MONITORING SYSTEM OF DRIVER'S HEALTH CONDITION TO PREVENT TRAFFIC COLLISION CAUSED BY HEALTH CONDITION RISKS AND COGNITIVE DECLINE

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ABSTRACT

Driving risks for elderly drivers are known to be associated with age-related diseases and cognitive decline. Furthermore, daily physical conditions such as drowsiness and fatigue also affect cognitive function and driving behavior. Therefore, in order to prevent traffic accidents involving elderly drivers, it is important to provide personal driver support that takes into consideration the effects of daily physical conditions. In this study, we explored the feasibility of a monitoring system utilizing daily physical condition data that can be assessed by wearable devices on elderly subjects. Focusing on the sleep characteristics that affect the physical condition, we found the relationship between attention function and driving behavior. As a result of the attention function evaluation by the Attention Network Test, irregular sleep time was associated with greater variation in attention function, suggesting that people with irregular sleep time had more unstable attention function. In addition, as a result of the driving behavior evaluation by the Driving Simulator Test, greater variation of the attention function was associated with the larger steering entropy and maximum acceleration of the car. These results suggest that instability of the attention function may cause the rough driving. Combined with the results of relationship between variability of sleep time and attention function, these results suggest that people with irregular sleep time are more likely to engage in rough steering and pedal operation, which may lead to sudden steering and acceleration that can cause accidents. It is also known that elderly people have problems in falling asleep and maintaining sleep than younger people. In order to eliminate traffic accidents involving elderly drivers, a support system that incorporates information on sleep habits will become more important. In recent years, the use of wearable devices has made it possible to objectively acquire daily activity and sleep data, and it is expected to utilize a wider range of daily activity data. In the future, we are planning to acquire actual vehicle driving data to understand the relationship between physical condition and driving behavior in more detail.

INTRODUCTION

Honda aims to achieve zero fatalities in traffic accidents involving Honda motorcycles and automobiles worldwide by 2050. The number of accidents involving elderly drivers is increasing along with the acceleration of the aging society in the world, and it is recognized as social-level problem [1]. Driving risk for elderly drivers is known to be associated with age-related diseases (such as cardiovascular disease, diabetes, sleep disorders, and other lifestyle-related diseases) and cognitive decline [2-3]. Furthermore, daily activity indicators that affect physical condition, such as sleep, exercise, and fatigue have also been reported to affect cognitive function and driving [4-6]. Thus, monitoring of daily activity is considered to be important for personal driver support in addition to conventional medical checkup data. In this study, we explored the feasibility of a monitoring system utilizing daily activity data that can be assessed by wearable devices. We report the relationship between daily activity indicators, attention function, which is important for safe driving, and the changes in driving behavior in elderly drivers.

METHODS

Ethics

This study was conducted in accordance with the Declaration of Helsinki and ethical guidelines for epidemiology research authorized by the Japanese government, and it was approved by Institutional Review Board of Oita University (Clinical Review Board Approval No. 2355-C45), of Eisai Co., Ltd. (Registration No. 2022-0793), and of Honda R&D Biotechnology Ethics Committee (No. 99HM014H). Written informed consent was obtained from all participants.

Study design

Elderly residents of Usuki City (Oita Prefecture, Japan) were asked to wear a smartwatch (VENU 2S, Garmin Ltd., Olathe, Kansas, USA) for two weeks to obtain daily activity data. Each participant was also administered the Attention Network Test (ANT) and the Driving Simulator Test (DST) four times, each at least two days apart during the two weeks. First trial of each assessment was served as practice session.

Participants

ANT was performed on 24 participants (age range 75-86 years, mean = 79.54, standard deviation (SD) = 3.39), of whom 16 (age: mean = 73.32, SD = 4.97) completed the DST. All participants held a driver's license (Table. 1).

