would occur. This would result in only a small decrease in BP, so that there would be no appearance of the <P^{-1}> region, where BP was oppositely raised due to an increase in sympathetic activity, taking the regulation of peripheral vasomotor constriction indicated by the NPV into consideration. On the other hand, the non-reactive BP response [Figure 3(e)] is an extraneous pattern, which might not be due to autonomic regulation following application of the ETS. This might be considered as a possible '*absent-minded condition*'.

Figure 4 schematically shows the criteria for classification of the BP response patterns following the ETS (*BPRP-ETS*). As seen in the upper part of Figure 4, the BP response pattern during the baseline session, BLS, is set as a reference, and the response patterns are classified into five compared to the reference as follows; *Stage-BR, -SBR, -SMR, -MR, and –NR*, as also shown in the lower panel.

These criteria of the *BPRP-ETS* (BP criteria) were compared with the AS criteria, i.e., Objective Judgment Level (OJL), using the test of Kendall's rank analysis, the summary of which is shown in Table 1. Significant correlation was obtained between the BP criteria and the OJL [r_k=0.763, P<0.001], strongly indicating that *BPRP-ETS* (*Stage-BR, -SBR, -SMR, -MR,* and *–NR*) could form the basis of a viable physiological index for

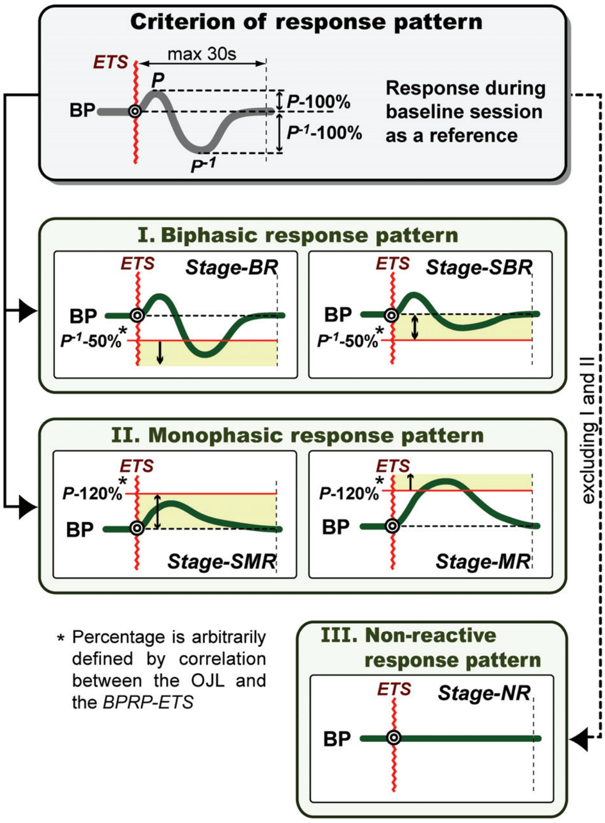


Figure 4: Schematic criteria for classification of BP response patterns following ETS (*BPRP-ETS*). See text for explanation.

Table 1: Frequency distribution between activation state criteria (*Level-0 ~ -3*) and *BPRP-ETS* (*Stage-BR, -SBR, -SMR, -MR, and -NR*).

AS criteria	BPRP-ETS Stage-BR	Stage-SBR	Stage-SMR	Stage-MR	Total	Stage-NR
Level-0	18	1	0	0	19	0
Level-1	11	14	1	0	26	6
Level-2	4	7	15	7	33	9
Level-3	0	0	2	15	17	2
Total	33	22	18	22	95	17

Kendall's rank correlation coefficient: 0.763 (p<0.0001)

the AS. We could therefore define the following levels: *Stage-BR; Normal level*, *Stage-SBR; Attention level*, *Stage-SMR; Danger level*, *Stage-MR; Serious accident level*, *Stage-NR; Attention or danger level.*

Conclusions

Under laboratory conditions, during the presentation to a driver of a monotonous screen image, we have successfully measured a number of physiological variables and their responses to a momentary test stimulation randomly applied to the subject, expecting that such responses may be related to the driver's activation state (AS). It was clearly demonstrated that sympathetic activity was increased relatively, whilst vagal tone appeared to be suppressed during the monotonous situation. As a result a gradual rise in BP was observed. Particular patterns of beat-by-beat change in BP in response to the ETS, which could be explained on the basis of a balance of autonomic activity, were successfully obtained in relationship to the level of the AS. Although these patterns would appear to be the basis of an appropriate and feasible index of activation state, further experiments under actual driving conditions should be made.

Acknowledgments: The authors wish to thank Mr. Masashi Kusumi and Mr. Koji Tanida, Honda R&D Co., Ltd., for their suggestive comments, and Mr. Kenta Matsumura, Hokkaido University, for his technical assistance.

References

[1] NAKAGAWARA M. and YAMAKOSHI K. (2000): 'A portable instrument for non-invasive monitoring of beat-by-beat cardiovascular haemodynamic parameters based on the volume-compensation and electrical-admittance method', Med. & Biol. Eng. & Comput., **38**, pp. 17-25

[2] YAMAKOSHI K., NAKAGAWARA M., TANAKA S. (2000): 'Current development in beat-by-beat cardiovascular monitoring with non-invasive and ambulatory techniques', (In Singh M., Radhakrishnan S., Ratil K. M. & Reddy M. R. S.(Eds): Medical Diagnostic Techniques and Procedures, Narosa Publishing House, New Delhi), pp. 132-141

[3] YAMAKOSHI K. (2003): 'Non-invasive cardiovascular haemodynamic measurements', (In Oberg P. A., Togawa T. & Spelman F.(Eds): Sensors in Medicine and Health Care (Sensors Applications, Vol. 3), Wiley-VCH Verlag, Weinheim), pp. 107-160

[4] SAWADA Y., TANAKA G. YAMAKOSHI K. (2001): 'Normalized pulse volume (NPV) derived photoplethysmographically as a more valid measure of the finger vascular tone', Int. J. Psychophysiol., **41**, pp. 1-10

[5] SHACHINGER H., WEINBACHER M., KISS A., RITZ R., and LANGEWITZ W. (2001): 'Cardiovascular indices of peripheral and Central Sympathetic Activation', Psychosomatic Medicine, **63**, pp. 788-796

[6] POMERANZ B., MACAULAY R. J. B., CAUDILL M., KUTZ I., ADAM D., GORDON D., KILBORN K. M., BARGER A. C., SHANNON D. C., COHREN R. J., and BENSON H. (1985): 'Assessment of autonomic functions in human by heart rate spectral analysis', Am. J. Physiol., **248**, pp. 151-153

[7] BERTINIERI G., DI RIENZO M., VAVALLAZI A., FERRARI A. U., and MANCIA G. (1988): 'Evaluation of baroreceptor reflex by blood pressure monitoring in unanaesthetised cats', Am. J. Physiol, **254**, pp. 377-383

[8] CODISPOTI M., BRADLEY M. M., and LANG P. J. (2001): 'Affective reactions to briefly presented pictures', Psychophysiol., **38**, pp. 474-478