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Variation of Driver's Arousal Level when Using ACC and LKA

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Abstract

In this study, we specifically considered decrease in arousal level stemming from using semi-autonomous driver assistances featuring ACC and LKA functions in operation. 10 young men took part in the experimental study using a driving simulator. For an average of 10 people, the participant rate for those who reached level 4 or above (level 1; Seems not sleepy at all, level 5: Very sleepy) on the sleepiness scale when the system was enabled increased by 34 percent compared with the system-disabled condition. The reaction time to visual stimuli was noticeably delayed and significant differences are acknowledged for a level 4 or above on the sleepiness rating scale. We believe that continuous long term investigation on actual driving (FOT; field operation test) should be carried out to validate the results in this study. We also analysed the relationship between eye closure ratio and the sleepiness rating scale and confirmed that eye closure ratio value of 0.26 corresponded to level 4 on the sleepiness scale where the reaction time delayed remarkably. Drawing on these findings, it is believed that a device can be designed to detect arousal level based on eye closure rate.

Keywords: Driving support; Drowsiness; Facial expression/Arousal level; Reaction time; ACC; LKA; Eye closure ratio

Introduction

LKA (Lane Keeping Assistance) and ACC (Adaptive Cruise Control) have variety of benefits about the lessening of driving workload and the enhancement of the risk-avoidance behaviour. A previous study has reported that the ACC and LKA system remarkably decrease the driver's workload in terms of braking and steering operation [1]. This experimental study reported that test subjects mentioned it is easy to concentrate on driving to avoid collision to a leading vehicle when ACC and LKA are implemented in the vehicle. For this reason, these systems are gradually pervading into the market, and are expected to be even more widespread in the future.

However, previous studies have reported that a lack of understanding of performance requirement and function of these driver assistance systems by drivers can result in inattentive behaviour at the wheel. On the backdrop of their spread, measures coping with these inattentive behaviours should be considered in the design of functionality of such system to enhance user and social acceptance. The case below exemplifies the kind of inattentive behaviour which drivers are exposed to when driving an ACC system-enabled vehicle. In this example, the driver is overestimating the driver assistance functions, which led her/him to rely on the system to perform specific tasks and to be oblivious of the unreliability of the system [2]. Besides, although there is no remarkable difference in arousal level for a vehicle non-equipped with an automatic stop function, it has been reported that such arousal level is more likely to decrease if a stop function system is enabled [3].

Driver assistance featuring ACC or LKA has obviously various merits in lessening driver's workload and supporting risk-averse behavior. However, actual utilization of such driving assistances has risen concerned over increase in inattentive behavior e.g. decrease in arousal level.

In this study, we specifically considered decrease in arousal level stemming from using semi-autonomous driver assistances featuring ACC and LKA functions in operation. We investigated variation of driver's arousal level through experimental studies using a driving simulator. 10 young men took part in the experimental study. The level of driver assistance functionality that is subjected to analysis corresponds to level 2 on the automatic driving level by NHTSA [4], whose quick diffusion is expected to occur in a near future.

The purpose of this research is broadly divided into the following four points.

I. Analysis of driver's arousal level

We analysed how the driver's arousal level is affected by comparing two running conditions: (1) featuring active ACC and LKA driver assistance; and (2) featuring disabled driving assistances. In this study, we estimated arousal level of drivers in terms of the sleepiness level. To estimate the arousal level of the initial timing of the drive, we used the Stanford Sleepiness Scale. For quantifying the fluctuation of arousal level during the use of ACC and LKA, we used the sleepiness objective evaluation values.

II. Correlation analyses of visual stimulation and arousal level

The purpose of this study is to clearly determine two conditions if marked drop in arousal level was observed owing to the utilization of ACC/LKA-enabled driver assistance system e.g.

(1) Arousal level presenting remarkable delay in reaction time; and

(2) Intensity of the driver's reaction time delay to visual stimuli.

III. Analysis of the driver's behavior when the arousal level is noticeably dropping

We made analysis in the feature of driving behavior of a driver whose arousal level markedly changed when the use of driver assistance featuring active ACC and LKA systems were found to drop the driver arousal level.

