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A STUDY OF EFFECTS OF DRIVER'S SLEEPINESS ON DRIVER'S SUBSIDIARY BEHAVIORS

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Abstract. *Traffic accidents caused by inattentive driving, including drowsiness, still occur frequently. Thus, as one of the approaches to prevent traffic accidents, developing a method for the early detection of low-arousal driving is critical. Our goal is to develop a driver status monitoring system for detecting a decrease in driver arousal by using small and low-cost wearable devices, such as wrist-worn accelerometers. As a basis for achieving this goal, in this paper, we designed and conducted an experiment to measure the frequency of subsidiary behaviors, including yawning, swaying of the head, and arm and hand activities associated with changes in sleepiness level. The correlation coefficient between the frequency of subsidiary behavior and sleepiness level obtained from the facial expression evaluation was then examined. In two of the four participants, the frequency of subsidiary behaviors increased as the sleepiness level increased, with correlation coefficients of 0.786 and 0.601. These results suggest the possibility of detecting a change in the driver's sleepiness level from the frequency of subsidiary behaviors, including arm and hand activities.*
Keywords: Subsidiary behaviors, Sleepiness, Driver status monitoring

1. **Introduction.** In Japan, about 20% of all fatal traffic accidents have been caused by *inattentive driving* including drowsiness driving [1]. Inattentive driving is caused by the lowering of the consciousness of the driver to the driving operations. One of the causes of the lowering of consciousness is decreased arousal due to fatigue and sleepiness. Therefore, the motivation for the study is to investigate a method for quickly and accurately detecting a decrease in driver arousal to prevent traffic accidents.

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Methods for auto-detecting drowsiness of a driver on driving can be classified into two categories according to the types of their input signals. The first uses the signals from the vehicle, such as those of its speed and steering angle [2, 3]. The other uses the driver's biological and behavioral signals such as eye movements and facial features [4, 5, 6, 7], heart rate [8, 9], and electroencephalogram (EEG) [10]. However, in their methods, it is difficult to stably measure the fine changes in the signals due to sleepiness and the detection accuracy varies greatly among individuals. Therefore, there exists a need for more stable measures to improve detection accuracy, such as the combination of biological and *behavioral* indicators [11, 12, 13].

As a behavioral indicator, the driver's body movements, called *subsidiary behaviors*, which are not directly related to driving operations, have been investigated. Roge et al. observed the driver's behavior during long-term monotonous driving tasks on a driving simulator and suggested a relationship between the frequency of occurrence of subsidiary behaviors and the arousal level [14]. Matsuo and Abdelaziz proposed a method to estimate sleepiness level via detection of eye closure rate, swaying of the head, and frequency of subsidiary behaviors based on image processing [11]. Sunagawa et al. also proposed using physiological signals, such as ECG or heart rate analysis, and the change in the driver's posture, as indicators of the change in sleepiness level [13]. However, these methods require cameras or in-vehicle seat sensors to detect driver behavior. On the other hand, wearable sensors, such as wrist-worn accelerometers, have the potential to detect driver behavior more accurately and at a much lower cost.

Our goal is to develop a driver status monitoring system for detecting a decrease in driver arousal by using wearable devices. To achieve this goal, it is necessary to clarify the effectiveness of subsidiary behaviors that can be measured using wearable devices as a sleepiness indicator. Thus, in this paper, we design and conduct an experiment to measure the frequency of subsidiary behaviors, including not only yawning and head swaying but also arm and hand activities, associated with changes in sleepiness level. Then, the feasibility of driver monitoring via wrist-worn sensors is discussed based on these experimental results.

2. **Overview of Experiment.** To observe the relationship between the driver's subsidiary behaviors and sleepiness level on driving, we conduct the following experiment using a driving simulator.

