Analysis of EEG spectral amplitudes during ambiguous information processing

Alexander Kuc
Neuroscience and Cognitive Technology Laboratory, Center for Technologies in Robotics and Mechatronics Components
Innopolis University
Innopolis, Republic of Tatarstan, Russia
kuc1995@mail.ru

***Abstract*—We analyzed the dynamics of EEG spectral amplitudes in α– and β–frequency bands during ambiguous visual stimuli processing. As a result, we described differences in the cortical activity during the processing of visual stimuli with high and low ambiguity.**

***Index Terms*—the Necker cube, wavelet transformation, neural activity, visual stimuli, cognitive activity**

I. Introduction

Analysis of neural activity in the human brain during sensory information processing is an essential task in the neuroscience. Understanding cortical activity mechanisms during visual processing will not only complement fundamental knowledge about the functioning of the human brain but also help in the development of systems for monitoring the brain state and improve the processing performance [1]–[3].

Here we analyzed EEG spectral amplitude in the α- and β-frequency ranges during visual information processing. We introduced ambiguous visual stimuli with different ambiguity degrees and described differences of cortical activity features during high and low ambiguity stimuli processing [4]–[6].

II. Method

Twenty healthy subjects, between the ages of 26 and 35 with normal or corrected-to-normal visual acuity participated in the experiments.

The Necker cube was used as a visual stimulus [7]. We demonstrated Necker cubes with varying visual interpretation ambiguity, depending on the contrast of the three middle lines of the cube. Similarly to our recent work [8], all stimuli were divided into two groups. The first group included low-ambiguity (LA) stimuli - Necker cubes with a visible orientation. The second group included high-ambiguity (HA) stimuli - bistable images of Necker cubes.

We analyzed EEG spectral power in α- and β-frequency bands, using continuous wavelet transformation [9]. The wavelet power spectrum $E^n(f,t) = (W^n(f,t))^2$ was calculated for each EEG channel $X_n(t)$ in the frequency range $f \in [1, 30]$ Hz including both α and β ranges. Here, $W^n(f,t)$ is the complex-valued wavelet coefficients calculated as

$$W^n(f,t) = \sqrt{f} \int\limits_{t-4/f}^{t+4/f} X_n(t)\psi^*(f,t)dt, \qquad (1)$$

where $n = 1, ..., N$ is the EEG chanel number ($N = 31$ is the total number of chanels used for the analysis) and "*" defines the complex conjugation. The mother wavelet function $\psi(f,t)$ is the Morlet wavelet which is defined as

$$\psi(f,t) = \sqrt{f}\pi^{1/4}\mathrm{e}^{j\omega_0 f(t-t_0)}\mathrm{e}^{f(t-t_0)^2/2}, \qquad (2)$$

where $\omega_0 = 2\pi$ is the wavelet parameter.

For α- and β-frequency bands the wavelet amplitudes $E^n_\alpha(t)$ and $E^n_\beta(t)$ were calculated as

$$E^n_{\alpha,\beta}(t) = \frac{1}{\Delta f_{\alpha,\beta}} \int\limits_{\Delta f_{\alpha,\beta}} E^n(f',t)df', \qquad (3)$$

where $\Delta f_\alpha = 8 - 12$ Hz, $\Delta f_\beta = 15 - 30$ Hz. In order to neglect the changes of the overall EEG signal amplitude, the values (3) were normalized to the EEG spectral amplitude in the 1-30 Hz frequency band.

The time-series of the wavelet power (3) was calculated for the whole time of the experimental session and then was split into the time segments $\tau^i_{\mathrm{pre}} = 0.5$ s and $\tau^i_{\mathrm{post}} = 0.5$ s, before and after the i-th visual stimulus presentation.

We identified EEG channels demonstrating a significant increase or decrease in the spectral amplitude of EEG signals during the stimulus processing (τ^i_{post}) in relation to the pre-stimulus state (τ^i_{pre}).

III. Result

Fig. 1 shows the dependence of the number of channels showing an increase or decrease in spectral energy on time for different frequency ranges and the complexity of the visual stimulus.

We used repeated-measures ANOVA to analyze the difference between the number of channels showing an increase or decrease in the spectral amplitude. The change in the amplitude (increase or decrease) and the moment (t) were used as within-subject factors.

