# A Preliminary Evaluation of Comfortable Arousal using Biological Information Measurement for Autonomous Driving

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**Abstract**: Safety and comfort are important for autonomous driving. As for safety, it is important to prevent accidents due to arousal level decrement. Therefore, a mechanism to increase and maintain arousal level is needed. In order to achieve comfort, the increment of the arousal should be in a comfortable state. Previously, there was an evaluation of the state during driving using EEG and heart rate variability, but no evaluation of comfortable arousal. In this research, we examined the method of detecting the state when the increment of arousal changes to a comfortable state from physiological indexes of EEG and heart rate variability. As a preliminary experiment, we measured brainwave and heart rate at the drowsiness and awakening states. Then, we performed correlation analysis between arousal index as well as the comfort index and the subjective evaluation results. As the result, our four proposed indexes are candidates of estimating comfort and arousal.

**Keywords**: Autonomous driving, Comfortable arousal, Biological information, EEG, Pulse sensor

## 1. Introduction

In recent years, autonomous driving systems are developing toward safety and prevention of accidents. Society of Automotive Engineers (SAE) defines six levels of driving automation, ranging from no automation to full automation [1]. In conditional automation (level 3), the autonomous driving system requires a change of driving mode from autonomous to manual driving. At the level, the drivers have to change their conditions from relaxation to arousal. Hirose et al., reported that the automation relieves the driver from driving tasks, which can cause drowsiness [2]. If the drowsiness or decreasing arousal occurs while the driver is taking over to control the vehicle, it can lead to accidents. Thus, it is necessary to raise arousal level to be high enough to satisfy safe driving. Moreover, we need to consider the emotional state of the driver that affects the driving performance. H. Cai described that different emotional states affected to different driving performance; the anger and excitement state of the drivers showed poorer lane control capability than neutral states [3]. Therefore, it is important to consider the emotional state of the driver when raising the arousal level at takeover. The emotional state, especially without anger and excitement, is comfortable state. Therefore, we define the high arousal and comfortable state as comfortable arousal.

Several studies presented methods to measure the arousal level with biological sensors. However, few studies focused on the comfortable arousal in driving. Hayashi et al. suggested the possibility to estimate the involuntary state while driving using brainwave signal and heart rate variability (HRV) that are generally used for measuring the change of emotional states in driving situation [4]. However, their emotion estimation method have not been discussed as arousal and comfort indexes.

Therefore, we propose to examine indexes to measure the comfortable arousal states while driving using the brainwave and heart rate variability. We compare the biological indexes that can evaluate such states effectively. However, it is unclear which indexes are more appropriate to be used for evaluating awakening and drowsiness. Therefore, this study also employed subjective evaluation method using Self-Assessment Manikin (SAM), to collect emotion evaluation result from subjects.

The organization of paper is as follows: Section 2 describes our evaluation indexes, Section 3 describes our experiment and discussion, and Section 4 concludes our study.

## 2. Evaluation Indexes

We used indexes from brainwave and pulse sensors to measure involuntary state while driving. Details are described as follows:

### 2.1 Arousal indexes

To measure the arousal state, we used Electroencephalogram (EEG) as it can measure the brainwave with high time resolution and non-invasive manner. The arousal state is mainly measured by the several power spectrums and their combination indexes from brainwave signals as shown in Table 1.

Table 1 Arousal indexes

| Brainwave type | Frequency range | Mental state |
|---|---|---|
| θ wave | 4-7Hz | Fantasy, imaginary, dream |
| α wave | 8-12Hz | Relaxed, peaceful, conscious |
| β wave | 13-30Hz | Thinking, awareness, Alert, upset, frustrated |
| Attention | - | Concentration |
| Meditation | - | Relaxation |
| α wave appearance rate [5] | - | High α wave appearance rate, low arousal |
| α/β [6] | - | High α/β, low arousal. |
| Attention-Meditation [7] | - | High Attention-Meditation, high arousal |

### 2.2 Comfort indexes

We used the heart rate variability (HRV) as it is generally used to comprehend the autonomic nervous system. The pNN50 index was calculated by time analysis of HRV obtained from the RR intervals. We used pNN50 to measure the comfortable state. The higher pNN50 value indicates the higher comfortable state.

