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Measurement of a driver's mental state using a 4K driving simulator

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Abstract

We have been researching a method that can induce a driver to drive more safely and more comfortably by grasping the mental state of the driver. For this purpose, we developed a 4K DS system to more realistically create the sense of driving through a landscape. We analyzed the gazing point distribution, oxygen concentration in the brain, pulse rate, skin potential, and the surface temperature of the face while driving. The subjects included 11 students from our university, aged 20~22 years old, who had driver's licenses. They simulated driving the full 120-km length of a road over the course of one hour. In the results, characteristic changes were seen in all parameters in every subject.

1 Introduction

As a result of the progress being made in automatic driving technology, the time when a person will be able to drive to a destination without operating the steering wheel is approaching [1]. On one hand, an automobile is an expansion tool for the walking function, allowing people to move long distances that they could not travel on foot, and it is also an important means of transportation in place of walking for people with disabilities.

The purpose of driving an automobile is not only to arrive at one’s destination especially quickly. The pleasure and feeling of achievement afforded by driving oneself are also important purposes of driving. We have been researching a method that can induce a driver to drive more safely and more comfortably by grasping the mental state of a driver who is driving him/herself. Many studies on grasping the mental state of the driver have already been reported [2, 3, 4, 5, 6, 7]. In particular, the measurement of eye movement during driving has been widely studied for the purpose of investigating visibility and preventing drivers from looking aside [8][9]. We have studied minute eye movements and are working on analyzing the driver’s degree of attention while driving [10]. However, verification with the various mental states of the driver is needed to prove the usefulness of measuring the miniature eye movement. So the mental state of the driver while driving was analyzed on the basis of the oxygen density in the blood in the brain, the pulse, the skin electric potential and the surface temperature of the face in addition to the eye movement using our 4K driving simulator (DS). The outline of the system and the experimental results are described here.

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2 Construction of 4K DS

UC/WIN Road (FORUM8 Co. Ltd, Tokyo) was used as the software for the DS. The 4KDS picture was shown using the VPL-VW500ES 4K projector made by Sony Corp. through an HDMI cable using a T954 laptop computer made by Toshiba Corp. A high-resolution picture is necessary to enhance the realism for the driver, which is why we introduced a 4K system. Driving Force GT was used to operate the steering, accelerator and brake, etc. This DS was developed to enable a driver to drive for more than one hour, because a certain degree of long-term driving is needed for changes in the driver's mental state, such as a decline in concentration or fatigue, to be captured. Furthermore, EyeX (Tobii AB, Danderyd, Sweden) was included in the DS for the measurement of eye movement, and the DS was designed so that the eye movement and driving operations could be recorded at the same time.

3 Measurement of physiological data during driving

The oxygen density in the blood in the brain, the pulse, the skin electric potential and the surface temperature of the face in addition to the eye movement were measured during driving as the physiological data. Some eye movements are defined by movement involving both eyes and some are defined by movements of each individual eye. Eye movements involving both eyes are classified into conjugate eye movements in which both eyes move in the same direction and convergence and divergence movements in which both eyes move in opposite directions [11].

When the eyes move on a two-dimensional plane or between objects equidistant from the viewer, conjugate eye movement occurs, and when the eyes move between objects at different distances three-dimensionally from the viewer or when the viewer is observing a three-dimensional image, convergence and divergence eye movements occur.

Each type of eye movement can be roughly divided into three movements: miniature eye movement (physiological nystagmus), smooth pursuit movement and saccade.

