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Evaluation of Driver Stress Using Biomarker in Motor-vehicle Driving Simulator

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Abstract—**Employing the analysis of a biomarker, an oculomotor angle and a subjective evaluation, we have examined the acute, psychological effect human stress of driving using a motor-vehicle driving simulator. Salivary amylase is used as a biomarker, as it is considered to be one of the indicators of sympathetic nervous activity. 20 healthy female subjects in their early twenties were enrolled in this study. The time-course change of their salivary amylase activity (sAMY) is analyzed before and during the driving. At the same time, using a questionnaire, subjective evaluations are conducted with each subject. As for comparison, the effect of operating a car navigation device, which is not directly associated with driving, is also evaluated. Our results indicate that the psychological effect of driving-induced stress, a condition that can not be easily detected or recognized by a subjective evaluation, is quickly quantified using a biomarker in saliva. Moreover, the results suggest that operation of a non-driving-related device may also reduce the capacity to concentrate on driving. These data imply that evaluation of driver stress using a biomarker can be very useful for improvement of safety during driving.**

Keywords—**Biomarker, Amylase, Sympathetic nervous system, Motor-vehicle, Driving**

I. Introduction

Society will experience a rapidly aging population over the next few decades. Even under conditions in which the number of economically productive citizens has been markedly reduced, we still need to maintain safety and security in our society. To successfully achieve this goal, it is essential for us to predict and reduce human errors and mishaps as far as is possible. In order to reduce human errors, there have been investigations to monitor stress or fatigue while driving [1]-[2].

While driving people feel stress whenever they respond very quickly to sudden steering or braking, whilst cautiously checking for the presence or absence of obstacles on the road, and turning on a sharp curve. However, since it is likely that investigation of these quick responses and their stress effects using a real motor-vehicle would cause an accident, it may be impossible, particularly from an ethical point of view, to evaluate driver stress by actually driving a commercial motor vehicle on regular roads. Instead, a motor-vehicle driving simulator (simulator) which consists of a driving unit and driving simulation software has recently been investigated. For quantitative evaluation of the physiological effects of motor-vehicle driving, physical measurements such as electroencephalogram (EEG), electrocardiogram (ECG), blood pressure and heart rate have been performed [3]. However, the physical measurements require the subjects to be physically restrained.

In contrast, a method of quantification of physiological effects has been investigated based on biochemical measurements using a biomarker present in saliva. Sampling saliva has the advantage that it is noninvasive, which makes multiple sampling easy, and it does not introduce distress. The authors have been investigating an evaluation method using salivary amylase activity (sAMY) [4]. sAMY can be a useful index of plasma norepinephrine concentration under a variety of stressful conditions, since it appears that increased sympathetic nervous activity is a major stimulator of amylase secretion [5].

The purpose of this study is to evaluate the acute psychological effect of motor-vehicle driving, using salivary amylase as a biomarker. A simulator is fabricated, which enables us to record the driver's responses. 20 healthy female subjects in their early twenties are enrolled, since women at around this age may be thought as being not inexperienced at driving. The time-course change in sAMY is quantitatively analyzed using a hand-held sAMY monitor before and during the driving using the simulator. In parallel, subjective evaluation using a questionnaire and measurement of oculomotor (eyeball movement) angle are conducted on each subject.

II. Methods

A. Subjects

20 healthy female adults without any oral disease (21.4 ± 1.0 yr, mean ± SD) were enrolled in this study. The study protocol was approved by the Ethical Committee of the Institutional Review Board of the University of Toyama, Medical Branch (Toyama, Japan). The study protocol was fully explained to all of the subjects in both spoken and written forms, specifically focusing on the purpose of the study, the precise procedures that would be used and any possible adverse effects. Signed informed consent was obtained from each subject who enrolled in the study.

For 1 hour prior to the experiment, subjects are not allowed

to take any food or drinks except for water, and in particular, intake of stimulants such as alcohol, caffeine and garlic is prohibited.

B. Motor-vehicle driving simulator

A simulator consists of a driving unit, a large display monitor and simulation software (Fig.1 (a)). Parts from commercial motor vehicles with an engine size of 2,000 – 3,000 cc are used for the seats and steering wheel for the driving unit (110 × 180 × 125 cm^3) (Fig.1 (b)). People simulate driving by operating the steering wheel, accelerator and brakes while they are watching a large display monitor (200 × 170 cm^2, Fig.1 (c)). Simulation software by which people can drive around a circuit course of approximately 1 km/round with 13 meters width is used. A snow-covered road is simulated in order to produce conditions in which a sudden dramatic change in the direction of a motor-vehicle body occurs because of a hard slip. The driving condition is set to be recorded as the width of deviation from the center of the driving course, which is calculated as a ratio of the base width (± 6.5 m) and shown as the absolute values (deviation values).