Table 1. Characteristics of the participants

Characteristic	All, n = 24	DST completed, n = 16
Age (years), range	75 - 86	75 - 86
Age (years), mean (SD)	79.54 (3.39)	78.81 (3.52)
Sex (male), n (%)	18 (75)	13 (81.25)
BMI (kg/m2), mean (SD)	24.24 (2.38)	24.28 (1.88)
Warning[a], n (%)	3 (12.5)	1 (6.25)
Crush[a], n (%)	1 (4.16)	0 (0)

a Self-reported number of the experiences in the past 2 years.

Wearable sensor data

The daily activity and related data were assessed using a smartwatch, VENU 2S (Garmin), and calculated by built-in algorithms developed by Garmin [7-9]. Sleep/wake parameters were estimated based on time data and RR-intervals (RRI), heart rate variability (HRV), respiration rate and wrist/body movement data assessed by optical sensor combined with accelerometer data. The number of steps were estimated by accelerometer data. Stress levels (0–100) were estimated primarily using a combination of RRI and HRV data.

Attention function assessment

Using the ANT, we evaluated three attentional networks that constitute the human attentional function; the alerting network, which is thought to be involved in maintaining arousal, the orienting network, which is thought to be involved in selective attention to sensory stimuli, and the executive network, which is thought to be involved in resolving conflicting information [10]. The test program was created and executed using Unity (Unity Technologies, San Francisco, USA) and displayed on a monitor with a resolution of 1920 × 1080. The test used three Cue conditions (No cue, Center Cue, and Spatial Cue). In the Spatial Cue condition, an asterisk indicated the location of the next target. Participants were asked to identify the direction of the arrow quickly and accurately in the middle of the target and press the corresponding keyboard button (left button for target arrow pointing left, right button for target arrow pointing right). Three target types were used for the evaluation (Neutral, Congruent, and Incongruent) (Figure 1).
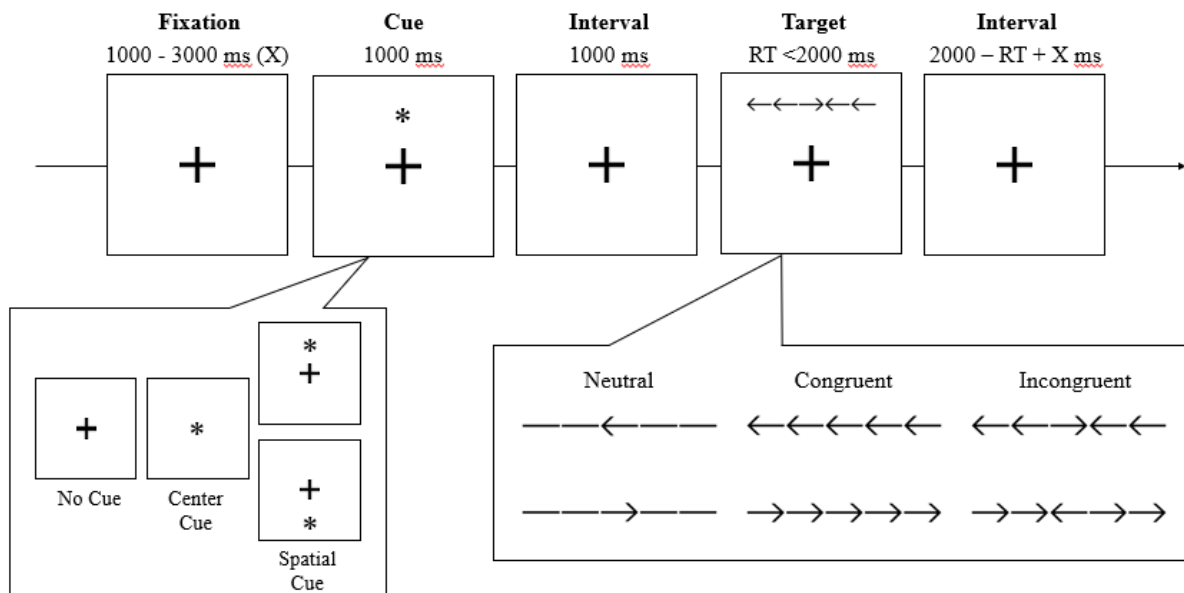

Figure 1. Schematic of Attention Network Test.

