Investigating the Relationship between Assisted Driver's SoA and EEG

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Abstract— **It is important to evaluate and maintain driver's sense of agency (SoA), because poor SoA of assisted driver may result in slow and inaccurate response in case decisions are required from the driver. This study investigated the relationship between SoA and alpha-band power of EEG in a simulated driving environment.**

I. INTRODUCTION

WHILE driving assistence is expected to reduce the number of traffic accidents, the assisted driver may feel less control over the vehicle. In other words, they may lose a sense of agency (SoA) over the vehicle. SoA refers to the subjective feeling of controlling events through one's own behavior [1]. It is reported that one's motor response to an event becomes slower in less SoA conditions [2]. It can be suggested that poor SoA of driver caused by driving assistance may result in slow and inaccurate response in emergency cases. Therefore, it is important to evaluate and maintain the driver's SoA during the assisted driving.

Self-rating with questionnaire has been a major evaluation method of SoA, but it is not suitable for monitoring the driver's SoA continuously without disturbing driving operations. This research focused on electroencephalography (EEG). Prior studies showed that the decrease in the power of alpha band (8 - 13 Hz) over central, parietal, and temporal regions was associated with stronger SoA [3][4].

In the present study, we examined the change in the power of alpha band during assisted driving, when the SoA could be potentially impaired by the driving asssitance. We hypothesized that relative power of alpha band would be stronger in lower SoA conditions.

II. METHOD

To verify the hypothesis, we designed three driving conditions with different SoA, and compared driver's EEG signals and SoA rating among these conditions. During experiment using a driving simulator, the speed of vehicle was fixed to 60 km/h and the participants were instructed to keep the vehicle on the center of the lane by executing steering operation only.

A. Driving Condition

To create driving scenes with different SoA, we designed 3 driving conditions:

(a) no assistance (i.e., self-control)
(b) assisted steering (i.e., assisted)
(c) automated steering (i.e., automated)

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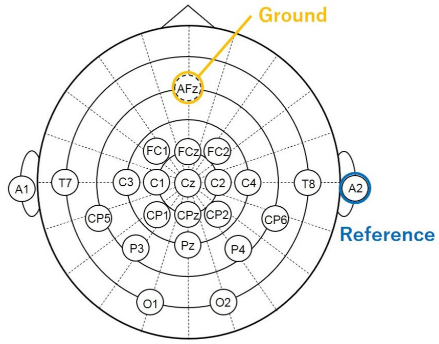

Fig. 1. Electrode position used for EEG measurement.

In the assisted condition, a program assisted the driver by interfering with the steering operation when the vehicle went away from the center of the road. In the automated condition, steering operation was carried out only by the program, and driver's operation did not affect the movement of the vehicle at all.

Participants were not notified about the driving conditions. They were only told that there could be cases in which driving operation did not work well. Each participant did 9 trials in total (3 repeats in each condition). The order of condition during experiment was randomized between participants.

B. Data acquisition and analysis

EEG data were recorded from FC1, FCz, FC2, T7, C3, C1, Cz, C2, C4, T8, CP5, CP1, CPz, CP2, CP6, P3, Pz, P4, O1, O2 according to the extended 10-20 system [5] using g.LADYbird active electrodes with a right earlobe reference and a ground electrode on AFz (Fig. 1). Sampling rate was 512 Hz. EEG during resting state were also recorded in same manner before each trial.

Regarding the EEG analysis, recorded signals were first re-referenced to an average of the left and right earlobes. Then a 7-30 Hz band pass filter was applied. Next, the spectral power of alpha band (8-13 Hz) was computed by applying a wavelet transform to continuous signals from all trials. We defined the relative power as the changes from baseline power and normalized data by dividing relative power by standard deviation of relative power during each trial. The baseline power for each trial was calculated by averaging the alpha band power of resting state before the trial over 20 s.

The relative power during each trial was averaged over 16 time windows. The time windows were defined considering the change of the curvature of the experimental course. The

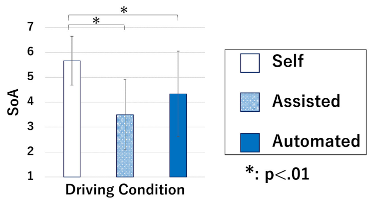

Fig. 2. Averaged SoA rating results of 10 participants in each condition.

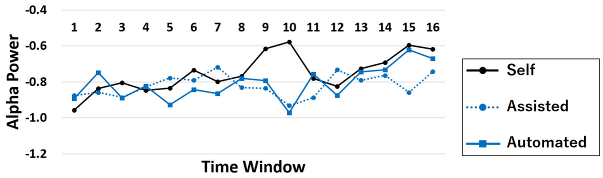

Fig. 3. Alpha power at Cz electrode in each condition.

length of each time windows was not longer than 6 s and there was no overlap between each window.