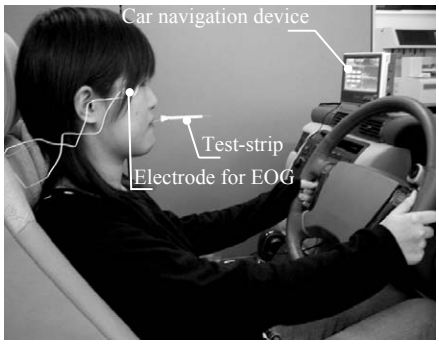
C. Measurements

A hand-held type sAMY monitor (hand-held monitor) with a saliva transcription device was previously fabricated by the authors [4]. This hand-held monitor consists of a disposable test-strip and an optical analyzer (126 × 130 × 48 mm^3; 350 g), which is incorporated within an automatic saliva transcription device. The test-strip consists of a collecting sheet attached to the collecting papers and a holder with which a reagent paper is attached. A volume of 20 – 30 μl of whole saliva is collected with the collecting paper placed under the tongue. When the test-strip is examined by the optical analyzer, the analysis is automatically controlled and the sAMY is shown on a display after completion of the measurement. A total of one minute was sufficient to analyse the sAMY.

An oculomotor angle reading is used as a physiological index of physical measurement. Three electrodes (Ambu Inc., Denmark) are placed at 1 cm down the right temple (+), 1 cm above the left temple (-) and forehead (ground) using an electro-oculography (EOG) [6] (Fig.1 (b)). A standard value is set as 0 V when subject is sitting and looking straight ahead. The angles right and left ± 30 degrees correspond to ± 0.5 V.

In order to measure the psychological effect of the driving, a self-assessed questionnaire of psychological state (pre: Q_1 and post: Q_2) is set, consisting of seven adjectives: *relaxed, fun, anxious, refreshed, stressed, uplifted* and *tired* as a subjective evaluation. The applicability of the adjectives to current mood is marked by the subjects on a scale of one to five: *strongly disagree* (1), *somewhat disagree* (2), *can not say either or not* (3), *somewhat agree* (4) or *strongly agree* (5).

(a) External view of a motor-vehicle



(b) Driving unit and measurements

(c) Simulation software

Fig. 1. Fabricated motor-vehicle driving simulator.

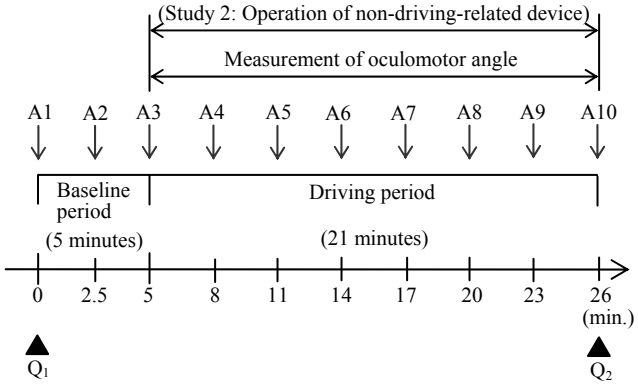


Fig.2. Protocol of an accelerated evaluation using a motor-vehicle driving simulator. ($Q_{1\text{-}2}$) Questionnaire of psychological states.

D. Study design

Study 1: Firstly, three electrodes are placed on the subject for the measurement of the oculomotor angle. Then, subjects answer the questions identified in the questionnaire regarding psychological state (Q1). Initially, each subject takes a sitting position for 5 min in order to measure the individual baseline ($A_{1\text{-}3}$, baseline period, Fig.2). The minimum value is set as the sAMY during the base line period (AMY_{base}). Next, the subjects drive for 21 min using the simulator, and sAMY is measured every 3 min (7 times) during this period ($A_{4\text{-}10}$, driving period, AMY_{dr}). The oculomotor angle is measured continuously during the driving period. Immediately after completion of the measurement, the subject fills in the psychological state questionnaire (Q2). The subjects are instructed to drive a car in the center of the lane as much as they possibly can.

Study 2: In order to investigate the effects of operation of a device, which is not directly related to driving a motor-vehicle, the subjects are instructed to input digit on the touch panel of the car navigation device, which is installed in the driving unit (non-driving-related device). With a method similar to Study 1, the subjects simultaneously perform two tasks, driving and inputting a number on the car navigation device and sAMY and other parameters are measured.