2.1. **Experimental design and procedures.** To simulate the situation in which the drivers' sleepiness level has worsened, we use a relatively simple and monotonous driving task. The driving scenario consists of a course that simulated a two-lane highway with an eight-shaped loop of approximately 30 km on one lap. We design the course on UC-Win/Road (FORUM8 Co., Ltd.). A part of the scene of the created course is shown at the top of Figure 1(a). Then, we conduct the experiment in the order shown in Figure 1(b). Participants in this experiment are instructed to follow the preceding vehicle under each condition shown in Table 1. In this experiment, the time of continuous driving is used as an experimental variable. The effect of the experimental variable is the induction of drowsiness owing to continued monotonous driving. Here, we set Conditions A and C as the baseline for participants to drive for 6 min. on the course to simulate normal driving. However, Condition C is set as a backup in the case of a problem with the Condition A measurement. In Condition B, based on a study of the effects of monotonous driving on vigilance decline [15], we set the experimental condition for participants to drive for 30 min. on the course to simulate the situation of inattentive driving.

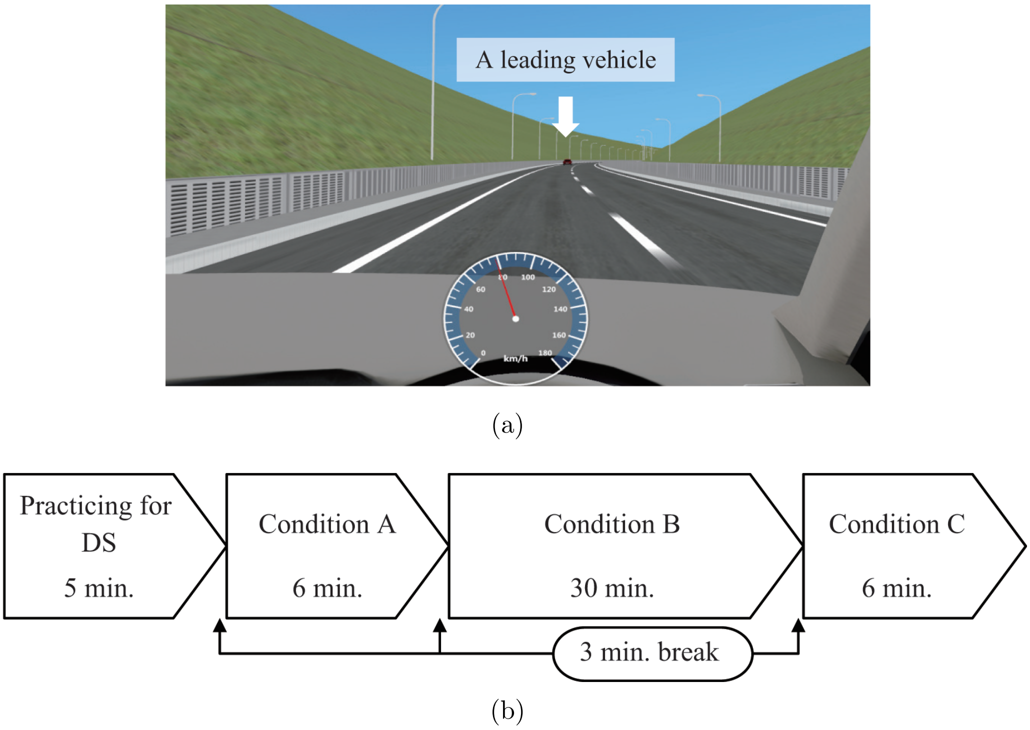


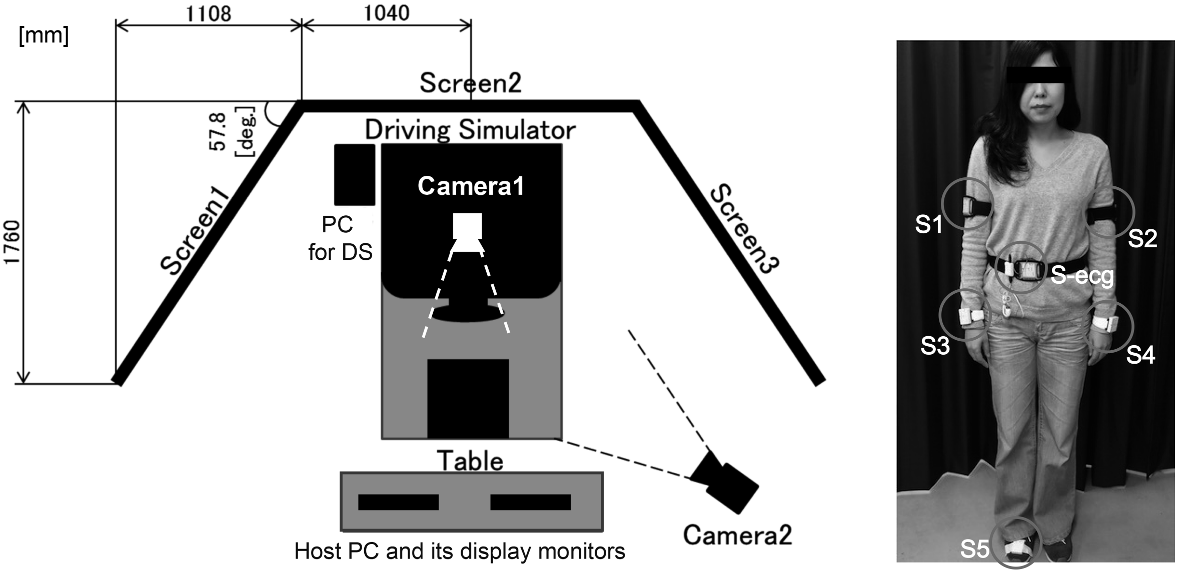
FIGURE 1. A course scene on driving simulator and driving scenarios

TABLE 1. Experimental conditions

Condition	Description
A	Follow the leading vehicle traveling at 80 km/h for *6 minutes*. There are only two vehicles: leading and following (own) vehicles, on the course.
B	Follow the leading vehicle for *30 minutes* under the same conditions as Condition A.
C	Follow the leading vehicle traveling at 100 km/h in the passing lane for *6 minutes*. There are only two vehicles: leading and following (own) vehicles, in the passing lane. And other vehicles traveling at 80 km/h appear randomly in the traveling lane.

