

Detect the Imperceptible Drowsiness

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ABSTRACT

Prediction of drowsiness based on an objective measure is demanded in machine and vehicle operations, in which human error may cause fatal accidents. Recently, we focused on the pupil which is controlled by the autonomic nervous system, easily and non-invasively observable from the outside of the body.

Prior to the large low frequency pupil-diameter fluctuation, which is known to associate with drowsiness, a Gradual Miosis was observed in most subjects. During this miosis period, the subjects were not yet aware of their drowsiness. We have developed a software system which automatically detects the Gradual Miosis in real time.

I. INTRODUCTION

It is said that when a driver drives a vehicle at low arousal levels where his/her physiological activity is low, mistakes and errors occur [e.g., 1] in predictive and reactive behaviors [2]. Accordingly, when driving under low arousal levels, serious accidents may occur. To prevent “doze-off and drowsy driving accidents” caused by low arousal levels, it is desirable to constantly and objectively monitor the arousal levels of the driver driving the vehicle and to assist the driver in driving the vehicle by monitoring his/her arousal levels.

The method of measuring the activity of the autonomic nervous system, which varies by arousal level, has been employed for evaluating the arousal level [3]. The activity of

the autonomic nervous system of a human being is normally observed through the activity of organs, which are under its control. Attention has been attracted to biosignals, such as heart rate and pulse as indices of the activity of these organs [e.g., 4]. In the vehicle driving environment, it is difficult, however, to accurately measure those biosignals as an objective index by using non-binding and non-invasive devices. For this reason, that the matter of how to measure the carrying of biosignals is an issue that needs to be solved [3]. Of the organs under control of the autonomic nervous system, the pupil diameter [5] may be non-invasively measured by optical means. The pupil diameter is considered suitable for the index for monitoring the activity of the autonomic nervous system.

In a night vision environment, when man perceives drowsiness, there are periodic “fatigue waves” in the pupil diameter, making the pupil an effective index for the diagnosis and medical treatment of narcolepsy. This fact has already been reported [6, 7]. Wilhelm et al. evaluated the relationship between drowsiness and the fatigue waves of the pupil diameter using the pupillary unrest index (PUI), and found that there is a correlation between objective drowsiness and the PUI. However, the PUI is not suitable as an index for detecting a driver's drowsiness because it is necessary to measure the pupil diameter of the subject for 11 minutes with the subject kept quietly in a completely dark field. The fact that the fluctuation of the pupil diameter has a correlation with drowsiness, and possibly predicts drowsiness has been little discussed or evaluated [e.g., 8].

With the above as background, we studied utilization of the pupil diameter fluctuation as a drowsiness predictor index in the two steps described below. In the first step, we studied lowering the arousal level of a healthy subject and the validity of the pupil diameter evaluation as an index to detect the predictor of the lowering of the arousal level. In this paper, we measured the response time (RT) in an anti-saccade task to quantitatively evaluate the lowering of the informative processing ability in the brain, which is caused by the lowering of the arousal level [9]. In the second step, we constructed an algorithm for automatically determining the arousal levels by using characteristic quantities calculated from the evaluation results. Experiments were made by an indoor driving simulation to lower the arousal level in a safe environment.

II. METHODS

A. EXPERIMENTAL SETUP

A driving simulator (DS) system was made up of a projector (EPSON ELP-73) for projecting a driving simulator on a screen, the screen, and a driver's seat (Logicool PRC-11000) equipped with a steering wheel, brake and accelerator pedal. A schematic diagram of the experimental setup is shown in Fig. 1. A subject sat comfortably in the driver's seat. The seat was set so that the head of the subject faced the center of the screen. The distance between the front of the subject's head and the screen was 2640 mm, and screen size was 100 inches (horizontal visual angle = ± 12.1 degrees, vertical visual angle = ± 10.7 degrees). The steering wheel was adjusted to the subject so as to maintain a comfortable position. The experiment was made in a dark room. The DS image projected on the screen showed a scene in the distance which, aside from the traffic lane and road shoulder, remained the same. The brightness and contrast of the projector were adjusted so that the pupil diameter of the subject stayed within the medium range (about 6 mm).

