International Journal of Physical Medicine & Rehabilitation
ISSN: 2329-9096

Sawada et al., Int J Phys Med Rehabil 2018, 6:5
DOI: 10.4172/2329-9096.1000491

Research Article Open Access

Frontal-Lobe Activation in Healthy Adults Using A Driving Simulator

Yasuhiro Sawada[1,2*], **Rumi Tanemura**[1], **Masako Fujii**[3], **Kazuaki Goshi**[4] **and Katsuya Matsunaga**[5]

[1]*Department of Health Science, Graduate School of Health Science, Kobe University, Kobe, Japan*

[2]*Chubu University, Kasugai, Japan*

[3]*Hirashima Hospital, Kobe, Japan*

[4]*Kyushu Sangyo University, Fukuoka, Japan*

[5]*Kyushu University, Fukuoka, Japan*

*****Corresponding author:** Yasuhiro Sawada, Department of Health Science, Graduate School of Health Science, Kobe University, Kobe, Japan, Tel: +81-568-51-9460; E-mail: sawada@isc.chubu.ac.jp

Received date: September 25, 2018; **Accepted date:** October 09, 2018; **Published date:** October 10, 2018

Abstract

Objective: This study aimed to analyze frontal lobe activity in healthy adult subjects as they drive when they make the left turn, right turn, and lane changes.

Methods: Twenty-six healthy adult subjects participated in the study. The Safe Driving Education Driving Simulator (DS) by Matsunaga and Goshi was partially revised to create the DS for Brain Activity Measurement (DSBAM) used in this study. Frontal-lobe activation was measured with functional near-infrared spectroscopy. Variables such as pedestrians and oncoming cars were introduced to driving conditions involving left turns (LTs), right turns (RTs), and lane changes (LCs).

Results: Simple LTs or RTs did not induce additional frontal-lobe activation compared to driving on a straight line. However, it was found that frontal-lobe activation increased when a pedestrian or oncoming car was added to the LT or RT. It was difficult to induce frontal-lobe activation with LC, regardless of the situation. Further, it was found that it was easier to increase activation in the right hemisphere than in the left hemisphere.

Discussion: Increased activity of the frontal lobe was achieved in the presence of pedestrians and oncoming cars in addition to simple driving in the healthy adult subjects as an effect of dual-tasking required in directing attention to pedestrians or oncoming cars.

Conclusion: We suggest that frontal-lobe activation was induced when a pedestrian or oncoming car was present because these conditions involved the dual task of driving and directing attention to the pedestrian or oncoming car. We propose that activation was more easily induced in the right than in the left hemisphere because the right hemisphere is involved in directed attention. Therefore, a driving simulation that could efficiently induce frontal-lobe activation requires inclusion of a pedestrian or oncoming car in addition to simple left or right turns.

Keywords: Frontal lobe; Driving attention; Directed attention; Near-infrared spectroscopy; Driving simulator; Healthy adults

Introduction

In addition to physical functions, cognitive functions are essential to driving an automobile. Among these cognitive functions, Reger et al. [1] reported, based on the results of neuropsychological testing, that attention and visual perception are vital. Further, regarding driving with impaired cognitive function, Schanke and Sundet [2] conducted an on-road driving experiment and reported that due to differences in attention between patients with traumatic head injury and healthy adults, overlooking bicycles and persons during left turns (LTs), for example, occurred frequently in patients with traumatic head injury and was linked to accidents. Formisano et al. [3] reported that the rate of accidents was 2.3 times higher in patients with traumatic head injury than in healthy adults. Accordingly, patients with traumatic head injury are unable to resume driving, which complicates daily-life tasks such as transportation to and from work. Hence, it can be said that establishing a rehabilitation program, which allows patients exhibiting impaired attention to resume driving is an important challenge for occupational therapy.