Miniature eye movements, which are a particular focus of this research, are the constant, involuntary, small movements that occur unconsciously at all times. Three kinds of eye movements are considered miniature eye movements as shown in Figure 1. These include "tremors," which are small irregular motions with a displacement angle of less than 15 min. and with a frequency of 30~100 Hz, "flicks or micro-saccades," which are step-like movements with a displacement angle of about 20 sec. and with a time interval of 30 msec~5 sec, and "drift," which is a drifting movement with a displacement angle of less than 5 msec. When retinal image fluctuation caused by miniature eye movement is perfectly stabilized, the phenomenon called a stabilized retinal image occurs, and the image on the retina gradually disappears [12]. Therefore, miniature eye movement is regarded as an important kind of movement by which an image on the retina is constantly refreshed. Here, recent knowledge is introduced about micro-saccades in the three components of a miniature eye movement. When the gazing point shifts by means of saccades, first, the attention shifts to the movement destination, and the saccade occurs after that. It has been reported that micro-saccades increase in the direction of the attention point [13]. There is a possibility that a change appears in miniature eye movements between the time when the driver’s concentration is high while taking notice of the visual field in various directions and the time when the degree of awareness drops or the car is driven aimlessly. Thus, the dispersion of the gazing point while gazing at something during driving was estimated in order to analyze the quality of the gaze.

The oxygen density in the brain is measured by near-infrared spectroscopy (NIRS) using near-infrared light, which tends to penetrate through living bodies non-invasively. NIRS is employed in the management of cerebral oxygen during surgery and in the ICU. It is used for the measurement of hemoglobin change in the muscle in the fields of sports medicine and rehabilitation, and it is used for measuring brain function by measuring cerebral bloodstream changes in brain function studies. We used the NIRO-200 of Hamamatsu Photonics Co. Ltd. to perform the measurement. It can measure the tissue oxygenation index (TOI), which shows the oxygen saturation level, the normalized tissue hemoglobin index (nTHI), which shows the percentage change in the amount of initial hemoglobin, as well as changes in the concentration of oxygenated hemoglobin (ΔO_2Hb), deoxygenated hemoglobin (ΔHHb), and total hemoglobin (ΔcHb), all in real time. The sensor by which the light-receiving part and the optical illumination part of the NIRS are shown in Figure 2 is attached to the forehead, etc. When the distance between the light-receiving part and light-emitting part is 4 cm, it is said that bloodstream changes at about 3 cm from the scarfskin or about 1 cm from the cerebral surface can be measured. When a cerebral function is active, the local cerebral bloodstream increases in volume, and the density of hemoglobin in the relevant part thus increases; the quantity of absorbed light increases due to the increased hemoglobin, and the quantity of detected light decreases. It has been reported that cerebral activity can be measured with such a mechanism. We assumed we could measure the mental state of the driver while driving using NIRS.

A heartbeat can be measured by the number of R waves that occur in 1 minute. The RT interval indicates the length of the shrinkage recovery process of a ventricle of the heart, and is regarded as an index of the recovery process of the heart function. It has been reported recovery takes place earlier in healthier persons, and also that reflects the activity of the autonomic nervous system. The autonomic nervous system includes the sympathetic nervous system, which governs the response to emergencies and causes excitement and the para-sympathetic nervous system which governs rest. It has been found that the RT interval is reduced by caffeine contained in coffee [14].

The ratio of LF/HF ,where LF which is the ratio between the slowly varying component and HF, which is the high frequency component of the heartbeat, is also employed as an index of stress. In contrast to the LF component, which appears in the fluctuation of the heartbeat when either the sympathetic or parasympathetic nerve is active, the HF component appears only when the parasympathetic nerve is predominant. Thus, LF/HF is large when the stress is high and small when the subject is relaxing [15]. We thus believe that the state of the autonomic nervous system during driving can be measured by the RT interval and LF/HF.