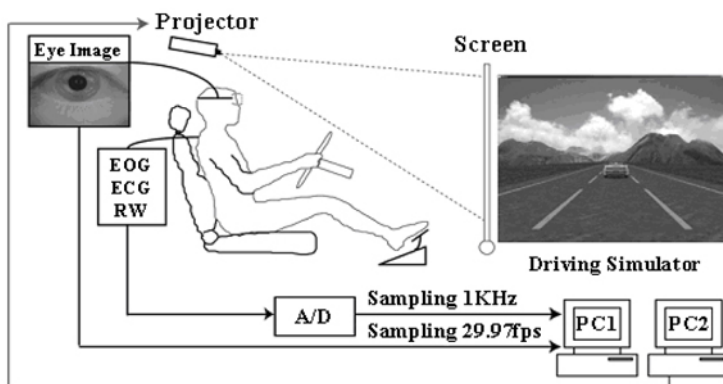


Fig. 1. Schematic diagram of the experimental setup.

B. MEASUREMENT DATA

Biosignals of the subjects to be measured included eyeball images, electro-oculograms (EOG), respiratory waves (RW), and electro-cardio grams (ECG). In this paper, special attention was paid to arousal degree, pupillary response, and response time (RT) of the anti-saccade task (to be described later), and analyzed the eyeball image and EOG (electro-oculogram). We will report, in another paper, the heart rate and the respiratory wave, which like the pupil, contained activity of the autonomic nervous system after analyzing the relationship [10] between them and the analysis results of the pupil diameter and the anti-saccade task. The eyeball image was measured at a frame rate of 29.97 fps (NTSC) by using goggles (NEOPTO · ET-60-L). The respiratory wave (RW) was measured with a strain gauge type respiration pickup sensor. Dish electrodes were used for the measurement of the electro-cardio gram (ECG) and the electro-oculogram (EOG). These measured biosignals were amplified by the bioelectric amplifier (MT-11; NEC San-ei). These biosignals were synchronized with the eyeball images using Spike2 software (Cambridge Electronic Design), and digitized at the sampling rate of 1 KHz by AD/DA device, Power1401 (Cambridge Electronic Design) and stored in a data storage PC. Eyeball image data were branched and fed into another PC. A pupil image was extracted from the eyeball image data by a custom program developed by LabVIEW software (NATIONAL INSTRUMENTS), and the pupil diameters were monitored in real time.

C. SUBJECTS

A total of 18 healthy subjects (mean $\pm$ SD: 22.8 ± 7.1 years old) participated in the experiment. All of the subjects had given their informed consent. The experiment procedures were considered with caution based on previous similar studies, following proven method. Very careful attention was paid for subjects, preventing simulator sickness or other pains during the experiment. Farsighted and nearsighted subjects wore contact lenses to correct their eyesight.

D. EXPERIMENT PROCEDURES

After attaching bioelectrodes and eyeball imaging device, each subject sat in the driver's seat in a natural posture and practiced operating the driving simulator for one minute. A time period of 10 minutes was set to adapt the retina of each subject to darkness in the laboratory. During this period, subjects were prohibited from manipulating the DS (driving simulator) system, but were allowed to participate in ordinary conversation to prevent them from becoming drowsy. Following the preparatory work described above, one of the following two experiment tasks was given to the subjects, and those biosignals were measured.

(1). Monotonous driving experiment

The subject drove at a constant speed in the center lane of a monotonous 3-lane straight road with no opposite lane, with the foreground scene remaining unchanged. The subjects were instructed to fix their eyes on the upper part (fixed point) of the name plate of the vehicle in front during DS operation. The DS operation time was set at any of 10, 15, 20, and 30 minutes. After the tests, they were also asked whether or not they had felt sleepy.

(2). “Monotonous driving + anti-saccade” experiment

A circular visual target (with a visual angle of 0.5 degrees) was randomly presented at a position (defined by horizontal visual angles of 10 degrees) for 0.2 seconds during the Monotonous driving in experiment (1). The subjects were instructed to perform an anti-saccade task in which immediately after recognizing the visual target in his/her peripheral visual field, each subject turned his/her eyes to the position located point-symmetrically with respect to the fixed point (while fixing his/her head), and instantly returning his/her eyes to the fixed point in the experiment (1). The visual target was presented at time intervals of 10 or 20 seconds and those biosignals were measured for 10 or 20 minutes. Then, they were asked to report on whether or not they became drowsy. To measure the performance of the anti-saccades when the subjects were at rest and quiet and awake, a 3-minute anti-saccade experiment was carried out multiple times to gather control data on another day without the present experiment. The subjects practiced the execution of the anti-saccade task in advance so they were sufficiently accustomed to it.