At the same time, it is thought that frontal-lobe activation is vital when driving, as prefrontal lobe and right hemisphere functions are essential for attention and visual perception. Analyses of brain activation while driving have been reported using recent advancements in imaging methods [4-9]. Walter et al. [4] analyzed brain activation imaged with functional magnetic resonance imaging (fMRI) while driving and found that the frontal motor area and the cerebellum were activated. Schweizer et al. [5] showed participants a video of driving and analyzed brain activation with fMRI. They reported that the ventrolateral prefrontal cortex was significantly activated when the participants were presented with cars as noxious stimuli, which was said to be largely attributable to the effects of attention and executive function. Accordingly, frontal-lobe functions pertaining to attention are essential to driving, and a condition capable of efficiently activating the frontal lobe while driving could be implemented to a rehabilitation program directed at returning to driving.

Considering the above, with the ultimate objective to develop a rehabilitation program aiming at helping patients with cognitive impairment to resume driving, our goal in this study was to review the types of situations, where the frontal lobe is active in healthy adults while driving. This study utilized a driving simulator (DS). This DS considers safety and can be used in both driving assessment and treatment [10-12]. Frontal lobe activation was examined using functional near-infrared spectroscopy (fNIRS). Unlike fMRI, fNIRS can measure activation in the frontal lobe accompanying actual movements. The Safe Driving Education DS developed by Matsunaga and Goshi was partially revised to create the Driving Simulator for Brain Activity Measurement (DSBAM) used in this study [13]. Subjects were individuals aged 20 to 60 years who drove regularly. The fNIRS device was placed on the head while the subject executed the driving simulation and frontal lobe activation was analyzed under various conditions including LTs, right turns (RTs), and lane changes (LCs).

This study was approved by the ethical review board of Kobe University School of Health Sciences (ethical review no. 204).

Methods

Subjects

Subjects were included if they met the following eligibility criteria: 1) Had driver's licenses and driving experience, 2) Did not have any diseases or cognitive impairment, 3) The practice run was intended to allow subjects to perform DS or other cars and to confirm that there were no obstacles to driving on the DS, such as simulator-sickness.

Subjects were 26 (13 male, 13 female; mean age 47 ± 15 years) healthy adults who consented to participate in the present study. There were five subjects in their 20s, seven in their 30s, four in their 40s, five in their 50s, and five in their 60s. The mean number of years since obtaining a driving license was 21 ± 11.

To confirm that attention was not impaired, the Simple Reaction Time (SRT) task, Trail Making Test A (TMT-A), and Trail Making Test B (TMT-B) of the Continuous Performance Test, a standard attention testing method, were implemented. No subject had attention impairment (Table 1).

Test	Score
SRT	306 ± 71 s
TMT-A	38 ± 12 s
TMT-B	74 ± 31 s

Table 1: Attention screening tests (SRT: Simple Reaction Time; TMT-A: Trail Making Test A; TMT-B: Trail Making Test B).

Driving simulator and driving tasks

The hardware used was a personal computer (DELL Inc, OS windows7), three displays (screen size 473 mm × 296 mm), and a steering wheel-shaped controller (Logicool, Driving Force GT in Switzerland). The software used was the Driving Simulator for Brain Activity Measurement developed by Matsunaga and Goshi et al. (Figure 1). This software and DS are commercially available.

Figure 1: Showing driving simulator software for brain activity measurement.

The simulation was conducted according to Japanese traffic laws on a virtual road with two lanes of traffic on each side and a speed limit of 60 km/h (indicated by signs). The simulation duration was approximately 15 min and the driving distance was approximately 15 km (Figure 2).