Scores for each of the three attentional functions were calculated using the following formula based on the Reaction Time (RT) of the two related parameters.

Alerting Effect = RT (No cue) − RT (Center Cue)

Orienting Effect = RT (Center Cue) − RT (Spatial Cue)

Executive Effect = RT (Incongruent) − RT (Congruent)

Higher Alerting Effect or Orienting Effect scores reflect the ability to use cues more efficiently, indicating better alerting or orienting attention function. On the other hand, higher Executive Effect scores indicate poorer function, indicating less ability to resolve conflicts between discrepant perceptual information.

Driving behavior evaluation

Driving behavior was evaluated using HONDA Safety Navi (Honda Motor Co., Tokyo). For this test, a scenario consisting of an urban area and a mountain road was created and conducted.

Participants underwent a 3-minute practice session followed by 3 x 5-minute main test sessions. If a subject reported feeling simulator sickness during the practice session, further testing was immediately stopped. The test included scenarios depicting situations such as pausing in an urban area, traffic lights, parked vehicles, and car jumps at intersections. The mountain road also consisted of a Winding Road consisting of an ascent and a descent (Figure 2). Input variables such as steering, accelerator, and brake recorded every 10 ms on the DST control PC and data on output changes such as vehicle coordinates and speed were acquired and used for analysis. Steering entropy was calculated according to Nakayama *et al.* (1999) [11].
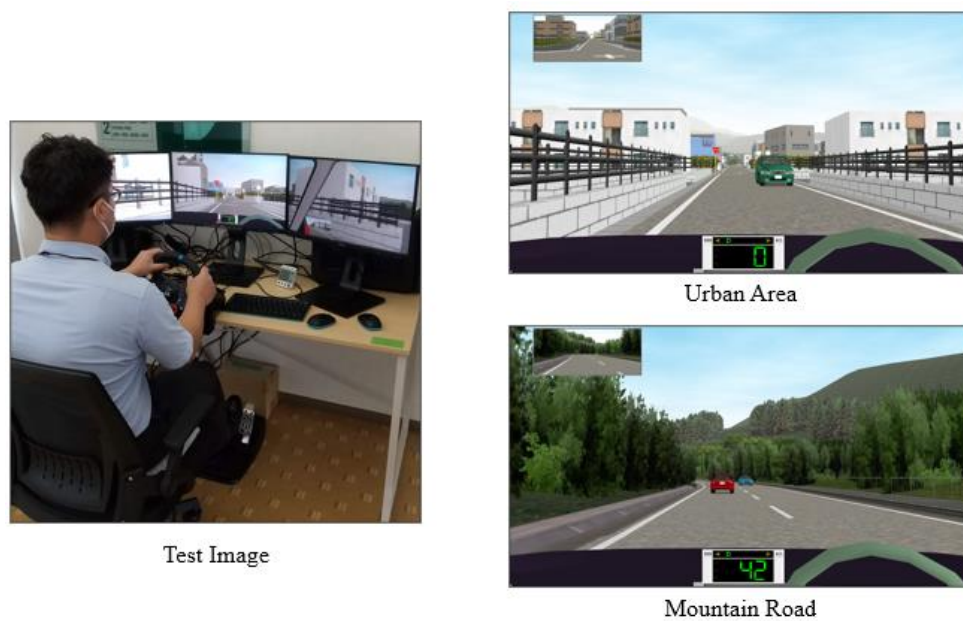

Test Image

Urban Area

Mountain Road

Figure 2. Schematic of Driving Simulator Test.

Statistical Analysis

Statistical analysis performed using python and scipy. The Pearson's correlation analysis was used to evaluate the relationships between daily activity data, attention function, and driving behavior. In all cases, $p < 0.05$ was considered statistically significant.