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IV. Correlation analysis between arousal level and eye blink

We examined the average eye closure rate (the ratio between eye closing and opening during for every 60 seconds) for each different arousal level and clarified the eye closure average rate at which the reaction time to visual stimuli is noticeably delayed.

Experimental Methods

ACC and LKA operating patterns

We made use of the driving simulator constructed by the Kagawa University and created an environment in which ACC and LKA systems were in operation. To help participants to practically get a grasp of the functions limitation as well as the different working patterns of the system, we set up a trial run practice before the experiment. This run practice featured the function of distance auto-regulation to an accelerating and decelerating vehicle ahead.

The ACC operating parameters were set forth as below: The distance to a leading car was set up so that the vehicle could maintain the time head way of 1.5 sec and the maximum deceleration control system was set to $3m/s^2$. The system control was also configured to stop functioning if the participants applied the brakes when the ACC system was in operation. Subsequently, we equipped the ACC system with a forward vehicle collision warning system. A warning alarm was set to be triggered for a Time to Collision value equivalent to 2.5 sec. The operating conditions of the LKA were set forth as explained below. A steering torque was set to minimize the lateral drift between the centre of vehicle and the lane one second after its estimation based on lateral acceleration and lateral velocity of the vehicle. This LKA was set to allow the system to automatically control the cornering motion without any steering correction by the driver up to 2.4 m/s^2 lateral acceleration at the vehicle center of gravity. The system was also configured to be overridden if the steering torque exerted by the driver exceeds that generated by the LKA system while in use. The LKA system was also equipped with a lane departure warning system. The system was set to prompt a warning alarm when the spare distance between the front tire center and the lane marker before a lane departure was less than 0.2 m. The driver assistance information about the maintenance of the car-to-car distance and the lane departure prevention were presented on the instrument panel, as shown in the Figure 1.

Running course

We designed a two-lane, highway-type of road with a lane width of 3.5 m in the simulator. Details of the shape-related features of the driving courses are listed below:

a) Minimum curvature radius; 700, 3000 and 5000 [m]

b) Longitudinal gradient; 0 [deg]

c) Percentage of straight line segments and curves section; straight segment: curves section = 40%: 60%

We also added straight and curvilinear easement segments based on actual Japanese road construction standard.

Participants

10 young men took part in the experiment. The average age and the standard deviation of ages were 22.3 ± 1.0 years old. The experiment participants took part in the experiment after following the inform consent procedure, which was carried out upon distribution of a paper-based explanatory document sent to them one week prior to the start of the test. Furthermore, the conduct of the experiments took place upon acceptance of the test content by the Kagawa University Ethics Committee, which was granted prior to the experiments.

Control methods of the initial value of arousal level

The Figure 2 shows a flow of the experiment. We set up a nondriving task just after the start of the test. During this task, experiment participants sat down on the seat in a driving simulator and did not drive a car. When we confirmed the experiment participants became low arousal state, we did an arousal-stimulating task for getting awakening effect. After this arousal-stimulating task, we initiated the actual running test with driving and we investigated what kind of differences would be actualized in terms of the decrease of arousal level with and without using the system. Our analysis of the driver's alertness level when using the semi-automatic driver assistance aimed at considering the differences in term of arousal level, which were observed by comparing the system-enabled configuration with the disabled one. Therefore, we unified the following two conditions. The first condition is the level of arousal at the start of the test without driving before the arousal-stimulating task and the level of arousal at actual start of the running test just after the arousal stimulating task. We asked the test participants to evaluate the arousal level at these two timings and proceeded with the experiments when we confirmed that

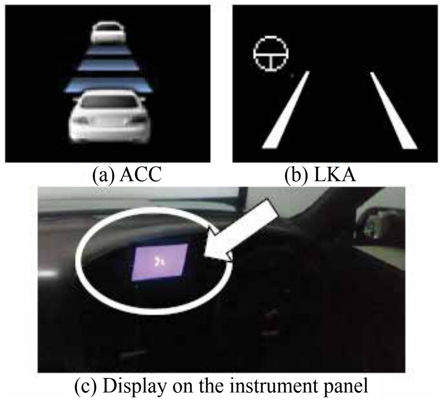

Figure 1: Icon displaying the ACC and LKA working status.