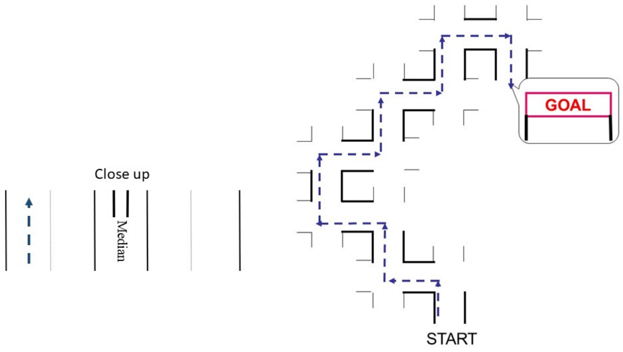

Figure 2: Showing simulation duration and driving distance.

There were in total eight driving conditions. The two conditions for LTs were an LT and an LT with a pedestrian crossing a crosswalk (LT + Pedestrian: LTP). The three conditions for RTs were an RT, RT with pedestrian (RT + Pedestrian: RTP), or with a pedestrian and an oncoming car (RT + Pedestrian + Oncoming car: RTPO). The three conditions for an LC were an LC and an LC with another car in the passing lane at 60 km (LC60) and at 80 km (LC80). The DS was programmed to randomly present each condition twice (Figure 3). When required to execute LTs, RTs, or LCs, the subjects were instructed with a verbal cue.

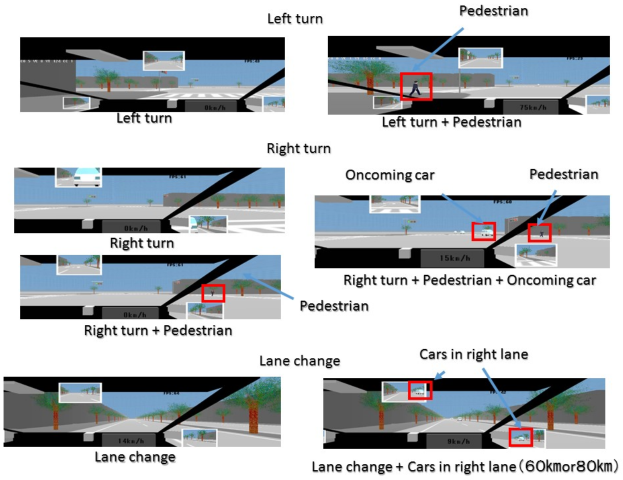

Figure 3: Showing driving simulation and conditions.

Frontal-lobe activation

Frontal lobe activation was assessed via cerebral hemodynamic changes as measured by a portable fNIRS device (Spectra Tech Inc. OEG-16, Yokohama, Japan). Probes were placed to correspond with [Fpz] of the international 10-20 method, which uses the central probe in the lowermost row for electroencephalographic measurements. Two by eight holders were placed allowing measurement of 16 channels. Measurements were performed with a 6.1-Hz sampling frequency for the near-infrared spectrum, and oxygenated hemoglobin concentration, which reflects brain activation, was used as the extraction parameter (Figure 4).

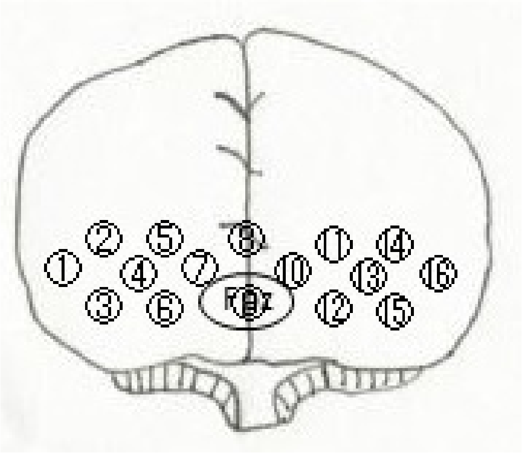

Figure 4: Showing frontal lobe activation.

The measurement of 300 m of driving on a straight line after driving 1 km of the 2 km straight section at the start of the driving simulation was used as the baseline frontal-lobe activation. The oxygenated hemoglobin values for two LTs, RTs, and LCs were averaged and compared. We measured frontal-lobe activation during LTs starting at 5 m before entering the intersection and ending at 5 m after executing the LT. Similarly, frontal-lobe activation during RTs was measured starting at 5 m before entering the intersection and ending at 5 m after executing the RT. An LC was established as the activation from the time of the announcement instructing an LC until the vehicle was entirely in the passing lane.