Parametric tests are used as appropriate (SPSS 14.0J, SPSS Japan Inc., Japan). Within group comparisons are performed using paired Student *t* test. Comparisons between groups are performed using unpaired Student *t* test. A value of $P < 0.05$ is taken to represent statistical significance. Unless otherwise stated, all data are expressed as mean ± standard deviation (SD).

III. Result and Discussion

There were no significant differences in the adjective scores between Q1 and Q2 in both Study 1 (driving) and Study 2 (driving and operation of non-driving-related device) (Fig.3). In other words, it was considered that the driver stress of 21 min driving could not be detected by a 5-scale subjective evaluation.

In addition, no significant difference in the deviation ratio was observed between Study 1 and Study 2 ($P > 0.05$), and the deviation ratio is relatively high 0.060 ± 0.08 and 0.63 ± 0.09 for their mean values in Study 1 and Study 2, respectively (Fig.4). Since the simulation setting was a snow-covered road, it was almost impossible for the subjects to keep driving a car in the center of the road.

The oculomotor angle markedly increased in Study 2 compared to that in Study 1 (Fig.4, $P < 0.01$). That is, the effects of a non-driving task, operating a car navigation device, on the subject's physiological condition were observed as a physical measurement quantity with the oculomotor angle.

sAMY during driving (AMY_{dr}) significantly increased compared to its baseline (AMY_{base}) in both Study 1 and Study 2 ($P < 0.01$), and the means of increasing rates were 55.4% and 67.5% for Study 1 and Study 2, respectively. There were certain correlations between time-course changes in sAMY values and individual input frequency with the car navigation device (Fig.5). These results suggest that the input operation might influence the psychological state of the subjects.

Therefore, the trend of the time-course changes in sAMY is compared for all the subjects. sAMY significantly increased during the driving period as compared to the baseline period ($P < 0.05$). If the mean values of sAMY at each time point between 3 and 21 min are linearly extrapolated, the slope is positive (+0.23) in Study 1, with a trend to increase, suggesting activation of the sympathetic nervous system (Fig.6 (a)). On the other hand, the slope is negative (-0.15) in Study 2, with a trend to decrease, suggesting inactivation of the sympathetic nervous system (Fig.6 (b)). These data suggest a possibility that repeated simple procedures such as operating a car navigating device, which are not directly related to driving itself, may reduce the driver's capacity to concentrate on driving.

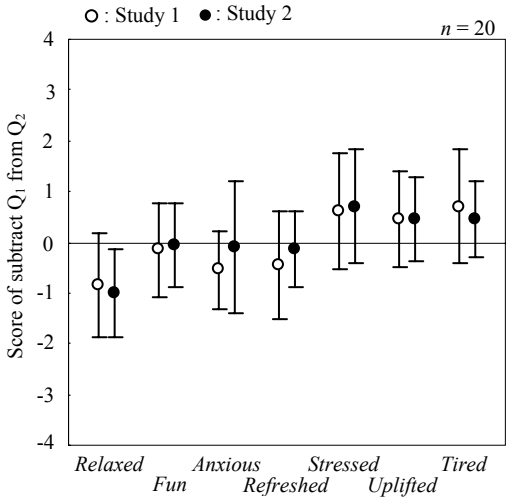


Fig.3. Score of psychological state questionnaire.

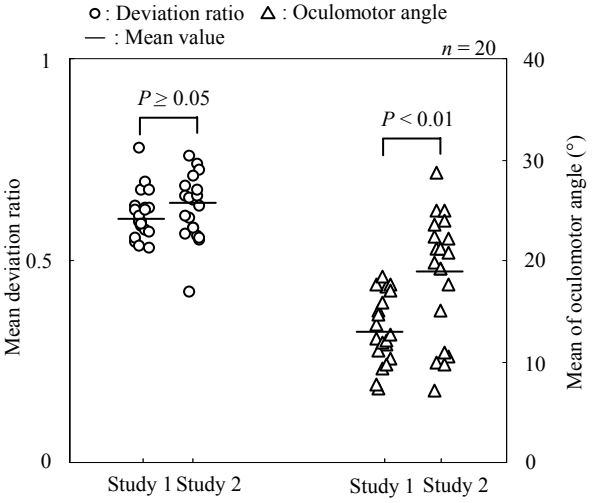


Fig. 4. Comparison between Study 1 and Study 2 by deviation ratio and oculomotor angle. Study 1: Driving, Study 2: Driving and operation of non-driving-related device.