The skin electric response is called electrodermal activity (EDA), and in this study, the EDA with perspiration was measured. Two kinds of perspiration exist, perspiration due to warmth and perspiration due to mental stress, which is conspicuous on the palm and the sole of the foot. Mental perspiration is an evolutionary adaptation useful for making wooden branches easier to grasp and for making it less likely that the foot will slip when danger is present. The skin potential reflex (SPR) occurs frequently as a result of sensing a change in the external environment through the sense of touch, hearing, or sight, or as a result of doing mental calculation, deep breathing, or body movement. It has been found that the amplitude of SPR has a linear relationship to the strength of the stimulus [16]. For example, the amplitude increases in language learning as the student works harder and as the study content becomes more novel. These activities relate to a rise in the level of arousal. The SPR amplitude increases with the generation of strong feeling. We assumed that we can know the mental state of the driver qualitatively by observing the skin electric response like these examples. We used the polymate AP216 by Digitek Lab. Co., Ltd., Tokyo, to record an electrocardiogram and measure the skin electric potential.

There is a report that the surface of nose part temperature can suitably represent the mental work load, i.e. stress, in particular as a stand-in for the face temperature [17]. We speculated that the mental state during driving could be measured by monitoring the surface temperature of the face by thermography using the TP-L0260EN made by Chino Corporation, Tokyo. The appearance of this measuring equipment as installed for our experiment is shown in Figure 3.

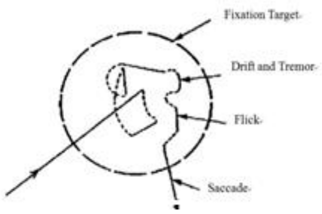


Figure 1: Miniature eye movement during fixation


Figure 2: Light receiving part and optical illumination of NIRS


Figure 3: The appearance of the experiment

4 Scenario for DS

The DS scenario was as follows. The distance of the designed road was 120 km. A freeway that was perfectly straight was designed first for pilot studies because the first goal was to assess the decline in the degree of wakefulness during driving from an expanse of a gazing point area. We thought that a more realistic road was necessary, however, because we observed some subjects who released their hands from the steering wheel and lifted their feet from the accelerator or brake when driving this straight road for more than 1 hour. Specifically, a loose curve and ups and downs were introduced in such a way that they could not be predicted in advance in order to make sure that the driver could not lift his/her foot from the accelerator or brake in order to maintain speed and that the hands always had to grasp the steering wheel in order not to deviate from the lane. The road was divided into 8 segments, and an 80 km/hr speed limit sign, a watch for animals sign and a strong winds sign were arranged in each segment.

5 Experimental procedure

The experiment was performed in an electromagnetic-shielded room at a room temperature of 22ºC and 50% humidity. First, the Tobii EyeX, which is eye-movement-measuring equipment, was calibrated using nine calibration points. Several minutes of driving practice were performed so the drivers could get accustomed to the DS. At the same time, the operation of the steering wheel, accelerator and brake pedal were checked to confirm whether there were any abnormalities in their functioning. NIRS, Polymate, and thermography data were acquired in the practice run, also to confirm whether there were any abnormalities. After that, a subject ran a scenario on a 120-km prepared road for about 1 hour, and these physiological data were acquired during the driving. The acquisition of the data started automatically after the scenario started. An event button was pressed several times to synchronize the time axes of the multiple measuring systems. The subject was administered a questionnaire asking about the precision of the DS and the subject's feeling of fatigue after the experiment.

6 Results of the experiment

The subjects were 11 students with driver's licenses at our university (20~22 years old; 4 male, 7 female). Subjects were instructed to watch the road conditions carefully and maintain the indicated speed while driving.

The analysis method was as follows. First, the driving data collected over about 60 min. of driving were divided into 12 segments, i.e., every 5 minutes, for each subject. Next, the gazing point was extracted for 30 sec. from the eye movement data after two min. of each time segment had passed. The gazing point was determined based on the eye movement components whose velocity was below 5 degrees/second. The standard deviation of the eye movement while gazing at the foreground scene was then calculated. Oxygenated hemoglobin (O_2Hb), tissue oxygenation index (TOI, TOI= O_2Hb/cHb), nasal skin electric potential, LF/HF and RT interval in each division were analyzed in the same way that the eye movement was analyzed. It was only three of 11 subjects that all physiological data were acquired well. Therefore the results of subjects A, B, and C which could acquire most physiological data precisely are shown in Figure 4, respectively, as examples. By the way, the SPA was not determined at this time, because the electromyogram was mixed in it during operating steering.