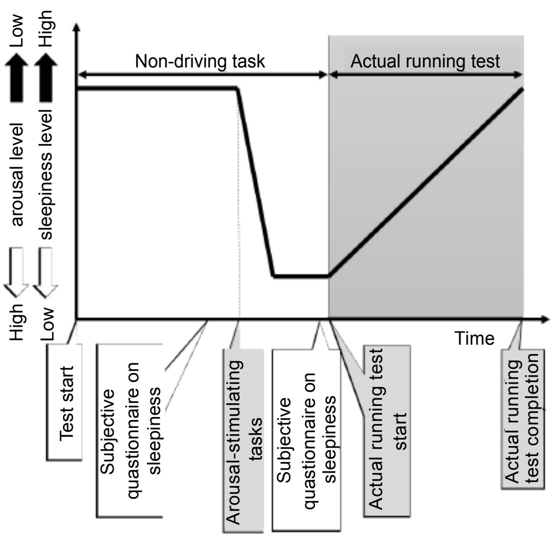

Figure 2: Experimental protocols with a unified variation of arousal level.

the test participants could realize the predetermined arousal level. The reason why we focused on not only at actual start of the running test but also the start of the test without driving is that it is important to realize the same transition of the arousal throughout two-day of the test for each experiment participant, as mentioned below.

To evaluate the arousal level, we conducted a subjective survey on sleepiness by applying the Stanford Sleepiness Scale (SSS) [5] as shown in Table 1. SSS is a sevenfold level-designed method of assessing the subjective feel of sleepiness of the driver. One indicates a normal state of arousal and seven shows the lowest state of vigilance. The test was launched after experiment participants had declared score equivalent to level 5 in the SSS questionnaire. The reason why level 5 of the SSS survey was chosen as a low arousal initial level lies in the fact the lowest level of arousal throughout the course of a whole day never exceeded level 5, according to the findings of a pre-survey in which the evolution of arousal level was monitored every hour over a period of one day.

The second condition is the transition of the arousal level. The conduct of the test was spread out over two days for two reasons:

(1) Time was needed, (2) To avoid ethical issues in terms of minimizing workload for participating in the test. Even if each experiment participant starts the experiments at the exact same time, it doesn't imply that the participant's arousal level transition is identical throughout the test. That is why we cannot succeed in determining whether the activation of the system was of any influences on the arousal level transition when the test was conducted in system disabled condition on the first day and in enabled condition on the second day. The experimental protocol was established to assign test participants with arousal stimulating task (stimulation) to provoke a unified variation of arousal. We could establish such protocol and carry out the test accordingly since we could ensure that the arousal level transition was identical throughout the two-day of test launched upon completion of the arousal-stimulating task and the subsequent alertness recovery. Besides, we managed to lessen the influence exerted by the order in which the experiment participants took part in the test, which was conducted with and without the driver assistance system (ACC+LKA) activated. Participants took strongly refreshing tablet candy (including menthol component) as an arousal-stimulating task. Products sold on the market effecting on level of arousal are composed of caffeine. The awakening effect cannot be quickly obtained from its use since the effect occurs 30 mins after consumption, upon absorption [6]. Thus, we tapped into caffeine-free, highly refreshing candy tablet during this experiment.

Evaluation method of arousal level

Facial expression-based sleepiness scale, which was reported as a useful rating tool by previous studies, was used in this study. This method consists of two examiners looking at the driver's facial expression and assessing the arousal level on a 5-fold level based scale, as shown in Table 2 [7]. For the test, we assessed the arousal level with a six-fold level rating scale, which included an extra level designated as "sleeping state". We added this extra level since drivers could possibly fall completely asleep during the experiment.

Experimental Results

Analysis of driver's arousal level

The Figure 3 shows a measure sample of the transition of the facial expression-based sleepiness evaluation value over a period of 30 minutes while a driver assistance system (ACC+LKA) was in use. In this measurement sample, the experiment participant reached level 5 on the sleepiness scale after a 20-minute drive. We subsequently considered the question of how many experiment participants out of the 10 involved in the experiment showed sign of low level of arousal for the two following drive conditions: (1) driver assistance system (ACC+LKA) enabled, and (2) driver assistance system disabled. The Figure 4 shows the average level of sleepiness over the entire run by each participant.