IV. CONCLUSION

A psychological effect of motor-vehicle driving that could not be easily detected by a subjective evaluation was rapidly and quantitatively evaluated by a biomarker in saliva. Moreover, the results suggested that operation of an non-driving-related device might induce a significant reduction in the driver's capacity to concentrate on driving. Thus, evaluation of driver stress using a biomarker is considered to be very useful to improve the safety and security of motor-vehicle drivers by quantification of driving-induced stress.

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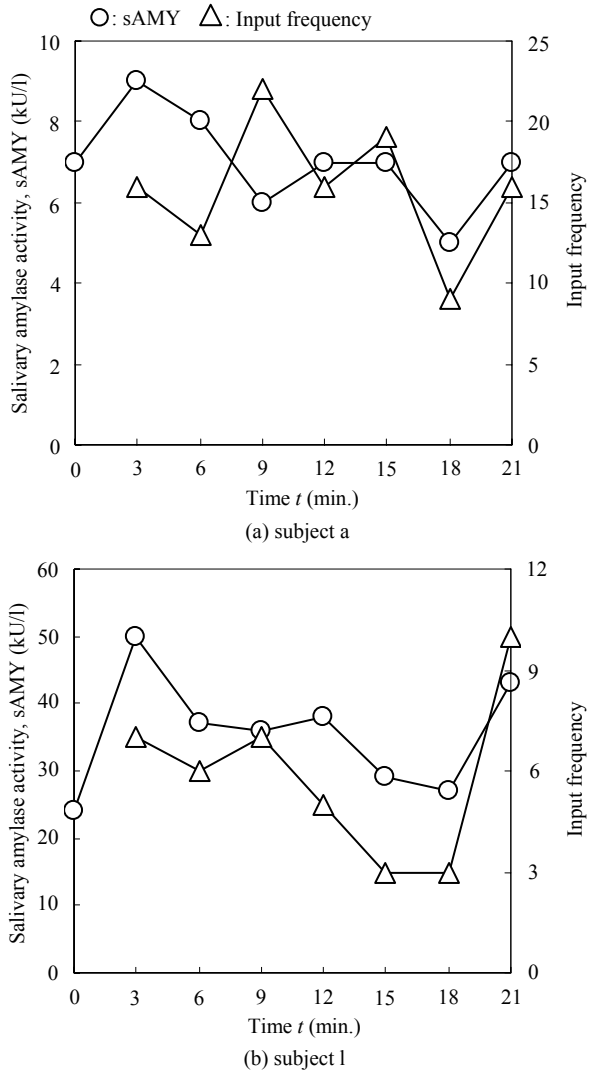

Fig. 5. Time-course changes in sAMY and input frequency over the driving for individuals.

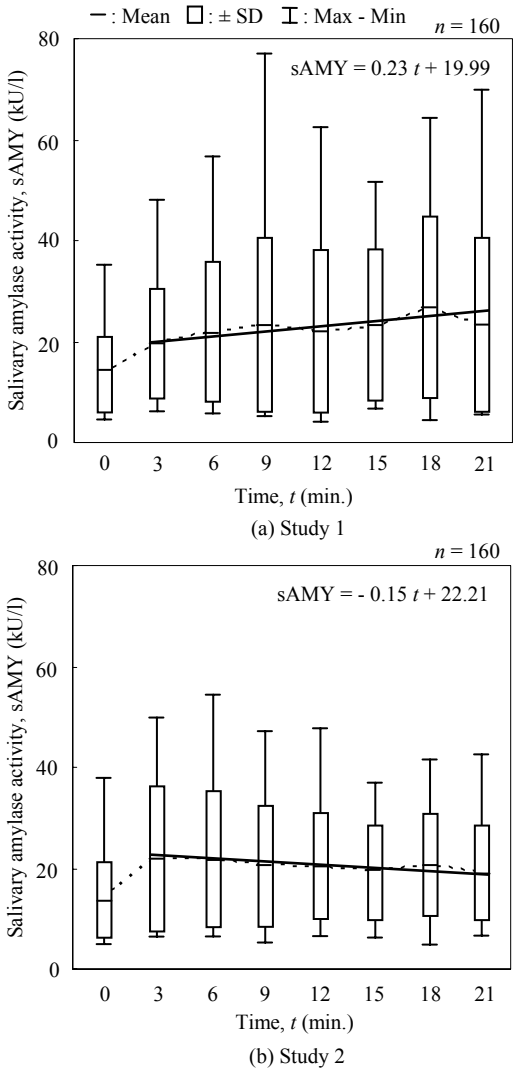

Fig. 6. Time-course changes of the mean value of sAMY.

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