RESULTS

Daily activity and attention function

Figure 3 shows data on total sleep time, number of steps, and stress level obtained using a smartwatch in each participant. We first tried to examine the relationship between sleep and attentional function based on previous reports [12-14].
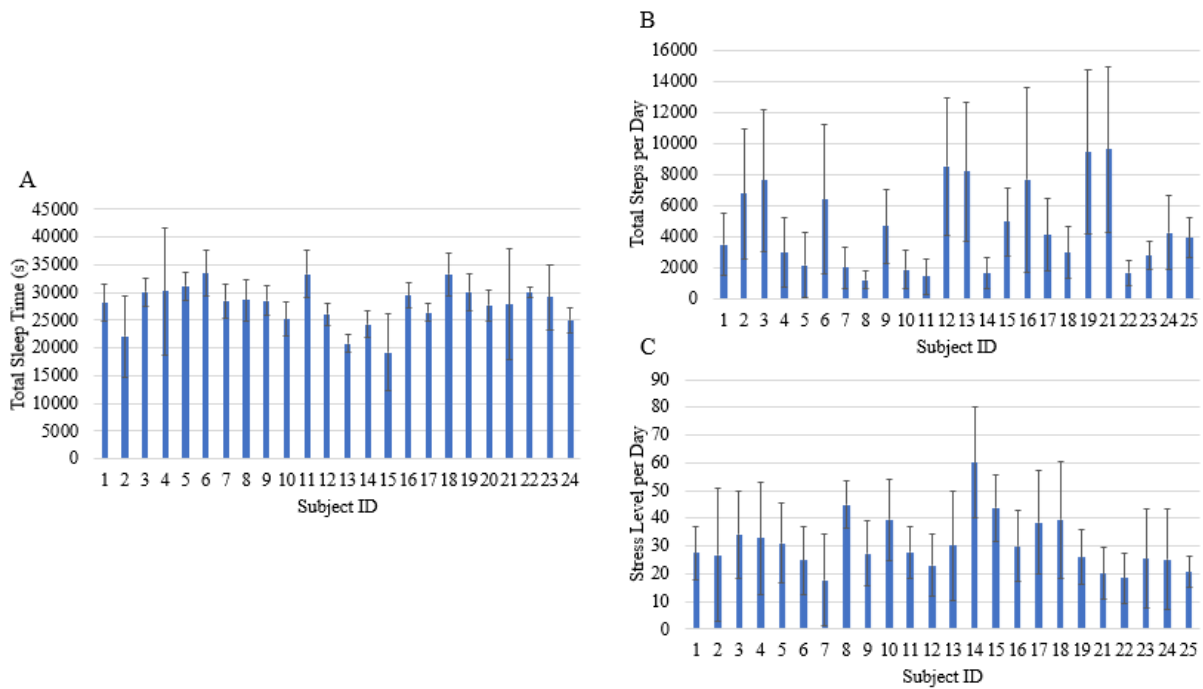
Figure 3. Daily activity log assessed by smartwatch. Each value represents mean ± SD.