SPSS version 16 (SPSS Inc., Chicago, IL) was used for the statistical analysis. After confirming homoscedasticity with an F test, one-way analysis of variance and Bonferroni multiple comparisons were used. The significance level was set to less than 5%.

Implementation procedure

The SRT, TMT-A, and TMT-B tasks were administered to all subjects after written consent was obtained, following which, a practice run on the DS was implemented. The practice run included thorough practice of LT, RT, and LC tasks without pedestrians or other cars and confirmed that there were no conditions such as simulation sickness, which could impair driving. After completion of the practice run, the fNIRS probes were set up. Measurement started after the subjects acknowledged the speedometer and confirmed the position of the rear view mirror. Before commencing the performance run, the tester performed an additional confirmation of the subject's physical condition, and conveyed instructions to drive while following traffic regulations, such as not exceeding the speed limit of 60 kmph and driving primarily in the slow lane; the subjects were also instructed to alert the tester if they began to feel unwell while driving. DS discontinuance criteria were established as situations in which there were repeated accidents and it was anticipated that the subject would not complete the run or in which the subject felt unwell while driving, including simulation sickness. Approximately 40 min were necessary for complete implementation.

Results

Left turn

LT and LTP were compared to the baseline frontal-lobe activation. It was found that frontal-lobe activation was significantly higher for both LT compared to baseline and for LTP compared to LT in 15 of the 16 channels (excluding channel 14). Activation increased most in the LTP condition. Further, activation increased in all channels in the right hemisphere (channels 1-7), while it did not in channel 14 in the left hemisphere (channels 10-16) (Figure 5).

Citation: Sawada Y, Tanemura R, Fujii M, Goshi K, Matsunaga K (2018) Frontal-Lobe Activation in Healthy Adults Using A Driving Simulator. Int J Phys Med Rehabil 6: 491. doi:10.4172/2329-9096.1000491

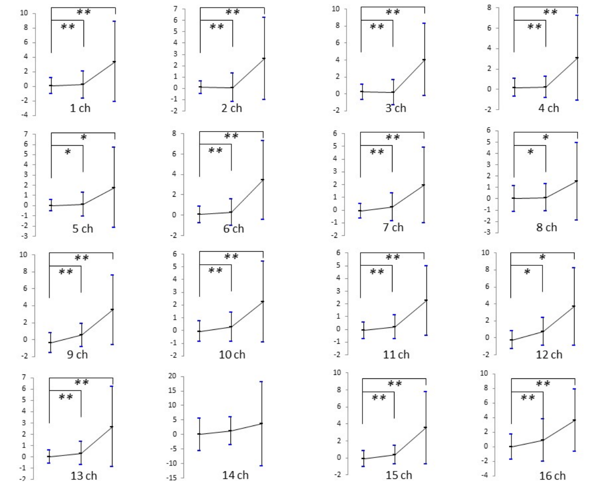

Figure 5: Showing 1-16 channels activity during left turn.

Right turn

Similarly, for RT, the Baseline frontal-lobe activation was compared to RT, RTP, and RTPO. It was found that 12 of the 16 channels (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13, 15, and 16) (p<0.05) demonstrated higher frontal lobe activation between the baseline and RTPO. Additionally, five of the 16 channels (1, 3, 4, 12, and 13) for RT compared to RTPO and seven of the 16 channels (1, 3, 4, 8,12, 13, and 15) for RTP compared to RTPO showed significant differences (p<0.05). Frontal lobe activation was highest for RTPO. Further, activation increased in all channels in the right hemisphere (channels 1, 2, 3, 4, 5, 6, and 7), while it did not in some channels in the left hemisphere (channels 10,12,13,15, and 16) (Figure 6).