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### 2.3 Subjective evaluation

We used SAM scale that is a non-verbal method, avatars with different facial expressions, to evaluate emotional states regardless of languages. Awakening state (arousal) and Comfortable state (valence) were evaluated on a scale of 1 (lowest) to 9 (highest). The subjects evaluated their emotions by selecting an item that expressed closest to their feelings [8]. Then the evaluation result was used to verify the biological indexes.

## 3. Experiment

### 3.1 Experimental setup and procedure

In our experiment, we measured the brainwave and heart rate in the awakening and drowsiness states. Then, we compared them to the SAM evaluation using correlation analysis to verify arousal and comfort indexes as described in the previous section.

During the experiment, the subjects wore brainwave sensor (NeuroSky Mindwave Mobile2) and pulse sensor (Switch Science) to measure brainwave and heart rate while they were watching driving video in awakening and drowsiness states. The SAM was output periodically while the subjects were watching the driving video to evaluate their emotional states at the moment.

Drowsiness state was defined when subjects felt sleepy. Awakening state was defined when subjects were not sleepy at all. Experiment was performed during those two states by the following procedure:

(1) Wear the brainwave and pulse sensors.
(2) Rest for 60 seconds and answer SAM scale.
(3) Watch the driving video for 300 seconds and answer SAM scale every 60 seconds.
(4) Rest for 60 seconds and answer SAM scale.

### 3.2 Experimental results

The subjects were three men in their twenties. The correlation results are shown in Tables 2 to 5. There were no significant correlations between arousal index and SAM results for all subjects. However, at awakening state, Subject 3 had a correct correlation. At drowsiness state, Subject 2 had a correct correlation. Subject 1 had a correct correlation at both states.

Table 2 Correlation coefficient between arousal index and SAM results (arousal) at awakening state

| | Subject 1 | Subject 2 | Subject 3 |
|---|---|---|---|
| α wave appearance rate | 0.094 | 0.3 | **-0.468** |
| α/β | 0.13 | -0.565 | **-0.593** |
| Attention-Meditation | -0.125 | -0.274 | **0.627** |

Table 3 Correlation coefficient between arousal index and SAM results (arousal) at drowsiness state

| | Subject 1 | Subject 2 | Subject 3 |
|---|---|---|---|
| α wave appearance rate | 0.234 | **-0.468** | -0.091 |
| α/β | 0.157 | **-0.593** | 0.015 |
| Attention-Meditation | 0.482 | **0.627** | -0.245 |

Table 4 Correlation coefficient between comfort index and SAM results (valence) at awakening state

| | Subject 1 | Subject 2 | Subject 3 |
|---|---|---|---|
| pNN50 | **0.915**** | 0.16 | -0.5 |

Table 5 Correlation coefficient between comfort index and SAM results (valence) at drowsiness state

| | Subject 1 | Subject 2 | Subject 3 |
|---|---|---|---|
| pNN50 | **0.772*** | -0.5 | -0.494 |

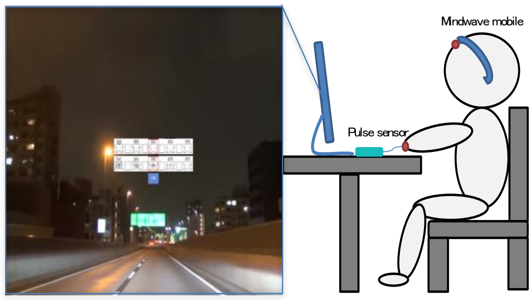

Fig. 1 Experimental environment

## 4. Discussion

The experimental results show the tendency of using our proposed indexes to estimate comfort (pNN50) and arousal (α wave appearance rate, α/β, Attention-Meditation). However, some subjects were not accustomed to the SAM evaluation method and had difficulty to select the avatars that fit their emotions, which might cause inaccurate results. In addition, we only performed experiment with three subjects. We need to improve the evaluation method to be more accurate as well as increase the number of subjects in our future work.

## 5. Conclusion

In this study, we performed preliminary experiment to examine the comfortable arousal indexes at each of the arousal and drowsiness states using brainwave and HRV. Our experimental result indicates that the four indexes are candidates of estimating comfort and arousal. However, due to the inconsistency of result among subjects, future work will improve the evaluation method.

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