Only experiment participants in the green frame fell to a lower arousal level when the driver assistance was disabled. 8 experiment participants out of 10 fell to a lower level of arousal at the driver assistance system was in operation.

Afterwards, we focused on the proportion of sleepiness levels and presented the average values of all the ten experiments participants in

Degree of Sleepiness Scale Rating Feeling	Rating
Feeling active, vital, alert, or wide awake	1
Functioning at high levels, but not at peak; able to concentrate	2
Awake, but relaxed; responsive but not fully alert	3
Somewhat foggy, let down	4
Foggy; losing interest in remaining awake; slowed down	5
Sleepy, woozy, fighting sleep; prefer to lie down	6
No longer fighting sleep, sleep onset soon; having dream-like thoughts	7

Table 1: The Stanford sleepiness scale.

Sleepiness Evaluation Values	Behavior Characteristics
Seems not sleepy at all	Quick and frequent gaze shift Regular eye blink Intense activity of the body
A little sleepy	Slow eyes shift Lips ajar
Sleepy	Slow eye blink Mouth in motion Sitting position readjustment and hands facial contact
Pretty sleepy	Seemingly conscious eye blink Needless movement of the whole body i.e. Shoulder shrug Frequent yawning and deep breathing Eye blink and eyes movement slowdown
Very sleepy	Closed eyelids The head is leaning forward The head is leaning backward
Sleeping	Closed eyes more than 90 percent of the time

Table 2: Sleepiness objective evaluation values and behaviour.

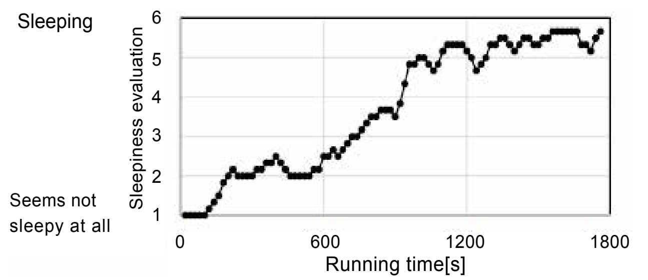

Figure 3: Measurement sample of facial expression-based sleepiness scale over time (ACC+LKA in use).

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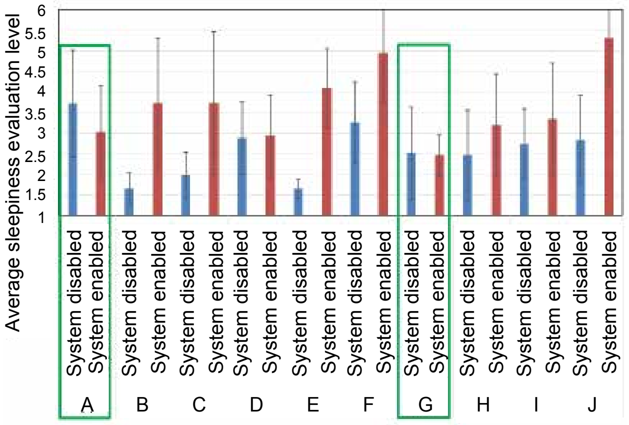

Figure 4: Average value of the sleepiness scale over the entire distance ran by each participant.