First the results for subject A are described. The standard deviation of the gazing point of subject A increased in three of the 12 sections, namely sections 4, 6, and 10, and was about 1 degree in the sections other than those three. Though the O_2Hb of the right frontal lobe (dashed line) increased a little in the first half of the experimental period, those of both the left (solid line) and right frontal lobes tended to decrease in the second half. O_2Hb rose only in section 12. No large variation was observed in brain TOI, but a tendency to decrease gently was seen. When the nose temperature tended to increase when the value measured just after the experiment started was compared with the value measured just before the end of the experiment. The nose temperature rose in particular in three sections, namely sections 5, 8, and 10. LF/HF rose in three sections, namely sections 3, 7, and 9. The RT interval was about 0.27 seconds; it decreased in sections 2 and 7 and rose in sections 6 and 10 in particular.

Next, the results for Subject B are described. The standard deviation of the gazing point of subject B increased markedly in three sections, namely sections 4, 5, and 11, and varied little in sections other than those. The O_2Hb of both the left and right frontal lobes increased gradually, while that of the right frontal lobe (dashed line) increased greatly in sections 3 and 11 and that of the left frontal lobe (solid line) increased greatly in section 8. The brain TOI showed the same tendency as O_2Hb. The nose temperature showed same tendency as that of Subject A. It rose in particular in three sections, namely sections 5, 8, and 10, just as in Subject A. LF/HF also rose in three sections, namely sections 3, 7, and 9, just as in Subject A; furthermore a large variation was seen in section 12. The RT interval was found to be about 0.28 seconds and increased in sections 4, 5, 8, and 10 in particular.