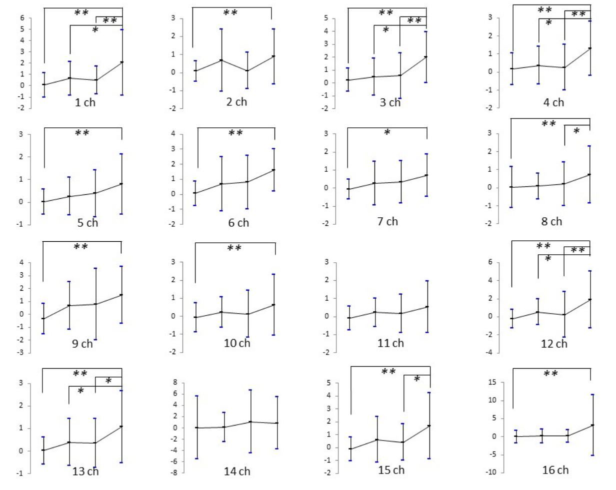

Figure 6: Showing 1-16 channels activity during right turn.

Lane change

Regarding LC, when the Baseline frontal-lobe activation was compared to LC60 and LC80, significant differences were found for channel 3 between the baseline and LC and for channel 6 between LC and LC60 (Figure 7).

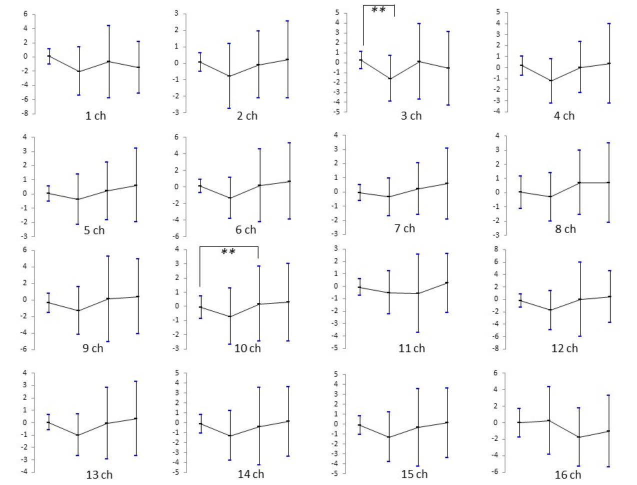

Figure 7: Describing lane change channels activity.

Discussion

Differences in frontal-lobe activation during left turns, right turns, and lane changes

Regarding LT, a significant difference was found between the baseline frontal-lobe activation and LTO with significantly higher frontal lobe activation in LTO. For RT, a significant difference between the baseline and RTPO was seen. The situational characteristics of LTO and RTPO included multiple tasks, which exceeded ordinary driving. In LTO, it was necessary to be mindful of pedestrians on the left, moving from behind to the side and to direct attention. For RTPO, in addition to a RT, it was necessary to be mindful of pedestrians moving at different speeds as well as of oncoming cars. According to Solberg et al. [14] attention involves various functions including sustaining attention, selecting one from among several stimuli, and simultaneously directing attention to two or more tasks. It has been reported that frontal and parietal lobe functions are essential in the process of directing attention to two or more tasks. Bogdanov et al. [15] reported that the function of the frontal lobe is to control attention, immediate decisions regarding emerging stimuli, and executive function. From the above, it is considered that LTO and RTPO are conditions under which attention is simultaneously directed to two or more tasks. Similarly, Manard et al. [16] reported increased activation in the prefrontal area when they implemented a dual task and examined brain activity with fMRI. Szameitat et al. [17] also reported increased activation in the middle frontal gyrus when implementing a dual task. From the above, it is considered that these tasks can more easily induce frontal-lobe activation than driving alone or executing simple left and RTs. These results showed that simply driving or turning left or right cannot efficiently induce frontal-lobe activation. Further, introducing two or three tasks such as pedestrians or oncoming cars into a left or RT increases frontal-lobe activation, suggesting that these may lead to improved attention and it is considered that they could perhaps be implemented in a rehabilitation program aiming at helping patients resume driving.