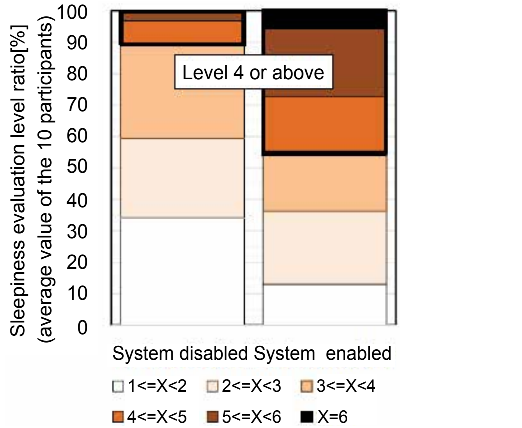

Figure 5: Distribution of sleepiness scale level (average value of the 10 participants).

the Figure 5. When the system is in operation, the ratio characteristically decreased for a sleepiness level lower than 4 and increased for a level higher than 4. When using a driver assistance system, 8 experiment participants out of 10 fell to a lower level of arousal than in absence of the system. The increased proportion of participants who showed at least level 4 of sleepiness (sleepy) is also salient if a driver assistance system is in use. For an average of 10 people, the time frequency of the driving that reached level 4 or above on the sleepiness scale when the system was enabled increased compared with the system-disabled condition.

Correlation analysis of visual stimulation and arousal level

We analysed the relationship between the arousal level and the experiment participants' reaction time to a red lamp, which was placed near the central visual field of the simulator, simulating the brake lights of the vehicle ahead. The reaction time was investigated by the means of a switch installed on the steering wheel. We used the sleepiness rating scale shown in Table 1 above for the estimation of the level of arousal. An average sleepiness level over a period of one minute before the lamp lights was leveraged in this experiment. Since we endeavored to parallel the difference in response time with the difference in arousal level, the reaction times obtained were classified by arousal level. It is known that the probability density function associated with reaction time doesn't pertain to a normal distribution but a logarithmic normal one. The distribution of the data must be of a normal nature to achieve a test of statistical significance, such as t-test. Therefore, we have carried on analysis with a verification method using t-test upon conversion into logarithmical data of the reaction time data, as reported in previous study [8]. The sleepiness level-specific reaction times are shown in the Figure 6 along with the significance test findings.

According to the Figure 6, the reaction time is noticeably delayed and significant differences are acknowledged for a level 4 or above on the sleepiness rating scale. It was confirmed that the reaction time is further delayed for at least level 4 of arousal on the sleepiness scale in contrast with a perfect state of awakening.

For levels less than 4, the findings suggest that drivers tend to react the same way as if perfectly awaken even if arousal levels drop. It is also suggested that a correlation exists between increase in the ratio of level 4 or above and the delay of reaction time to visual stimuli. This is a result describing the reaction time to visual stimuli and is different from the reaction time for taking over the system when the systems are difficult to support driving.

But, same tendency that reaction time in level 4 or above on the sleepiness scale is prolonged can be estimated. To investigate the relation between sleepiness level and the reaction time for taking over the systems will be an additional study.

The differences in arousal level with and without driver assistance system (ACC+LKA) are referred to in the Figure 5 above.

The ratios within the black boxes in the Figure 5 indicate the level 4 and above share on the sleepiness scale. Our findings suggest that the arousal level has lessened due to the use of driver assistance system.

Analysis of the drivers' behavior when the arousal level noticeably dropping

We analyzed the behavioral changes associated with the fluctuation of the driver's arousal level. We carried out analysis to contribute to the basic data intended to detect low arousal level in keeping with the driving behavior. We also considered the characteristics of the drowsiness-prone driver when a driver assistance system was in use. The horizontal axis of the chart below indicates the increase of level 4 ratio if driving assistance was in use compared to it was not in use. We

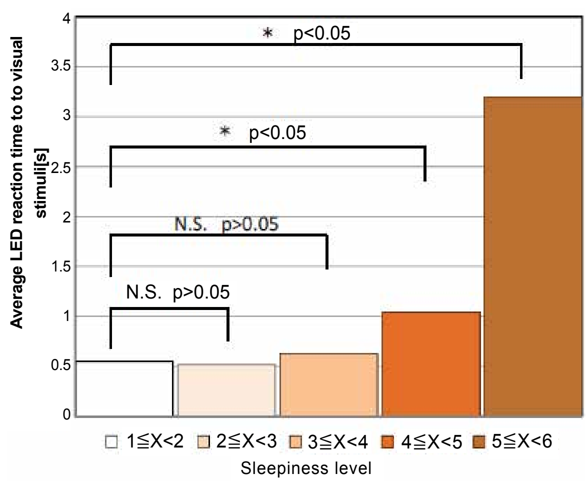

Figure 6: Reaction time to visual stimuli for each sleepiness level (Average for the entire 10 test participants).