To obtain more obvious changes in sleepiness level, all experiments start from 2 P.M. to 6 P.M. In addition, all participants are asked to avoid drinking alcohol and drinks including caffeine, a day before the experiment. The research ethics committee of Toyohashi University of Technology approved the experiment, and each participant received informed consent in advance.

2.2. **Data collection.** We use two USB webcams (Logicool Co., Ltd., HD Pro C920) to record participants' facial expressions and subsidiary behaviors. The cameras are placed at the position shown in Figure 2(a). Cameras 1 and 2 capture participant's face images and body movements, respectively. In addition, we use 6-axis inertial sensors (ATR-Promotions Inc., TSND121) to record the acceleration signals associated with the body movement of a driver during driving. The five inertial sensors are attached to the participant's body segments, as shown in Figure 2(b). The collected acceleration data from the inertial sensors are used to confirm fine movements that are difficult to confirm on video visually. In addition, we will use the collected data to investigate the methods for detecting subsidiary behavior using body-worn accelerometers as future work. Both of the



(a) Driving simulator (b) Sensor layout

Figure 2. Experimental setup

videos obtained from two USB webcams and acceleration data obtained from five inertial sensors are recorded to a host PC. In addition, the driving simulator and its software are operated on a dedicated PC for controlling driving environment in 3D virtual space.

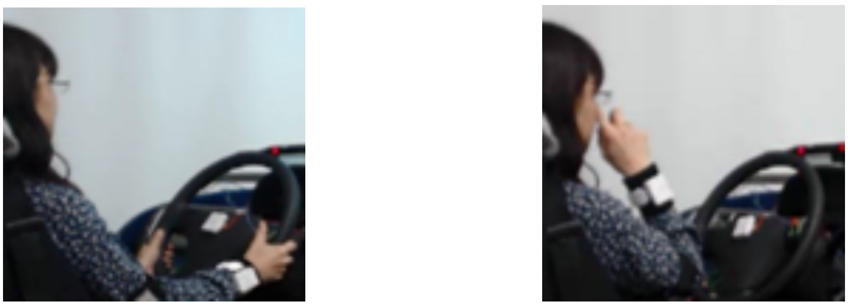
To obtain the subjective self-assessment of sleepiness level, we use MWS (Roken Mental Work Strain) checklist. The MWS checklist consists of 12 questions about sleepiness, activity, etc., and 7 levels of subjective evaluation are required for each item. The 12 items include factors of relaxation, sleepiness, tension, overall activity, attention, and motivation [16]. The participants are asked to answer at the end of each session.