Two sleep parameters, mean sleep duration and sleep duration variability (Figure 3A), were used to compare with the results of the ANT. The results showed that sleep duration variability is highly correlated with attentional function (Figure 4D-F) than mean sleep duration (Figure 4A-C) in all three attentional functions, alertness, orientation, and executive functions. These results suggest that irregular sleep duration may cause the unstable attentional function.
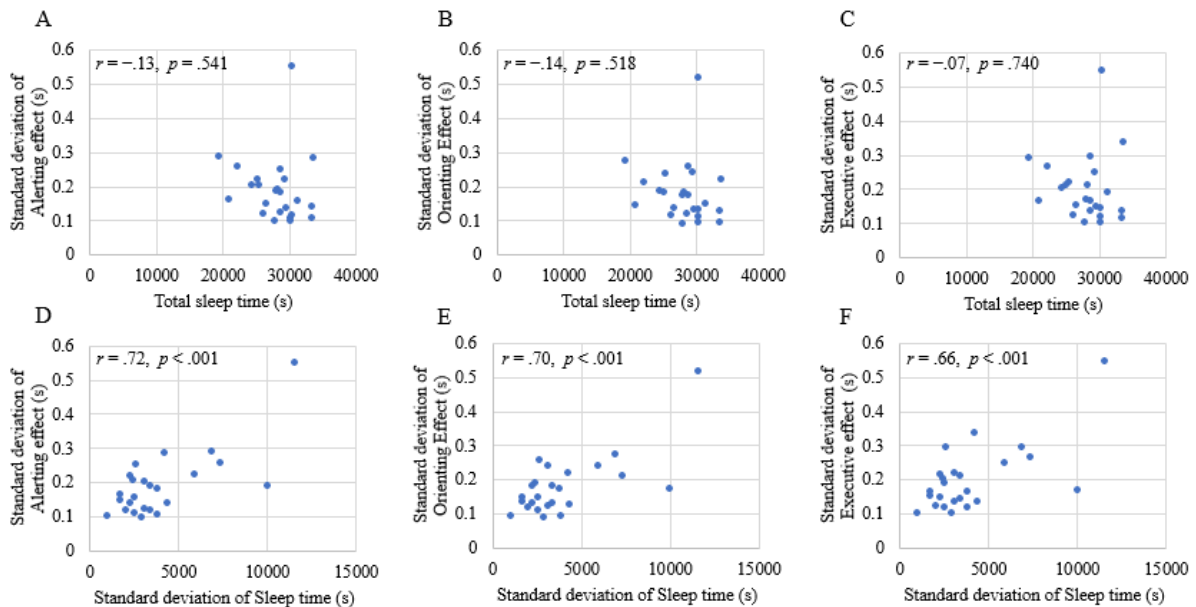

Figure 4. Relationship between sleep parameters and attention function.

Attention function and driving behavior

Driving behavior analysis using DST was conducted to examine the effects of attention function instability on driving behavior. This study focused on steering and pedaling on mountain roads.

Steering entropy was used to evaluate steering operation [11]. We found the significant correlations between steering entropy and variability for all three attention functions, alertness, orientation, and executive functions (Figure 5A-C). For pedaling, the average of the maximum acceleration for each of the nine tests was used for the evaluation. As a result, we also confirmed the relationships between maximum acceleration and variability of all three attention functions (Figure 6A-C). In short, both higher steering entropy and maximum acceleration were associated with greater variation of attention functions.
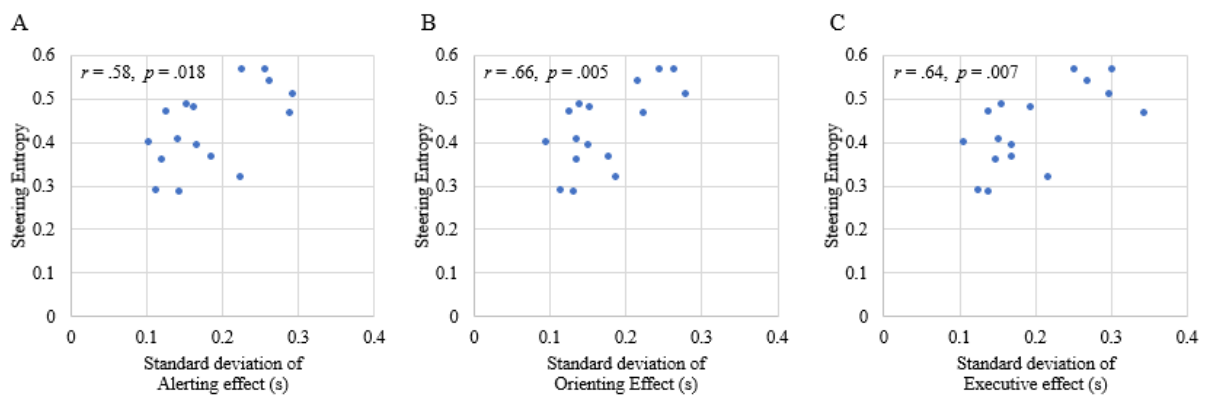