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brought our attention on level 4 and above because the reaction time was further delayed in such condition. More specifically, we focused on the increased percentage of level 4 or above and expressed on the horizontal axis. We expressed the resulting increase of each variable on the vertical axis when the system was in use. Yet, additional analysis will be necessary in the future to substantiate these findings since the amount of data collected presently was insufficient.

The Figure 7 shows the relationship between the increase percentage of level 4 or above and accelerator/brake readiness rate. Almost no correlation can be seen ($0 < | r | \leqq 0.2$).

The Figure 8 shows the relationship between the increase percentage of level 4 or above and gripping percentage e of the lower half of the steering wheel. Low correlation was confirmed ($0.2 < | r | \leqq 0.4$). We observed that the more the arousal level of the driver dropped down the more likely she/he was to grip the lower half of the handle.

The Figure 9 shows the relationship between the increase percentage of level 4 or above and single-handed steering wheel grip ratio. A correlation was confirmed in this relationship ($0.4 < | r | \leqq 0.7$). We observed that the more the arousal level of the driver dropped down the more likely she/he was to grip the steering wheel of the car single handedly. We asked test participants after the investigation why they tended to show the single-handed grip. During the use of ACC and LKA, test participants felt that they can rely on the driving support devices and showed a tendency to grip a steering wheel with a single hand.

It is believed that this driver behaviour like the rate of singlehanded grip of the steering wheel can be used to detect the situation that the driver becomes low arousal.

Correlation analysis between arousal level and eye blink

There are many possible methods to estimate the arousal level by analysis of the eye blink. The eye closure average rate has been used as an indicator in this study. Eye closure rate is reported as a highly

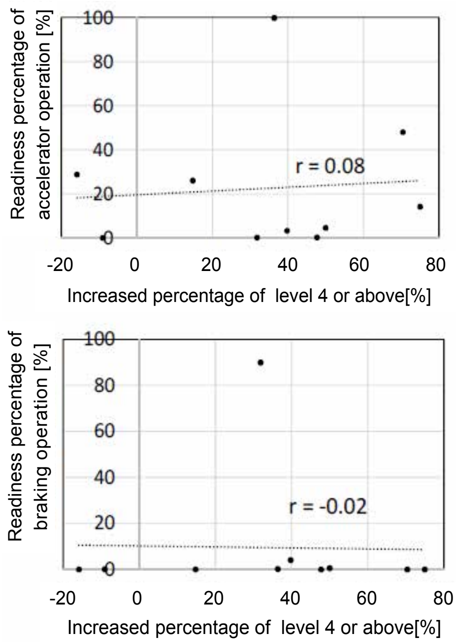

Figure 7: Relationship between the increase of sleepiness level and accelerator/brake readiness rate.

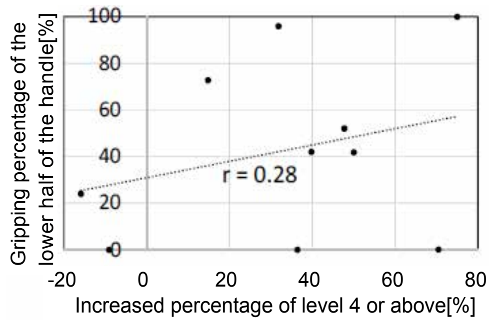

Figure 8: Relationship between the increase of sleepiness level and the gripping rate of the lower half of the handle.

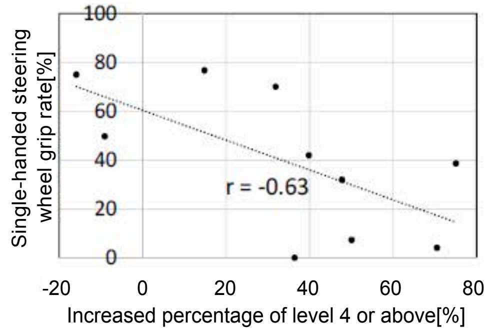

Figure 9: Relationship between the increase of sleepiness level and the rate of single-handed grip of the steering wheel.

accurate arousal level indicator by previous study [9]. The eye closure rate is obtained by the ratio between eye closure and eye opening for a given unit of time.