E. DATA ANALYSIS

(1). Eyeball image analysis

The eyeball image was digitized at an appropriate level to extract the pupil image from the eyeball image, and the varying pupil diameters were monitored in real time using a custom program developed by LabVIEW software (NATIONAL INSTRUMENTS). Further, the eyeball image data was analyzed in off-line mode by MATLAB (MathWorks) to calculate the vertical and horizontal diameters of the pupil and the coordinates of the center of the eyeball [10]. The data generated during the following periods were not analyzed, but appropriate thresholds were set for the subjects: a period during which it was impossible to accurately calculate the pupil diameter because of blinking or saccadic motion of the eyeball, and another period during which it was impossible to measure the maximum diameter of the pupil because the eyelid of the subject had dropped owing to drowsiness.

(2). Anti-saccade analysis

A response time (RT) ranging from the instant that the visual target for anti-saccade was presented until the saccadic velocity was reached at maximum, was used as an index for evaluating the in-brain informative processing ability of the subject. The saccadic velocity was calculated by subjecting the digitized EOG data to a low-pass differential process (cutoff frequency: 13.4 Hz) [4].

III. RESULTS

A. RESULTS OF MONOTONOUS DRIVING EXPERIMENT

Fig. 2 is a graph showing fluctuations of pupil diameters of two typical subjects. Fig. 2(a) shows a fluctuation of the pupil diameter of a subject MK who reported after the test that he perceived strong drowsiness from the middle to the end of the experiment time. Fig. 2(b) shows the fluctuation of the pupil diameter of subject SK who reported no drowsiness during the experiment. In the case of MK, a substantially monotonous gradual miosis continued from approximately one minute to four minutes after the start of the experiment (Fig. 2(a), Gradual Miosis: GM). After the monotonous gradual miosis, viz., four minutes, a large low-frequency fluctuation (in the same figure, large low frequency fluctuation (LLFF)) was observed. The case of SK, who perceived no drowsiness in the experiment, is shown in Fig. 2(b). Neither the monotonous gradual miosis nor the large fluctuation of the pupil diameter appeared. Of 18 subjects, 12 subjects were measured one time for data gathering, 5 subjects were measured two times, and the remaining one subject was measured three times. A total of 25 pieces of data were gathered through the measurements. Table 1 tabulates the monotonous gradual miosis and presence or absence of the large fluctuation in the measurement data by the observation, and drowsiness or no drowsiness perception by the introspective report. In the Monotonous driving experiment, of the 25 pieces of data, 16 pieces of data show subjects reporting that they perceived drowsiness during the experiment. Of these 16 pieces of data, 14 pieces (87.5%) contained large fluctuations. Large fluctuation was not found in the 9 pieces of data that included reports of no drowsiness. Of the 14 pieces of data containing the large fluctuations, 11 (78.6%) described a large fluctuation following a monotonic gradual miosis. It is known that a large fluctuation of the pupil diameter of the subject reporting drowsiness, which appeared in the later half of the experiment, is associated with subjective drowsiness of the subject [8, 11]. This was also true in the reports made by the subjects in this experiment. Furthermore the subjects of 3 pieces of data, which only contained the large fluctuation but did not contain monotonic gradual miosis, reported drowsiness. And other subjects of 3 pieces, which only contained monotonic gradual miosis but not contained large fluctuations, did not perceive drowsiness.

From the facts described above, it could be said that in the monotonic gradual miosis period observed before the large pupil-diameter fluctuation appeared, the subject did not perceive drowsiness or that the drowsiness predictor was present in the subject.