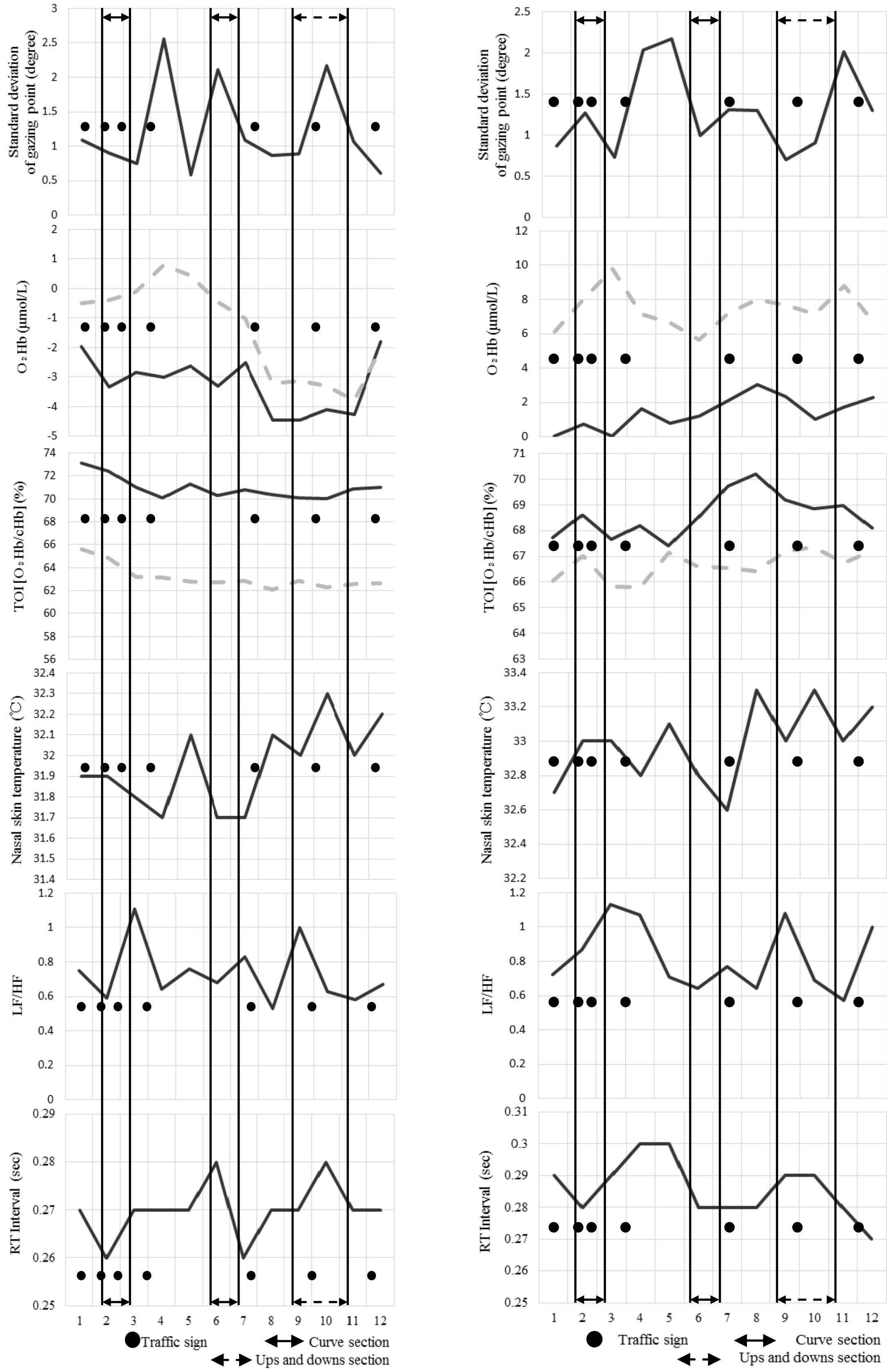


Figure 4: Result of three subjects (Left: subject A, Right: subject B)