We analysed the eye closure ratio for the 5 different levels of the facial expression-based sleepiness rating scale. Results are shown in the Figure 10.

The Figure 10 reveals that increase in eye closure rate is commensurate with an increase in facial expression-based sleepiness levels. However, the rate did not increase in a linear function but exponentially. In a previous study by author [9] to evaluate the sleepiness level, we have already clarified that there is a non-linear relationship between the sleepiness level and eye closure rate. We make an exponential approximation to pass through the median values, a red dashed line graph can be obtained, as shown in the figure above. Working on the principle of a relationship between eye closure rate and sleepiness level as shown by the dashed-line chart, we confirmed that eye closure ratio value of 0.26 corresponded to level 4 on the sleepiness scale where the reaction time delayed remarkably. Drawing on these findings, it is believed that HMI device can be designed to prevent the low arousal situation by emitting arousal-stimulating alarm signals before the eye closure rate value exceeds 0.26.

Conclusion

We have listed below a summary of the findings presented above.

Analysis of the arousal level of the driver

We can draw the conclusion that the arousal level is likely to drop down if a driver assistance system (ACC+LKA) is in operation since 8 out of 10 experiment participants saw their arousal decreasing when such a system was enabled.

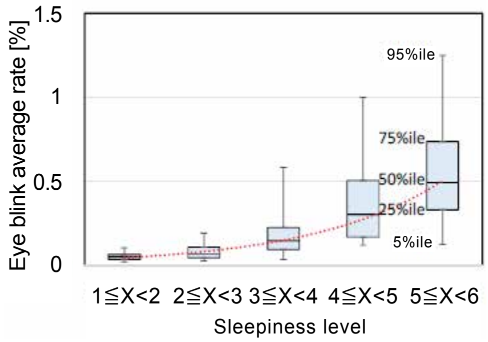

Figure 10: Relationship between sleepiness levels and eye closure rate.

The increased temporal frequency of sleepiness scale level 4 or above (sleepy, very sleepy, and sleeping) is apparent when a driver assistance system is in use.

Correlation analysis of visual stimulation and arousal level

The reaction time is further delayed for a level 4 or above of arousal on the facial expression-based sleepiness scale rather than in a perfect state of awakening. Comparing both conditions e.g. driver assistance system enabled or disabled, the arousal level has lessened due to the use of driver assistance system and that the inattentive driving rate increased in comparison with the system disabled condition. This is a result describing the reaction time to visual stimuli and is different from the reaction time for taking over the system when the systems are difficult to support driving. To investigate the relation between sleepiness level and the reaction time for taking over the systems will be an additional study.

Analysis of the driver's behaviour when the arousal level is noticeably dropping

It was shown the relationship between single-handed steering wheel grip ratio and the arousal level. A correlation was confirmed in this relationship ($0.4 <| r | \leqq 0.7$). We observed that the more the arousal level of the driver dropped down the more likely she/he was to grip the steering wheel of the car single-handedly.

Correlation analysis between arousal level and eye blink

We analysed the eye closure ratio for the 5 different levels of the facial expression-based sleepiness rating scale. Working on the principle of a relationship between eye closure rate and sleepiness level, we confirmed that eye closure ratio value of 0.26 corresponded to level 4 on the sleepiness scale where the reaction time delayed remarkably. Drawing on these findings, it is believed that a device can be designed to detect arousal level based on eye closure rate. In this study, we have investigated the actualization of low arousal situation of driver in using semi-autonomous driving support systems featuring adaptive cruise control and lane keeping assistance. We have observed that the driver tends to become low arousal situation earlier when using the system than when the system is disabled. This investigation was carried out in a driving simulator with participants of only 10 young test subjects. We think it is difficult to say somewhat that the completely same tendency will be actualized in real driving on public road. We believe that continuous long term investigation on actual driving (FOT; field operation test) should be carried out to validate the results in this study.

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