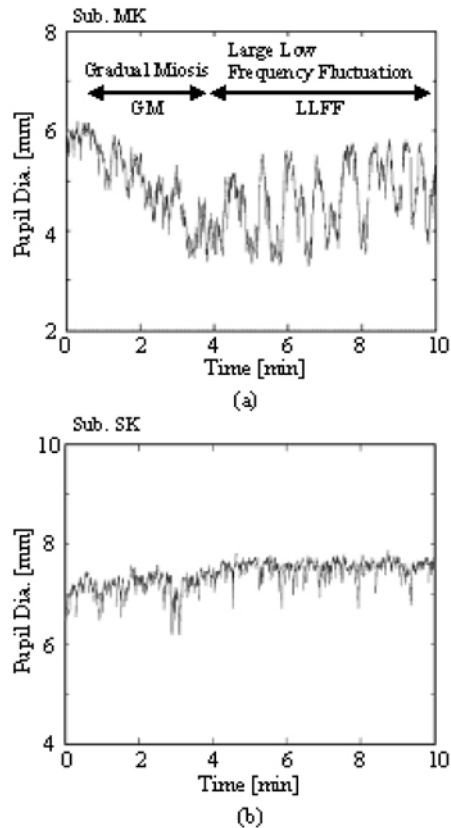


Fig. 2. Change of pupil diameter during the driving simulation. Data during blinks and saccades were eliminated and interpolated. (a):a typical subject who reported drowsiness after the experiment. (b):a subject who did not report drowsiness after the experiment. Note that in (a) there is a monotonic decrease period (gradual miosis) followed by a large low frequency fluctuation period (large low frequency fluctuation) which is not observed in (b).

Table 1. Change in pupil diameter vs. sleepiness.

Change in Pupil diameter		Sleepiness	
Gradual miosis	Large low frequency fluctuation	YES	NO
Observed	Observed	11	0
Observed	Not Observed	0	3
Not Observed	Observed	3	0
Not Observed	Not Observed	2	6

B. RESULTS OF EXPERIMENT FOR EVALUATING DROWSINESS PREDICTOR

Of 18 subjects who participated in the experiment, 4 subjects who easily became drowsy in the Monotonous driving experiment participated multiple times in the experiment on another day. In this experiment, the DS (driving simulator) operation was stopped in the monotonic gradual miosis period and the large pupil-diameter fluctuation period, and the subjects were asked whether they were drowsy. Fig. 3 shows variations of the pupil diameter until measurement was stopped in each period. A variation of the pupil diameter shown in Fig. 3(a) was measured when the measurement had been stopped before the large pupil-diameter fluctuation appeared. A variation of the pupil diameter shown in Fig. 3(b) was measured when the measurement was stopped when the monotonic gradual miosis appeared and then the large pupil-diameter fluctuation appeared. When the DS operation was stopped in the monotonic gradual miosis and immediately after the large pupil-diameter fluctuation occurred, none of the subjects reported drowsiness. In an experiment in which the experiment was stopped and the subjects were requested to make reports during observation of the large pupil-diameter fluctuation, the four subjects reported drowsiness, just like the 14 subjects who experienced the large fluctuation in pupil diameter in the previous Monotonous driving experiment. As seen from the description above, this monotonic gradual miosis phenomenon could be an imperceptible predictor signal of perceptible drowsiness, which occurs several minutes after monotonic gradual miosis.

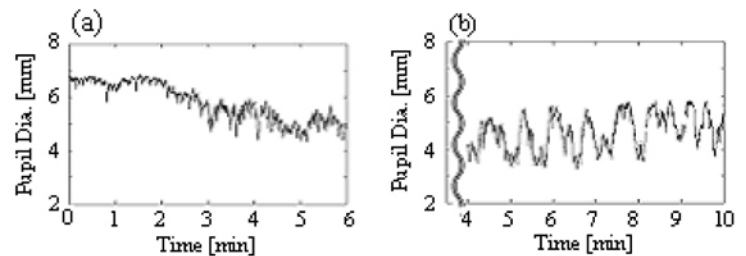


Fig. 3. Change in pupil diameter during the monotonous driving situation simulation in which the experiment was terminated when the subject showed gradual miosis ((a) at 6 min) or large low frequency fluctuation ((b) at 10min). The subject in (a) reported he was sleepy. In (b), only the last 6 min of the data are shown.

C. “MONOTONOUS DRIVING + ANTI-SACCADE” EXPERIMENT RESULTS

Figs. 4(a),4(b),4(c) are graphs showing fluctuations and variations of pupil diameter (a), RT (response time) of the anti-saccade (b), and EOG (electro-oculogram) (c) when the