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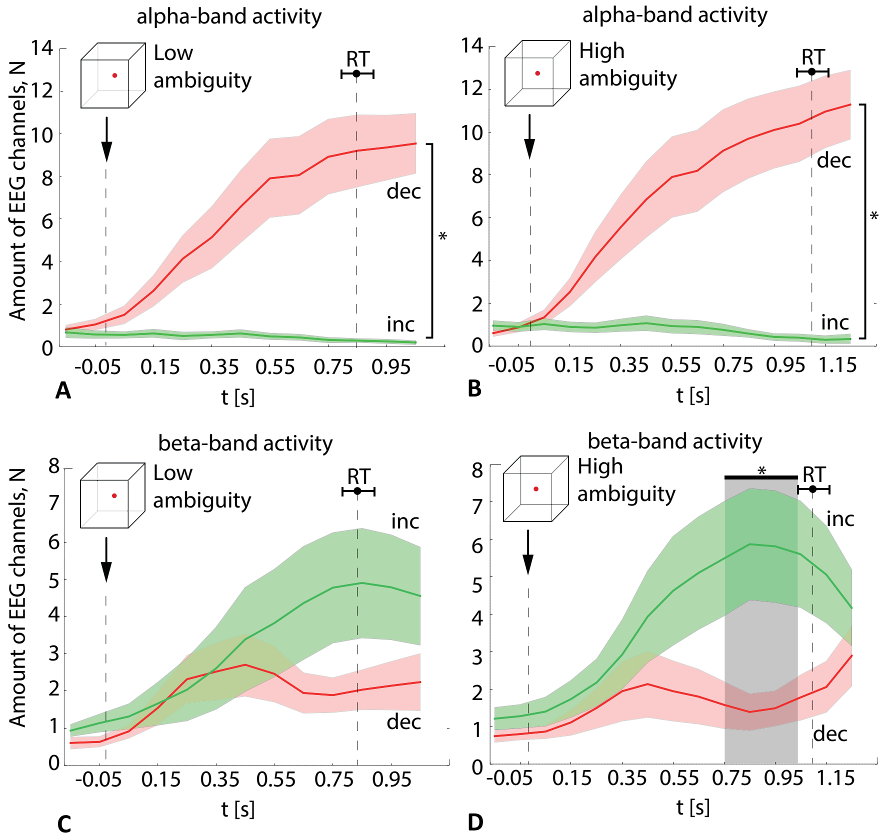

Fig. 1. The number of EEG channels with increasing N_{inc} and decreasing N_{dec} spectral amplitude for the different stimulus ambiguity (LA and HA) and the different frequency band (α and β). Vertical dashed lines indicate the moment of the stimulus presentation and the median response time.

for LA stimuli in the α-frequency range (Fig. 1, a), ANOVA with the Greenhouse-Geisser correction showed a significant difference between N_{dec} and N_{inc} ($F_{1,19} = 18.542, p < 0.001$), as well as between different moments of time ($F_{1.57,29.89} = 20.368, p < 0.001$). In addition, a significant effect was observed for the interaction (change in amplitude*moment of time) ($F_{1.62,30.79} = 21.646, p < 0.001$). It means that during visual stimulus processing, the number of EEG channels that decrease spectral amplitude prevails.

For HA-stimuli in the α-frequency range (Fig. 1, b), ANOVA with Greenhouse-Geisser correction showed a significant difference between N_{dec} and N_{inc} ($F_{1,19} = 17.143, p = 0.001$), between different time points ($F_{17.14}, 31.43 = 21.3, p < 0.001$) and for interaction (change in amplitude*moment of time) ($F_{1.54,29.26} = 24.11, p < 0.001$).

For LA-stimuli in the β-frequency range (Fig. 1, c), ANOVA with Greenhouse-Geisser correction indicated insignificant difference between N_{dec} and N_{inc} ($F_{1.19} = 0.942, p = 0.344$). At the same time, there was a significant effect over time ($F_{2.1,40.0} = 12.266, p < 0.001$).

For HA-stimuli in the β-frequency range (Fig. 1, d), ANOVA showed insignificant difference between N_{dec} and N_{inc} ($F_{1,19} = 2.937; p = 0.103$). At the same time, there was a significant effect for the moment of time ($F_{1.88,35.76} = 12.022; p < 0.001$) and the interaction effect (change in amplitude*moment of time) ($F_{1.51,28.86} = 3.713; p < 0.048$).

IV. Conclusion

Processing both simple and complex visual stimuli is associated with a decrease in the spectral amplitude in the α-frequency range for most EEG channels. We demonstrate that the number of EEG channels showing a reduction of α-band spectral amplitude increases with time during the visual stimulus processing.

Processing of LA stimuli in the β-frequency range is associated with changes in the number of EEG channels with increasing and decreasing amplitudes over time, but there is no difference between them. During HA-stimuli processing, the number of EEG channels with increasing β-band amplitude exceeds the number of EEG channels with decreasing β-band amplitude.

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