3. Method.

In this paper, we show the definition of subsidiary behaviors during driving and count the number of occurrences of them. Then, we evaluate the relation between the sleepiness level and the driver's subsidiary behaviors.

3.1. Definition of subsidiary behaviors.

Subsidiary behaviors are a set of unnecessary acts to carry out the main work. In a driving situation, Figure 3(a) shows a scene of normal driving operation, and 3(b) shows a scene of touching own nose while driving operation. That is, "touching own nose" is one of the unnecessary acts for driving operation. We



(a) Driving without subsidiary behaviors (b) Driving with "Touch own nose"

Figure 3. An example of subsidiary behavior

TABLE 2. Definition of subsidiary behaviors

Label	Description of behaviors
Touch Own Head	The acts of taking own hand off the steering wheel and touching own nose, eyes, hair, or other parts of own face or head.
Yawning	The acts of opening or closing own mouth wide or moving own mouth including a deep breath.
Strong Blink	The acts of closing own eyes tightly, frowning between own eyebrows, or moving around own eyes as opposed to normal blinking.
One-handed Operation	The acts of putting one hand on a place other than the steering wheel or performing an action other than steering operation outside of "Touch Own Head".
Change of Holding Style	The acts of changing the position of gripping the steering wheel or releasing own hand from the steering wheel and holding again.

define the subsidiary behaviors with driving operation as Table 2. In this paper, two referees count the number of occurrences of subsidiary behaviors shown in Table 2 from the recorded video sequence.

3.2. **Definition of sleepiness level.** To evaluate the sleepiness level, the expression rating value of face image data is used as an index of the sleepiness level. Three human referees observe the captured face images. They are evaluated for the sleepiness level based on the participant's facial expressions and gestures on a 6-point scale shown in Table 3 at 5-second intervals, referring to [18, 19]. To eliminate the order dependency, information on the order of the videos presented to the referees was blinded.

TABLE 3. Definition of sleepiness level based on facial expression

Score	Description of facial expression
0	It seems not sleepy at all
1	Looks vague
2	Somewhat sleepy
3	Sleepy
4	Quite sleepy
5	Very sleepy

3.3. **Evaluation index.** The evaluation index investigates the strength of the relationship by calculating the correlation coefficient using the subsidiary behavior and the sleepiness level described in Sections 3.1 and 3.2, respectively. We use the following Spearman's rank-order correlation coefficient, which is defined as Pearson's correlation coefficient for the rank variables.

$$r = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\left(\sum_{i=1}^{n} (x_i - \bar{x})^2\right)\left(\sum_{i=1}^{n} (y_i - \bar{y})^2\right)} \tag{1}$$

Here, x_i and y_i represent the number of the subsidiary behaviors per one minute and the sleepiness level per one minute, which are converted into rank variables. $\bar{x}$ and $\bar{y}$ are the average values of x_i and y_i, respectively. n is the number of data. Note that the number of occurrences of the subsidiary behaviors is counted at one-minute intervals. While, the facial expression rating is evaluated at five-second intervals, and their data length is not equal. Therefore, the sleepiness level is calculated by averaging at one-minute intervals from the facial expression rating results.

4. **Results.** A total of five legally licensed drivers (two males and three females) participated in the experiment, as shown in Table 4. Their average age was 32 years (range: 20-40 years), and their average driving experience was 12.6 years (range: 2-25 years). All participants were required to drive at least once a week daily and have no history of simulator sickness symptoms, such as feeling sick from a 3D game or stereoscopic 3D vision. However, the data of Subj.02 was excluded because the facial expression data had missing values due to a problem in face images (The eyes were too dark on the face images).

