"Implementation of System to overcome the drowsiness by using Cardio Respiratory Phase Synchronization"

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***Abstract*—Preventing accidents caused by drowsiness has become a major focus of active safety driving in recent years. A variety of things may cause drowsiness. These include mental state and life choices to serious medical conditions. Certain life choices may lead to increased drowsiness, such as working very long hours or switching to a night shift. Many automobile companies and institutions have been studying ways to monitor drowsiness and keep drivers awake. When drowsiness is detected during driving, audible sound, vibrations, or messages on a display are generally used to warn the driver to concentrate on driving or to take a rest. These methods help to prevent drowsiness-related crashes to some extent, but for greater safety, methods need to be developed to physiologically overcome drowsiness. The key to overcoming drowsiness is to keep the body constantly supplied with oxygen. Experimental results demonstrate the feasibility of quantitatively estimating drowsiness level using cardiorespiratory phase synchronization (CRPS).This study found it possible to induce CRPS by paced breathing (PB) using pulse sound, which synchronized with heartbeats. In conclusion, inducing CRPS by PB using pulse sound synchronized with the heartbeat has the potential to reduce drowsiness physiologically**.

Keywords- Cardiorespiratory phase synchronization (CRPS),SpO2,Heart rate detecting circuit, electrocardiogram

I. INTRODUCTION

Drowsy driving is the silent hidden killer that haunts the roads. It could be your life or someone close to you that's cut short or ruined by drowsy driving, if you or a fellow traveler falls asleep at the wheel or just aren't fully awake while driving. The National Highway Traffic Safety Administration conservatively estimates that about 100,000 police reported crashes and are the direct result of drowsy driving each year. The study further discloses that Driver Drowsiness was a contributing factor in 20% of all crashes.

However, the official government statistics are widely regarded as substantial underestimates of the true magnitude of the problem. The statistics reported by the NHTSA are based on data compiled from reports completed by police officers investigating the scenes of motor vehicle crashes. However, unlike impairment by alcohol, impairment by sleepiness, drowsiness, or fatigue does not leave behind physical evidence, and it may be difficult or impossible for the police to ascertain in the event that a driver is reluctant to admit to the police that he or she had fallen asleep, if the driver does not realize or remember that his or her performance was impaired due to fatigue, or if the driver is incapacitated or deceased and thus unable to convey information regarding his level of alertness prior to the crash. This inherent limitation is further compounded by the design of the forms that police officers complete when investigating crashes, which in many cases obfuscate the distinction between whether a driver was known not to have been asleep or fatigued versus whether a driver's level of alertness or fatigue was unknown. The absence of this distinction precludes the use of standard statistical methods such as multiple imputation to estimate the proportion of drivers whose alertness or drowsiness could not be ascertained in the field who were likely to have been drowsy.

The key to overcoming drowsiness is to provide the body with a constant supply of oxygen. It is generally known that oxygen desaturation deteriorates brain activity and brings about a loss of attentiveness and concentration. It reported that drowsiness gets severe while oxygen rate is lowered and is weakened while high rate of oxygen is supplied. It also found usefulness of oxygen for enhancing the alertness of a driver. There are some studies in which highly concentrated oxygen with fragrance also resulted in the reduction in drowsiness of a driver. According to this correspondence of oxygen and drowsiness, oxygen desaturation is also used as a means to detect drowsiness while driving. Some systems have been proposed to avoid drowsy driving by enriching oxygen in the passenger compartment of a car. These oxygen enrichments are practiced by opening windows or delivering high concentrated oxygen from air conditioner vents. However, they require oxygen stock container or generator and vent systems, find it difficult to control be the density of the oxygen, and cannot expected to have an immediate effect in reducing drowsiness. It is desirable to have a method that enables absorbing the oxygen into the body more directly and constant with less installation of equipment.