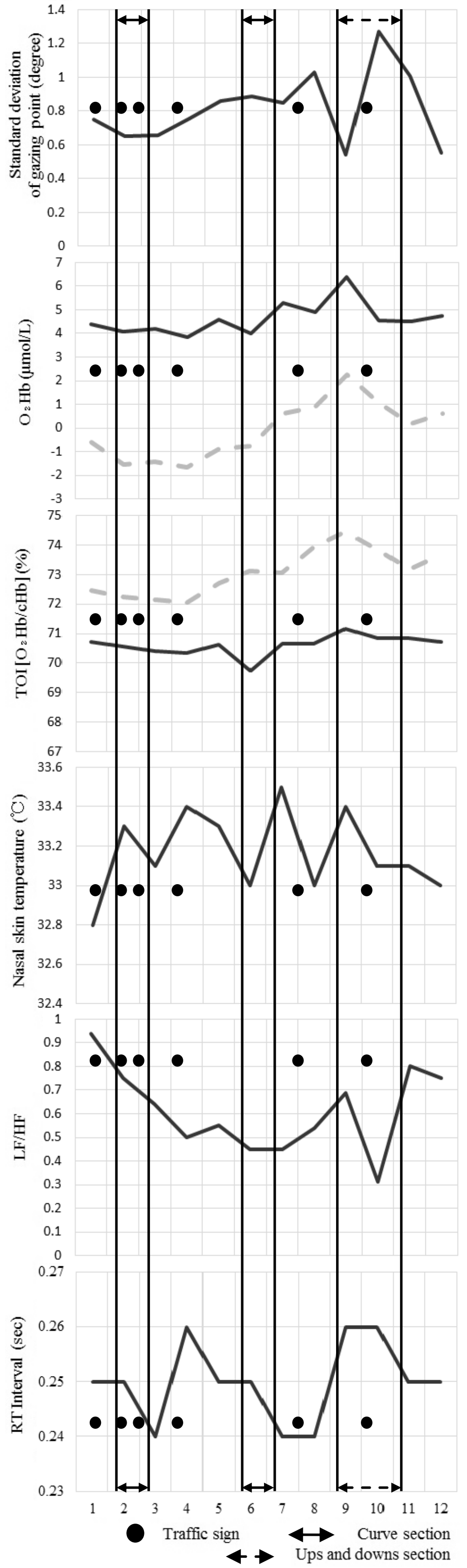
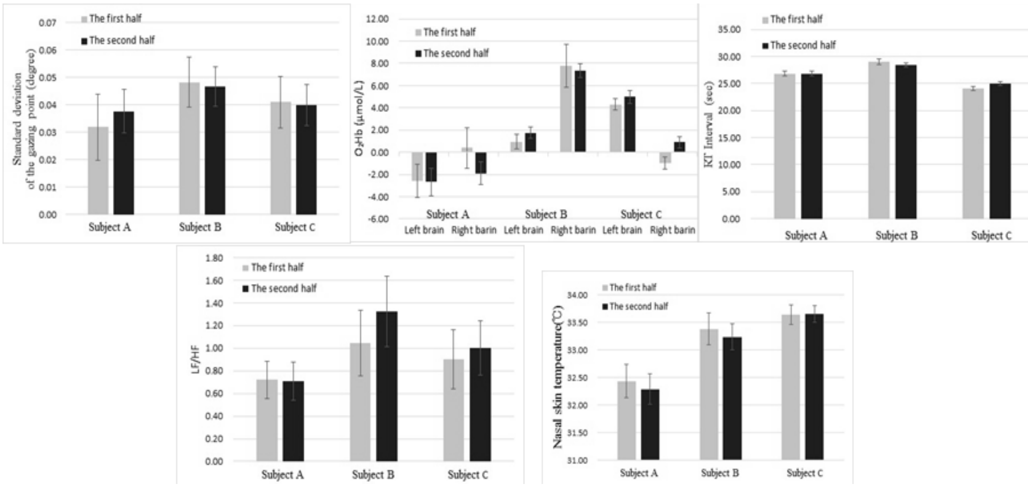


Figure 4: Result of three subjects (subject C)

Finally, the results for Subject C are described. The standard deviation of the gazing point of subject C increased in section 10, decreased in section 9, and varied little in the other sections. The O_2Hb values of both the left (solid line) and right (dashed line) frontal lobes increased gradually and showed their peak values in section 9, after which they decreased. Brain TOI did not show great variation. It increased gradually toward the second half of the experiment. The nose temperature showed great changes in several sections. LF/HF decreased from just after the start of the experiment to the middle stage of the experiment and tended to increase after the middle stage. However, it decreased markedly in section 10. The RT interval was about 0.25 seconds. It increased in sections 4, 9, and 10 and decreased in sections 3, 7, and 8.

Next, physiological data for each subject were separated from the start of driving in 30 minutes and 30 minutes until a driving end after it. These data were graphed to assess the change in the driver's concentration ratio (Figure 5). As a result, the standard deviation of the gazing point of subject A rose in the second half, and the other physiological data for this subject decreased compared with the first half. It was shown that, in subject B, the standard deviation of the gazing point, the nose temperature and the oxygenated hemoglobin density of the right brain decreased, and that the RT interval, LF/HF, and the oxygenated hemoglobin density of the left brain increased. Only the standard deviation of the gazing point and the RT interval decreased in subject C, while the other physiological data increased in this subject. Therefore, subject C's physiological data were changing in the same way for the most part in Figures 5.