C. SoA rating

The subjective rating was used to confirm the validity of our experimental design. Following each trial, participants rated their SoA over steering operation during the trial by 7 levels (1: not at all, 7: a lot).

D. Experimental setup

We used a driving simulator composed of CarSim 2017.1, MATLAB Simulink and Logitech G920. EEG data were recorded using active EEG electrode system g.GAMMAsys and g.USBamp. During experiment, participant and devices were coverd by electromagnetic shield.

E. Participants

Ten volunteers (9 men and 1 woman, age: 21.6±0.6) including 2 men without driver's license participated in the experiment.

III. Results

A. SoA rating

The results of the subjective rating showed that the SoA was lower in the assisted and automated conditions, compared with the self-control condition (Fig. 2). The results confirmed our assumption that the SoA would be impaired by the driving assistance, because the program was actually taking a part of control, and the driver was able to perceive the lack of control.

In addition, in the automated condition, the SoA results of five participants were actually comparable with the self-control condition, although their steering operation did not control the vehicle at all. They probably did not notice that the program was taking over the control. Especially, those without driver's license showed such tendency. This may be because that the drivers shared the same goal with the program (i.e., maintaining the vehicle in the center of the lane), and those participants paid more attention to this distal goal rather than each single response of the vehicle [6][7].

B. Power of alpha band

In EEG analysis, two male participants with driver's licenses were excluded from results because of technical problem during the measurement. The averaged EEG results of eight participants showed no significant difference between conditions (Fig. 3), opposing the initial hypothesis. For individual results, while six participants showed significant difference between conditions (ANOVA, $p < 0.05$), they had different tendencies.

The EEG results showed that during the driving scene, the relation between the alpha band power and the SoA may be more complicated than the simple paradigms used in prior research [3][4]. First, some drivers detected the assistance of the computer and reported the lack of control, while some other drivers shared the "joint-control" with the program in the driving task and maintained the SoA [8]. Second, the alpha band power is also related to computational demands and task difficulty [9][10].

Therefore, during continous long trials, it might be influenced by how the participants involved in the task, and how difficult/easy they found the task, which might be affected by their driving skill. Nevertheless, although we did not find direct correlation between driver's SoA and change in the alpha band power, we indeed observed the change of alpha band power in some of the assisted driving conditions. In future research we will further control the driving difficulty (e.g., curing vs straight road), and use exploration approach to find out the link between SoA and EEG signals.

References

[1] P. Haggard, "Sense of Agency in the Human Brain," Nature Reviews Neuroscience, Vol. 18, Issue 4, pp. 197-208, 2017.
[2] M. R. Longo and P. Haggard, "Sense of Agency Primes Manual Motor Responses," Perception, Vol. 38, pp. 69-78, 2009.
[3] W. Wen, A. Yamashita and H. Asama, "Measurement of the Perception of Control during Continuous Movement using Electroencephalography," Frontiers in Human Neuroscience, Vol. 11, Article 392, 2017.
[4] S. Y. Kang, C-H. Im, M. Shim, F. B. Nahab, J. Park, D-W. Kim, et al. "Brain Networks Responsible for Sense of Agency: An EEG Study," PLOS ONE, Vol. 10, Issue 8, e0135261, 2015.
[5] "American Electroencephalographic Society Guidelines for Standard Electrode Position Nomenclature," Journal of Clinical Neurophysiology, Vol. 8, pp. 200-202, 1991.
[6] W. Wen, A. Yamashita and H. Asama, "The influence of goals on sense of control. Consciousness and Cognition," Consciousness and Cognition, Vol. 37, pp. 83-90, 2015.
[7] A. Van der Weiden, K. I. Ruys and H. Aarts, "A matter of matching: How goals and primes affect self-agency experiences," Journal of Experimental Psychology: General, Vol. 142, Issue 3, pp. 954-66, 2013.
[8] J. A. Dewey, E. Pacherie, and G. Knoblich, "The phenomenology of controlling a moving object with another person," Cognition, Vol. 132, Issue 3, pp. 383-397, 2014.
[9] F. Boiten, J. Sergeant and R. Geuze, "Event-related desynchronization: the effects of energetic and computational demands," Electroencephalography and Clinical Neurophysiology, Vol. 82, Issue 4, pp. 302-309, 1992.
[10] K. Dujardin, J. L. Bourriez and J. D. Guieu, "Event-related desynchronization (ERD) patterns during memory processes: effects of aging and task difficulty," Electroencephalography and Clinical Neurophysiology, Vol. 96, Issue 2, pp. 169-182, 1995.