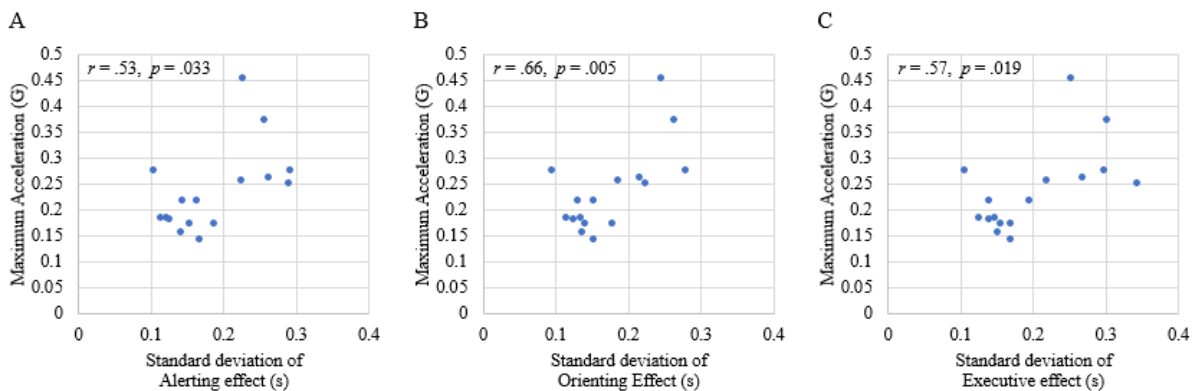Figure 5. Relationship between attention function and steering entropy.

Figure 6. Relationship between attention function and maximum acceleration.

DISCUSSION

The present study focused on relationships between sleep, attention function, and driving behavior. We found that the variability of daily sleep duration had more influence on attentional function than the mean sleep duration (Figure 4). Continuous sleep loss and circadian rhythm disruption are reported to cause poor attention function [15-16]. An association between disturbed circadian rhythm and cognitive dysfunction has been also reported [17], and thus, we are planning to further explore the relationships between irregular sleep time, circadian rhythm disturbances, and instability in attention function.

The results on attention function and driving behavior showed that those with unstable attention function tended to have larger values of steering entropy and maximum acceleration on mountain roads (Figure 5 and 6). Combined with the results of relationship between variability of sleep time and attention function, these results suggest that people with irregular sleep time are more likely to engage in rough steering and pedal operation, which may lead to sudden steering and acceleration that can cause accidents.

It has been reported that elderly people have sleep related problems such as difficulties in falling asleep and to maintaining sleep than for younger people [18]. In addition, the frequency of sudden and unexpected driving risk is thought to be increased in the elderly than in younger people, and it can be hypothesized due to a combination of sleep problems, age-related cognitive decline, and unstable attentional function. Therefore, those relationship should be carefully addressed to develop the driver support systems utilizing daily physical condition data to prevent accidents among the elderly.

In recent years, wearable devices have made it possible to easily obtain data on daily activities. Further accumulation of a wider range of daily activity data in the future will make it possible to study the effects of daily driving risk in more detail. As a next step, we are planning to conduct correlation analysis with actual driving data to evaluate the importance of monitoring system in real world.

Currently, as advanced driver assistance systems related to the risk of physical condition while driving, we are conducting research on medical emergency stop systems using driver monitoring cameras, driver availability/sleepiness monitoring systems, etc. In order to further improvement of the effectiveness of these systems, highly accurate estimation of the driver's condition is essential. The use of drivers' daily data as input data for this purpose is expected in the future.

CONCLUSION

This study examined the potential of the driver support system to utilize daily activity data. It was found that among the elderly, irregular sleep time may cause the instability of the attentional function. Furthermore, the results of driving behavior analysis revealed that unstable attention function may lead to rough steering wheel and pedal operation. These findings indicate the possibility of prediction of driving risk based on daily activity data.

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