We attempted to induce CRPS by pacing subjects breathing and examined the results in three steps as follows. At the first step, we observed how oxygen saturation changes at the heart when drowsiness appears and is overcome. Then, we investigated how much recovery of oxygen saturation serves to overcome drowsiness. At the second step, we attempted to induce CRPS by instructing subjects to pace their breathing by using a pulse sound indicator synchronized with the heartbeat. This paced breathing (PB) method was aimed to match the timings of the heartbeat and the timings of inspiration and expiration. At the last step, we investigated whether the induced CRPS recovers a sufficient amount of oxygen saturation by comparing with the results obtained at the first step.

In this paper, we focused on cardiorespiratory phase synchronization (CRPS) to recover from oxygen desaturation during drowsiness in order to reduce drowsiness physiologically and help the driver to prevent crashes. CRPS is a temporary coordination of cardiac and respiratory rhythms, which improves pulmonary gas exchange efficiency. It is hypothesized that an increased venous return due to a negative intrathoracic pressure of inspiration associated with CRPS optimizes pulmonary gas exchange efficiency. Positioning the diastolic phase of the cardiac cycle at inspiration increases the transmission of blood volume to the pulmonary circulation, when abundant oxygen exists in the lungs. In contrast to inspiration, positioning the systole of the cardiac cycle within the expiratory period may facilitate the transmission of arterial blood because vascular resistance decreases by the relaxation of respiratory muscles. Following this hypothesis, CRPS may have an effect to cure drowsiness if it can be intentionally induced.

II. METHOD

Two experiments were conducted in order to implement the aforementioned three steps. The first step was examined in experiment I. Subjects were instructed to drive one hour with a driving simulator to observe the relationship between drowsiness and oxygen desaturation. The second step was examined in experiment II. We investigated whether it is possible to induce CRPS intentionally by using PB and how SpO2 changes during the inducement. The third step was examined with the data obtained from both experiments. We investigated whether the proposed method has an adequate increase to overcome drowsiness by comparing the SpO2 increase in three situations: during CRPS, frequent appearance of deep breaths and yawns, and a period when drowsiness is overcome. The details of the experiments are as follows.

A. Experiment I

Experiment I was done in cooperation with 16 subjects (seven males and nine females) who provided written informed consent. Subjects who had sleep deprivation before the test were not allowed to participate in this experiment. All of the subjects drove an hour with a driving simulator. A highway tunnel was selected as a driving condition to make the subjects drowsy and to reduce the influence of surrounding landscape changes. Monitor 1 (TH-50PHD6, Panasonic, screen diagonal length: 1269 mm) was used for the Panasonic, screen diagonal length: 1269 mm) was used for the course projection, and the subjects kept their head 2 m away from it (see Fig. 1). The subjects were required to steer the wheel to keep the white lines on the edges of the shadow, which was projected on the screen to simulate driving (see Fig. 2).

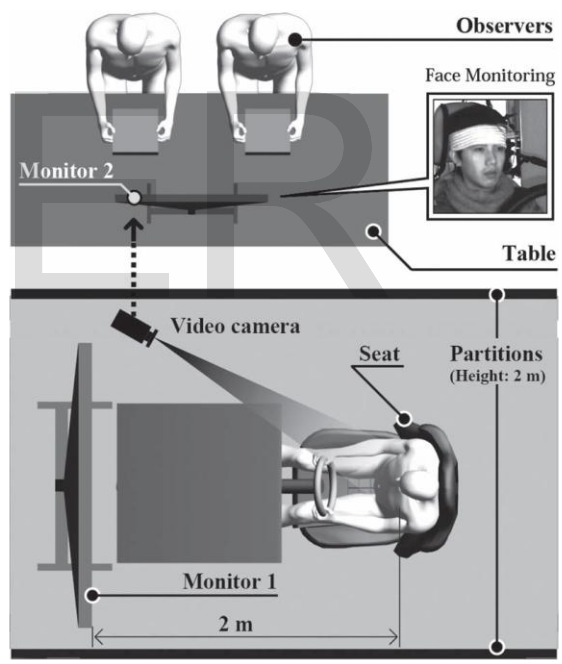

Fig.1. Layout of equipment used in experiment I. Subjects were seated on the driving simulator with their head 2 m away from monitor 1. Two observers were positioned behind the partitions with the subject's facial features monitored by a video camera mounted beside monitor 1.