Citation: Sawada Y, Tanemura R, Fujii M, Goshi K, Matsunaga K (2018) Frontal-Lobe Activation in Healthy Adults Using A Driving Simulator. Int J Phys Med Rehabil 6: 491. doi:10.4172/2329-9096.1000491

In contrast, the fact that a significant difference was not obtained with LCs could be explained as follows; in addition to only checking in primarily one direction (only the right side), the operation only requires turning the steering wheel slightly to the right; compared to a left or RT, an LC is simple.

Left- and right-hemisphere differences

In this study, fNIRS measurements were obtained for the right hemisphere from channels 1 to 7 and for the left hemisphere from channels 10 to 16. For LTO and RTPO, the LT and RT conditions, in which frontal-lobe activation was significantly increased, activation increased in all channels from 1 to 7, but it did not in some channels from 10 to 16. In addition, it is thought that the part of the same brain region of the frontal lobe was activated by both the left turn and the right turn while driving by this result. As represented by unilateral spatial neglect, the right hemisphere is essential for the attentional aspect of visual perception and directed attention. Conversely, the left hemisphere primarily controls verbal functions. Mesulam et al. [18] proposed a concept of directed attention in which the right hemisphere directs bilateral spatial attention, while the left hemisphere directs only right spatial attention. The symptom of unilateral spatial neglect, in which left spatial neglect occurs due to injury to the right hemisphere, is offered as a disorder representative of this. Janssen et al. [19] reported that a phenomenon occurs in patients who have had the right frontal lobe removed in which they fail to notice food on the left when eating, suggesting the importance of the right hemisphere in directed attention. From the above, it is hypothesized that the reason why a significant difference was widely seen in channels 1 to 7 in the present study while a significant difference was not always seen in channels 8 to 16 is due to the effects of directed attention.

The DS we developed is easily and cheaply available compared with a commercially available thing. Therefore, the DS can be conveniently used every day at the hospital. In a clinical setting, the patient can use the DS to practice LTP and RTPO scenarios. We expect that such practice using the DS will lead to improvements in driving skill and cognitive impairments.

Research Limitations

In this study, we recorded frontal lobe activation during the implementation of DS using fNIRS. From the results, it is considered that frontal lobe activation increases under several conditions. However, the subjects think small with 26 volunteers in this study. Therefore we must consider whether we increase subject in future. And this study only used LT, RT, and LC conditions. When actually driving, there are other factors such as the sudden appearance of cars or people, the presence of traffic lights, and multiple intersections. Further, in the course used in this study, visibility was good, and it cannot be denied that the course was easy to drive. In the future, the number of DS courses and tasks should be increased. Compared to methods such as fMRI, fNIRS analysis methods and interpretation of the result are much less established. This is recognized as a challenge that should also be examined in the future.

Conclusion

We examined frontal lobe activation in healthy adults driving in a DS. It was found that frontal lobe activation significantly increased as per the different LT and RT conditions. It is hypothesized that these differences are attributable to the effects of multitasking on attention and directed attention. These results suggest that, when a driving simulation is incorporated in programs aiming at helping patients to resume driving, frontal lobe activation may be efficiently increased by adding a pedestrian to a LT or using an oncoming car and a pedestrian in a RT. In the future, it is considered necessary to investigate differences in the effects of the tasks and the effects of driving itself on patients with cognitive impairments.

Acknowledgements

In producing this research, we would like to thank the healthy volunteers who participated in the driving simulation.

Conflict of Interest

The authors declare no conflicts of interest associated with this manuscript.