TABLE 4. Description of participants

ID	Gender	Age	Driving experience	Driving frequency
Subj.01	Female	40s	Over 20 years	Everyday
Subj.02	Male	24	5 years	Everyday
Subj.03	Female	37	17 years	Everyday
Subj.04	Male	20	2 years	Everyday
Subj.05	Female	32	2 years	Everyday

In the following, we discuss the comparative results of the continuous driving of Conditions A and B if no problems such as missing measurements occurred in Condition A. However, since there was difficulty in evaluating sleepiness level under Condition A of Subj.04 due to video image problems, in Subj.04, Condition C was used as the baseline condition instead.

4.1. **Change of sleepiness level.** Figure 4 shows the comparative results of sleepiness level between the baseline and Condition B for each participant. In Figure 4, the left axis shows the sleepiness level from facial expression, and each marker shows the average sleepiness level per minute of three referees' scores. The right axis is the MWS score, representing the subjective sleepiness level that participants self-reported at the end of each session. We can see that the sleepiness level is significantly higher under Condition B in four participants including Subj.04, compared to the baseline condition ($p < 0.05$, Wilcoxon rank-sum test). The results indicate the designed driving scenarios induced a decrease in the arousal of participants in Condition B.

4.2. **Relation between subsidiary behaviors and sleepiness level.** Figure 5 shows the relation between the number of occurrences of the subsidiary behaviors and sleepiness level obtained from the facial expression in Condition B for each participant. In Figure 5, the red line represents facial expression rating, and the blue bar represents the number of occurrences of subsidiary behaviors (S.B.) at one-minute intervals. r is the correlation coefficient, and p is the p-value for testing the null hypothesis of no correlation. From the results, Subj.01 and Subj.04 have a significant correlation between sleepiness and the number of occurrences of the subsidiary behaviors ($r > 0.6$, $p < 0.001$). In addition, at the latter of 15 minutes in Subj.01 and Subj.04, the number of occurrences of subsidiary behaviors increased with the increase of sleepiness level. At the time, we have observed the increase of "Touch Own Head" such as to touch own mouth or rub own eyes when yawning. The change in the number of subsidiary behaviors per minute between baseline and Condition B is shown in Figure 6 by body parts. In Figure 6, "with Arm" means that the number of occurrences of "Touch Own Head", "One-handed Operation", and "Change of Holding Style" in Table 2 are summarized as *arm* movements. Also, "with Face" means