(A) Change of SD of the gazing point (upper left)

(B) Change of O_2Hb (upper center)

(C) Change of RT interval (upper right)

(D) Change of LF/HF (bottom left)

(E) Change of Nasal skin temperature (bottom right)

Figure 5: Change of each physiological index

7 Discussion

The results for the three subjects shown on the chart divided into 12 sections are described here. First the standard deviation of the gazing point was determined. The standard deviations of the gazing points of the three subjects did not show large variation in the early stage of the experiment which included a curve and numerous traffic signs, and we believe the subjects kept concentrating and focusing on one point of the scene. But the values for subjects A and B rose, and the variance increased when driving on a curve or at the fourth traffic sign in the middle stage of the simulation. The standard deviation of the gazing points of all three subjects increased greatly in the area where the road went up and down. To explain this result, it was concluded that the Standard deviation of the gazing point increased because the driver's attention shifted toward the instruments displayed on the lower part of the screen in order to maintain speed while watching the front view and driving through an area where the road had up-and-down variation.

Next, we discuss the O_2Hb results. Only subject A's O_2Hb decreased after the mid-point of the experimental course. Subject A told us that she was sleepy while driving at that time on the questionnaire after the experiment. The O_2Hb of subject B's right brain increased while navigating the curve and traffic signs in the early stage, and that of subject B's left brain slightly decreased. These results suggested that subject B used the right brain more than the left brain. The same tendency was seen in the section with up-and-down variation. Subject C's O_2Hb gradually increased in the section with up-and-down variation. It then decreased toward the last section. We considered that the traffic signs and curves had no influence on subject C's O_2Hb. The O_2Hb values of subject A's and subject B's right brains were higher than that of subject C's right brain. The O_2Hb of subject C's left brain was higher than those of subject A's and subject B's s left brains. We considered the possibility that some changes in the cerebral work performed occurred on the basis of gender, since subjects A and B were female and subject C was male. The brain TOI showed changes that were generally proportional to those of O_2Hb.

For the nose temperature, all three subjects' temperatures rose toward the end of the experiment, although slight changes occurred during the experiment. However, we thought that an increase in concentration caused the decrease in the nose temperature in all three subjects while driving in the curb section. Nevertheless, all three subjects showed temperature increases in the section with ups and downs, and no significant change was observed in the traffic signs section.

As for LF/HF, it is suggested that the sympathetic nerve functioned predominantly by making the driver consciously concentrate on the road situation, thus causing the LF/HF of subjects A and B to increase in the area with traffic signs or in the area with ups and downs. However, subject C's LF/HF did not change due to the traffic signs or the curve and even decreased in the section with ups and downs. Nonetheless, subject C's LF / HF was significantly higher than the other two subjects' LF/HF values just after the experiment began. In other words, subject C may have felt more stress than the others.

Finally we discuss the RT interval. The RT interval is believed to indicate relaxation, and all three subjects' RT intervals decreased at the start and middle of the experiment. Therefore, it is considered that they relaxed in these sections. However no significant change was obtained.

8 Summary

We have been researching a method that can induce a driver to drive more safely and more comfortably by grasping the mental state of the driver. For this purpose, we developed a 4K DS system to more realistically create the sense of driving through a landscape. We analyzed the gazing point distribution, oxygen concentration in the brain, pulse rate, skin potential, and the surface temperature of the face while driving.

The standard deviation of the gazing point in the area with ups and downs was distributed more widely in all three subjects. This result is believed to show that the driver's attention was shifted to the meter on the lower part of the display while also looking at the road in front to maintain the speed limit while traveling up and down hills. As for the O_2Hb concentration, only that of subject A decreased. Subject A stated on the questionnaire given after the experiment that she felt sleep, which is probably why the O_2Hb concentration decreased in that case. The nose temperatures of the three subjects had a tendency to rise gradually from the beginning to the end of the experiment. However, there is a possibility that the nose temperatures of the three subjects fell because they were concentrating on steering by the second turn. It is suggested that the sympathetic nerve functioned predominantly by making the drivers consciously concentrate on the road situation, thus causing the LF/HF values of subjects A and B to increase in the area containing traffic signs or in the area containing ups and downs. The RT interval indicates relaxation, but no significant change in the RT interval was observed.

In the future, we will consider the correlations among data in a more detailed analysis to attempt to grasp the mental state of the driver.

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