References

1. Reger MA, Welsh RK, Watson GS, Cholerton B, Baker LD, et al. (2004) The relationship between neuropsychological functioning and driving ability in dementia: a meta-analysis. Neuropsychol 18: 85-93.
2. Schanke AK, Sundet K (2000) Comprehensive driving assessment: Neuropsychological testing and on road evaluation of brain injured patient. Scand J Psychol 41: 113-121.
3. Formisano R, Bivona U, Brunelli S, Giustini M, Longo E, et al. (2005) A preliminary investigation of road traffic accident rate after severe brain injury. Brain Inj 19: 159-163.
4. Walter H, Vetter SC, Grothe J, Wunderlich AP, Hahn S, et al. (2001) The neural correlates of driving. Neuroreport 12: 1763-1767.
5. Schweizer TA, Kan K, Hung Y, Tam F, Naglie G, et al. (2013) Brain activity during driving with distraction: an immersive fMRI study. Front Hum Neurosci 7: 53.
6. Calhoun VD, Pekar JJ, McGinty VB, Adali T, Watson TD, et al. (2002) Different activation dynamics in multiple neural systems during simulated driving. Hum Brain Mapp 16: 158-167.
7. Campagne A, Pebayle T, Muzet A (2004) Correlation between driving errors and vigilance level: influence of the driver's age. Physiol Behav 80: 515-524.
8. Graydon FX, Young R, Benton MD, Genik RJ 2nd, Posse S, et al. (2004) Visual event detection during simulated driving: identifying the neural correlates with functional neuroimaging. Transport Res Part F: Traffic Psychol Behav 7: 271-286.
9. Hsieh L, Young RA, Bowyer SM, Maran JE, Genik RJ 2nd, et al. (2009) Conversation effects on neural mechanisms underlying reaction time to visual events while viewing a driving scene: fMRI analysis and asynchrony model. Brain Res 1251: 162-175.
10. Bédard MB, Parkkari M, Weaver B, Riendeau J, Dahlquist M (2010) Assessment of driving performance using a simulator protocol: Validity and reproducibility. Am J Occup Ther 64: 336-340.
11. Lengenfelder J, Schultheis MT, Al-Shihabi T, Mourant R, DeLuca J (2002) Divided attention and driving: a pilot study using virtual reality technology. J Head Trauma Rehabil 17: 26-37.
12. Cyr AA, Stinchcombe A, Gagnon S, Marshall S, Hing MM, et al. (2009) Driving difficulties of brain-injured drivers in reaction to high-crash-risk simulated road events: a question of impaired divided attention? J Clin Exp Neuropsychol 31: 472-482.
13. Kazuaki Goshi, Masaki Hayashi, Katsuya Matsunaga (2012) Safe Driving Education System ASSIST-Education Anywhere, Anytime. 2012 9th International Conference on Ubiquitous Intelligence and Computing and 9th International Conference on Autonomic and Trusted Computing 4-7.
14. Sohlberg MM, Mateer CA (1987) Effectiveness of an attention-training program. J Clin Exp Neuropsychol 9: 117-130.

15. Bogdanov M, Schwabe L (2016) Transcranial stimulation of the dorsolateral prefrontal cortex prevents stress-induced working memory deficits. J Neurosci 36: 1429-1437.

16. Manard M, François S, Phillips C, Salmon E, Collette F (2017) The neural bases of proactive and reactive control processes in normal aging. Behav Brain Res 320: 504-516.

17. Szameitat AJ, Schubert T, Müller K, Von Cramon DY (2002) Localization of executive functions in dual-task performance with fMRI. J Cogn Neurosci 14: 1184-1199.

18. Mesulam MM (1981) A cortical network for directed attention and unilateral neglect. Ann Neurol 10: 309-325.

19. Janssen LK, Duif I, van Loon I, Wegman J, de Vries JHM, et al. (2017) Loss of lateral prefrontal cortex control in food-directed attention and goal-directed food choice in obesity. Neuroimage 146: 148-156.