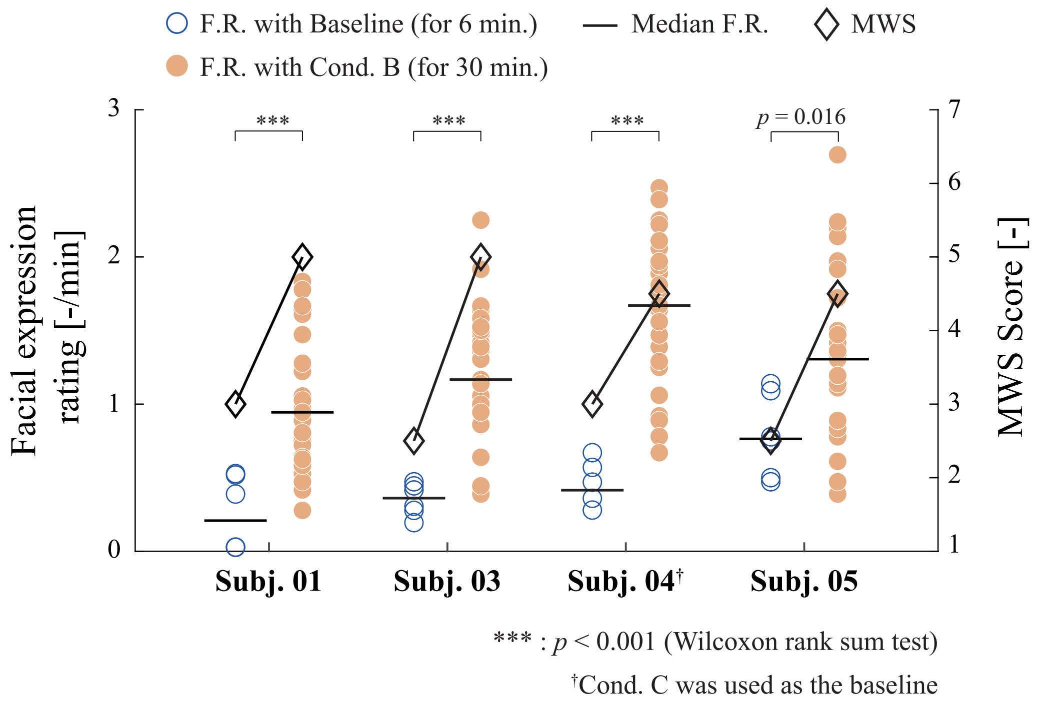


FIGURE 4. Results of MWS score and facial expression rating (F.R.) for each participant

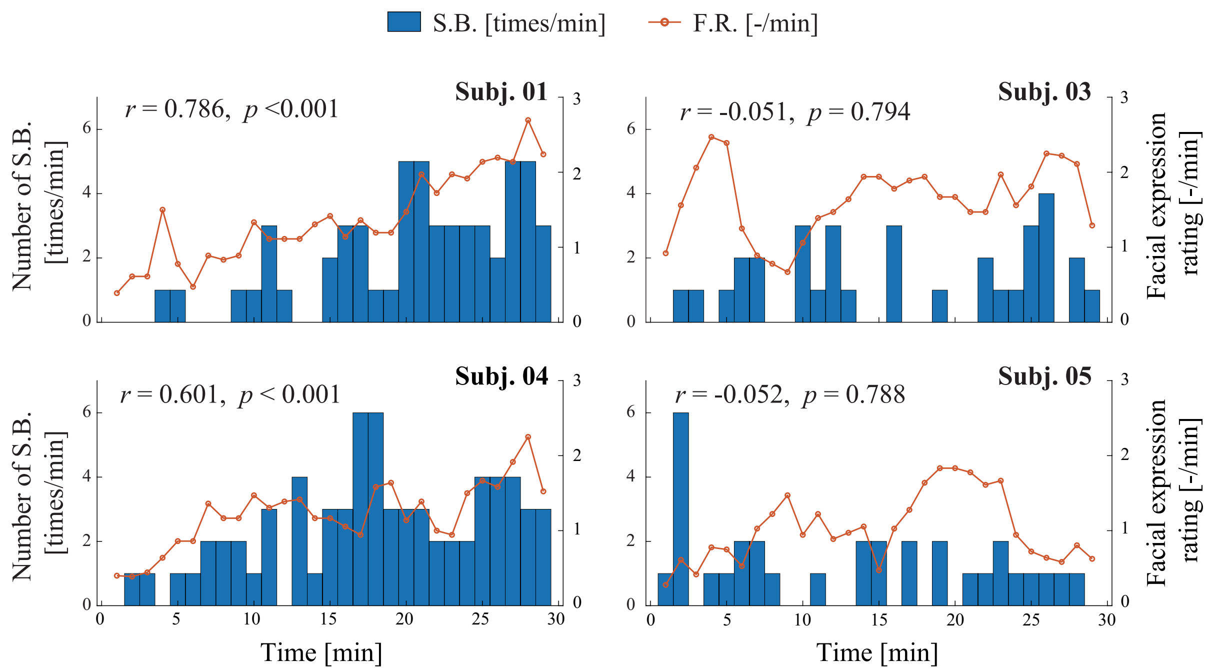


FIGURE 5. Relation between degree of sleepiness and subsidiary behaviors (S.B.)

both the number of occurrences of "Yawning" and "Strong Blink" are summarized as *facial* movements. From the results in Subj.01 and Subj.04, we can see that not only the face movement but also the frequency of arm movements increase under Condition B compared to the baseline condition.

These results suggest that the frequency of subsidiary behaviors, including arm and hand activities, might be an effective indicator for detecting driver drowsiness changes.

