 DOI:10.3217/978-3-85125-260-6-110

# Classification of Auditory Steady-State Responses Incorporating Alpha Waves

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***Abstract.*** We attempted to incorporate alpha waves in an auditory steady-state response (ASSR)-based classification problem. With eight subjects, the proposed system achieved an average classification accuracy of 90 ± 5.65% for a binary classification problem. The average information transfer rate was 6.37 bits/min.

*Keywords:* EEG, Auditory Steady-State Responses (ASSR), Alpha Waves, Common Spatial Patterns (CSP), Linear Discriminant Analysis

## 1. Introduction

While many brain-computer interface (BCI) systems are based on EEG arising from visual stimuli, another possible approach is to use auditory stimuli. Since auditory-based BCIs do not involve visual stimuli, they could be used by subjects who are unable to control their eyeball movements. [Kim et al., 2011] built such a BCI system and demonstrated high classification accuracy provided that the signal window sizes are reasonably long (10-20 s), whereas the accuracy with shorter window sizes (~5 s) degraded. In the work described in this paper, we attempted to improve the classification accuracy of a short-time ASSR-based classification problem by incorporating alpha waves, in addition to EEG power spectra of the stimulation frequencies.

Alpha waves are defined as brain waves in the frequency range of 8-13 Hz. There are several theories explaining the causes of alpha oscillations. One of them is memory scanning [Klimesch et al., 2007], and another is paying attention to a certain auditory stimulus [Müller and Weisz, 2012]. [Kelly et al., 2005] report that alpha band features improved classification accuracy in a steady-state visual evoked potential (SSVEP)-based classification problem.

## 2. Experiments

### 2.1. Experimental setup

To evaluate our proposed method, we used EEG signals recorded from eight healthy participants (5 male, 3 female; 20-24 years old). The Ethics Committee of Waseda University approved this experiment. EEG data were recorded at a sampling frequency of 500 Hz with five active electrodes (Fz, Cz, C3, C4, and Pz) according to the international 10-20 system. Each subject was seated in a comfortable chair with their eyes closed and provided with stimulus sounds. The sounds were amplitude modulated (AM) ones (left: 2500 Hz carrier modulated by 37 Hz; right: 1000 Hz carrier modulated by 43 Hz).

In each experimental trial, first the subject was played a 2 s indicated sound that he or she was expected to attend to later. Second, the subject listened to both left and right sounds for 5 s and attempted to attend to the indicated sound. Finally, the sounds were stopped, and the subject rested for 2 s to prepare for the next trial. Each subject completed 60 trials with loudspeakers and another 60 trials with headphones. In total, there were 480 data for the loudspeakers and another 480 for the headphones.

### 2.2. Algorithm

Our algorithm consisted of three steps.

Step 1: For each electrode, four band-pass filtering processes were performed on the raw EEG data with the following pass-bands:

(i) alpha band 1: 8-10 Hz, (ii) alpha band 2: 10-13 Hz, (iii) stimulus signal band 1: 36.9-37.1 Hz, (iv) stimulus signal band 2: 42.9-43.1 Hz

Step 2: The outputs from Step 1 were fed into a common spatial pattern (CSP) filter [Blankertz et al., 2008].

Step 3: Classification was performed by linear discriminant analysis (LDA) [Bishop, 2006].

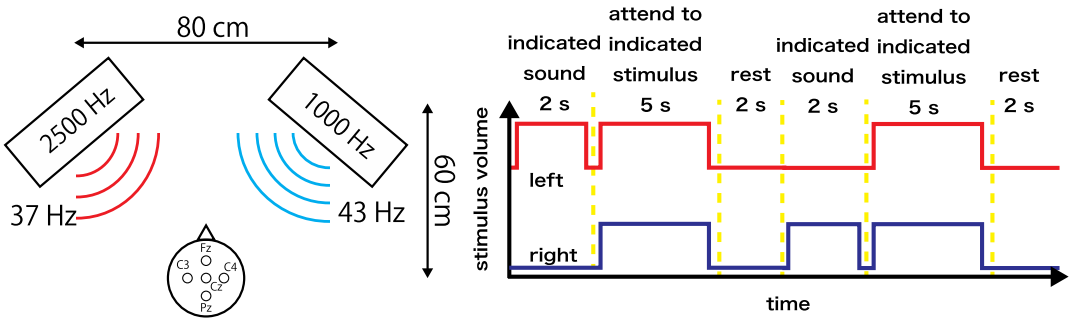


***Figure 1.*** *The experimental set-up. Shown on the left are the positions of the subject and the equipment. The right figure shows the time-series stimulus signals.*

## 3. Results

Leave-one-out cross validation was performed, and the results are summarized in Table 1. The table also makes a comparison with the results of [Kim et al., 2011].

***Table 1.*** *Classification accuracies.*

| *Method* | *Accuracy for the 8 subjects* | | | | | | | | *Average Accuracy [%]* | *Standard Deviation [%]* |
|---|---|---|---|---|---|---|---|---|---|---|
| | *A* | *B* | *C* | *D* | *E* | *F* | *G* | *H* | | |
| Proposed method with headphones | 85.0 | 93.3 | 83.3 | 100 | 83.3 | 91.7 | 95.0 | 88.3 | 90.0 | 5.65 |
| Proposed method with loudspeakers | 95.0 | 85.0 | 68.3 | 93.3 | 70.0 | 88.3 | 86.7 | 88.3 | 84.4 | 9.31 |
| [Kim et al., 2011] | | | | | | | | | 74.0 | 4.76 |

The average information transfer rates (ITR) were 6.37 bits/min with the headphones and 4.50 bits/min with the loudspeakers. The proposed method outperformed [Kim et al., 2011] (accuracy: 74.0%; ITR: 2.08 bits/min) at least in this experiment ($p < 0.001$ with headphones, and $p < 0.05$ with loudspeakers).

## 4. Discussion

We have proposed a new method for ASSR-based classification problems by incorporating alpha wave information. The average accuracy with eight subjects was 90 ± 5.65%, which outperformed previous work reported in the literature. The average information transfer rate was 6.37 bits/min. In future work, it will be interesting to elucidate the reasons why incorporating alpha waves resulted in improved classification accuracy.

### References

Bishop CM. Pattern Recognition and Machine Learning. Springer, 2006.

Blankertz B, Tomioka R, Lemm S, Kawanabe M, Müller K-R. Optimizing spatial filters for robust EEG single-trial analysis. *IEEE Sig Proc Mag*, 25(1):41-56, 2008.

Kelly SP, Lalor EC, Reilly RB, Foxe JJ. Visual spatial attention tracking using high-density SSVEP data for independent brain-computer communication. *IEEE Trans Neural Syst Rehabil Eng*, 13(2):172-178, 2005.

Kim DW, Hwang HJ, Lim JH, Lee YH, Jung KY, Im CH. Classification of selective attention to auditory stimuli: toward vision-free brain–computer interfacing. *J Neurosci Meth*, 197(1):180-185, 2011.

Klimesch W, Sauseng P, Hanslmayr S. EEG alpha oscillations: the inhibition-timing hypothesis. *Brain Res Rev*, 53(1):63-88, 2007.

Müller N, Weisz N. Lateralized Auditory Cortical Alpha Band Activity and Interregional Connectivity Pattern Reflect Anticipation of Target Sounds. *Cereb Cort*, 22(7):1604-1613, 2012.