The shadow repeatedly moved from right to left at a frequency of 0.1 Hz. Subjects were instructed not to sleep during the task. Each subject did the task three times on different days. In total, 48 task data were obtained in the experiment. ECG, respiration, electrooculogram (EOG), and saturation of hemoglobin with oxygen using pulse oximetry (SpO2) were continuously acquired at 1 kHz per channel via a multichannel telemeter system (WEB7000, Nihon Kohden).

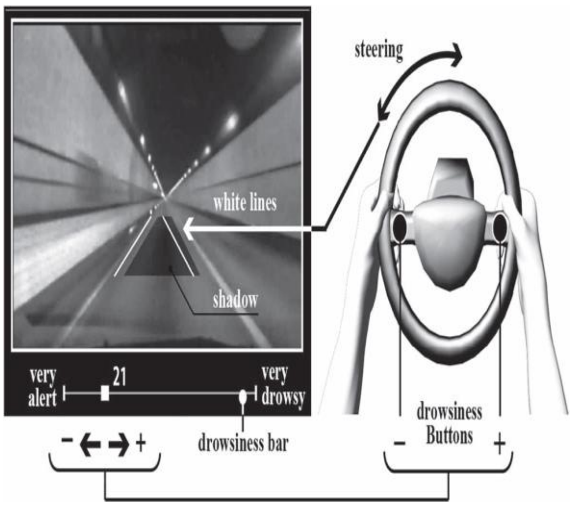

Fig.2. Tracking task with a wheel steering to keep white lines on the edges of the shadow, this was projected on the screen. Shadow repeatedly moved from right to left at a frequency of 0.1 Hz.

ECG was obtained by a bipolar lead, whereas respiration was achieved by a strain gauge bandaged to the subject's abdominal region. The electrodes for EOG were placed above and below the left eye. SpO2 was measured by two frequencies of light (red and infrared) from a pulse oximeter attached to the left side of the forehead. Experiment I was aimed to observe how oxygen saturation changes at the forehead when drowsiness appears and overcomes. The multiplex measure was used for drowsiness detection in order to have reliable investigation. We used the following parameters to define the point when drowsiness appears and is overcome: self-evaluated drowsiness (SED), for subjective report measure; New Energy and Industrial Technology Development Organization (NEDO) scale, for physical measure; and percentages of eye closure (PERCLOS) and heart rate variability (HRV) parameters, i.e., low frequency/high frequency (LF/HF) and HF, for biological measures.

Subjective Report Measure: SED: Visual analog scale is one of the effective methods to assess the momentary degree of drowsiness. A subject indicates a response along a linear100-mm line between labels of "very drowsy" and "very alert." Although this scale is useful in tracking symptoms of drowsiness during a given time epoch, it requires an interruption of a task for assessing, which might awake a driver. Therefore, we used buttons on a steering wheel (see Fig. 2) for indication of drowsiness. A subject responded to drowsiness on the line shown at the bottom of the screen by pressing the buttons every time the subject felt drowsiness changes. The left end of the line showed "very alert," and the other end showed "very drowsy." Drowsiness was graded according to 100 levels and was recorded into the data logger through the receiver every second. Physical Measure: NEDO Scale: Scaling of self-evaluations of drowsiness differ by individuals. Therefore, external evaluation of drowsiness is needed as a complement.

Facial expression is one of the reliable indications of drowsiness. It is known that humans have an ability to interrelate facial expressions and emotions, and it has a similarity in scaling of emotional facial expressions. Furthermore, dimension of alertness corresponds to movements of facial parts such as eye, eyebrow, or mouth. The NEDO scale is one of the useful scales for assessing facial expression of drowsiness. This scale was developed by NEDO.It is reported that the NEDO scale is reliable for drowsiness observation from the point that it has high correspondence of grading between two observers (0.765) and because of the high-correlation coefficient of the NEDO scale and the Roken Mental Work Strain Checklist (0.795). This scale has been already used in a number of studies related to drowsy driving. NEDO scale was evaluated every minute by two observers. They monitored behaviors of subjects, such as limb, gaze, or head movements captured by a video camera mounted beside monitor 1. Two observers were positioned behind partitions (height: 2 m), as shown in Fig. 1. The drowsiness was graded according to five levels, as shown in the following.