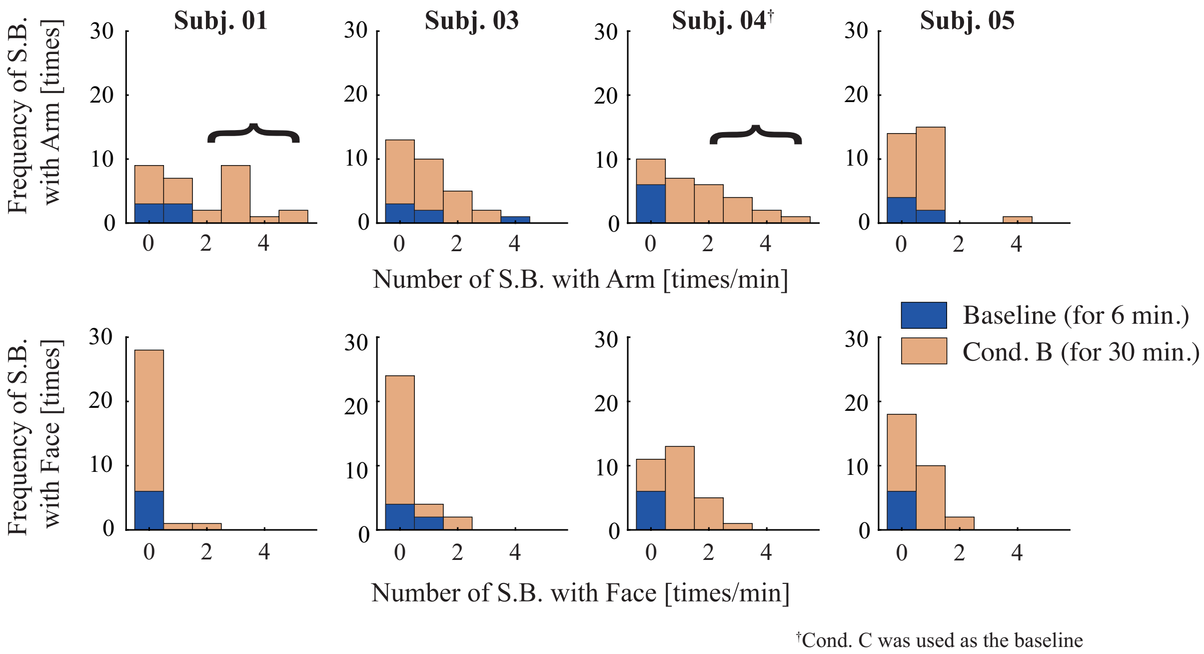


FIGURE 6. Comparison of the number of subsidiary behaviors (S.B.) by body parts

Moreover, since wrist-worn accelerometers might accurately detect arm and hand activities, it is considered to realize driver status monitoring via wrist-worn sensors. However, the number of subsidiary behaviors exhibited in this paper was visually counted by two referees from the video sequence. Further investigation of the method to detect and count the subsidiary behaviors from body-worn accelerometer data is required.

5. **Conclusions.** In this paper, we defined the driver's subsidiary behaviors, including yawning, swaying head, and arm and hand activities. Then we experimented and investigated the correlation between subsidiary behaviors and sleepiness level. First, we designed and experimented with monotonous driving behaviors to measure the frequency of subsidiary behaviors associated with sleepiness levels on the driving simulator. Subsequently, we discussed the correlation coefficient between the sleepiness level and the subsidiary behaviors from the results of the four participants. In two of the four participants, the frequency of subsidiary behaviors increased as the sleepiness level increased, with correlation coefficients of 0.786 and 0.601. As the first step of this research, these results suggest the possibility of detecting a change in the driver's sleepiness level from the frequency of subsidiary behaviors, including arm and hand activities. Moreover, since wrist-worn accelerometers might accurately detect arm and hand activities, it is considered to realize driver status monitoring via wrist-worn sensors.

However, the results of this paper were from a limited number of participants. According to NHTSA guidelines [20], further investigation of the effect of drowsiness on subsidiary behaviors for a wide range of age groups is required. We will then investigate how to apply behavioral features, including arm and hand activities, as a drowsiness indicator. In future work, we will also develop an automatic counting algorithm for subsidiary behaviors from body-worn accelerometer data and expand the size of the dataset for verification.

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