Level 1: "not drowsy at all" Characteristics: fast saccade, stable frequency of blinks, active body movements.

Level 2: "slightly drowsy" Characteristics: mouth opens, slow saccade.

Level 3: "drowsy" Characteristics: frequent occurrence of slow blinks, mouth movements, reseating or changing sitting posture, touching face.

Level 4: "fairly drowsy" Characteristics: intentional blinks, slow saccade, body movements such as shaking one's head or up and down motion of the shoulders, frequent yawns and deep breathing.

Level 5: "very drowsy" Characteristics: closing eyes, nodding one's head, head inclining backward.

B. Experiment II

We recruited 16 healthy males and compared SpO2 and estimated exhaled tidal volume (TV) and respiration rates (RR) during periods of induced CRPS against periods when CRPS was absent, which corresponds to the aforementioned second and third steps mentioned. Experiment II was conducted with the subjects' informed consent. All subjects were tested in a sitting position in temperature (mean +/- SD = 26.2 +/- 4.2 ◦C) and humidity (mean +/- SD = 60.3 +/- 7.8%) controlled laboratory. Intermittent sounds were generated from earphones for 5-min periods during PB after 5-min periods of spontaneous breathing (SB1). Another 5 min of spontaneous breathing (SB2) were established after PB in order to see the effects and responses of PB. The inspiration and expiration at a ratio of 2 : 2 beats was chosen for the PB because this pacing(a period of around 4 s) is most commonly seen under resting conditions. CRPS is thought to be the triggering of inspiratory timing by arterial or intracranial presser receptor afferents, so that the pacing of expiratory timing seems unnecessary. However, we instructed subjects to pace their breathing to both inspiratory and expiratory timings to make it easier to adjust the timings of breathing to fluctuated intervals of intermittent sounds. For the comparisons of ECG RRI PB, we selected the following four patterns of PB in this study: fixed (1000 ms) and random (mean+/- SD = 1000+/- 200 ms) intervals of PB with inspiration and expiration at a ratio of 2 : 2 beats and ECG RRI PB with inspiration and expiration at ratios of 1 : 1 and3 : 3 beats.

The fixed and random intervals of PB were used to clarify the fact that CRPS did not appear accidentally. The other two patterns were chosen to eliminate the possibility that the results of SpO2 may differ by an increase in TV and RR during periods of simulated CRPS. The PB with inspiration and expiration at a ratio of 1 : 1 beat increases RR, and a ratio of 3 : 3 beats enlarges TV by a prolongation of breath intervals. Those four patterns of PB were established in different orders for each subject. Intermittent sounds were generated every time an R-wave was detected on ECG, which was measured from electrodes attached to the subjects. ECG, respiration, and SpO2 were continuously obtained at 1 kHz per channel via a multichannel telemeter system (WEB7000, Nihon Kohden) in the same way as in experiment I. The Douglas method was used for the measurement of TV. Subjects attached a mask connected to two Douglas bags (150 L) with tubes on the face. The bags were changed by using a junction lever at the start and end of a PB period. Expired gases were sampled via Douglas bags, and TV was estimated from total amount of respiration and exhaled gas, which was measured by an oxygen uptake monitor (AR-1, ARCO SYSTEM).

III. CONCLUSION

In conclusion, inducing CRPS by PB using pulse sound synchronized with heartbeats has a potential to prevent drowsiness physiologically. By adjusting the breathing pattern of driver to the reference pattern we can check driver is in drowsy state or not. By providing sufficient oxygen into the body drowsiness can be overcome. This method is useful from the point that it eases drowsiness physiologically, not just warns a driver by sounds, vibrations, or displaying messages. It is also necessary to clarify that inducing CRPS will not aggravate physical conditions to cause hyperventilation.

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