Estimating elementary cognitive functions based on EEG signals analysis

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***Abstract*—Human performance in complex mental tasks relies on elementary cognitive abilities, e.g., information processing speed and working memory capacity. These elementary functions can be measured on a behavioral level using elementary tasks, e.g., reaction time and memory scanning tasks. Cognitive and behavioral neuroscience aims to reveal cortical activity features underlying human performance in the elementary cognitive tasks. In this work, we designed a reaction time task based on the processing of ambiguous sensory stimuli. We found a correlation between the task performance on the behavioral level and the sensor-level cortical activity.**

***Index Terms*—EEG signals, Reaction time task, Ambiguous stimuli**

I. Introduction

There is a view that intelligence partly depends on elementary cognitive abilities, such as information processing speed [1]. It can be estimated as the reaction time (RT) to perform elementary cognitive tasks (ECTs) [2]. Different studies demonstrate a linear relationship between the amount of processed information and RT [3]. Another elementary cognitive ability is the short-term memory retrieval rate. It can be estimated using the Sternberg memory scanning task [4], according to which RT increases linearly with the memory set size.

Neubauer and Knorr demonstrated the direct correlation between mental speed and mental abilities (intelligence) 20 years ago based on the paper and pencil test [5]. They showed that more intelligent individuals exhibited lower RT. Nowadays, an exciting task of cognitive and behavioral neuroscience is revealing EEG biomarkers that predict human mental abilities [6].

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With this goal in mind, we analyzed correlations between the reaction times and sensor-level cortical activity of subjects during a sensory processing task.

II. Methods

Participants. We recruited twenty healthy subjects aged 26 to 35 with normal or corrected-to-normal visual acuity to participate in the experiments. All of them provided written informed consent in advance. The experiments were performed under the Declaration of Helsinki and approved by the local Research Ethics Committee of Innopolis University.

Task. Participants responded to visual stimuli presented on a computer screen. Each stimulus was an ambiguous image, Necker cube [7], containing two possible interpretations. The task was to define its interpretation and to press a corresponding key on the joystick. The stimulus presentation lasted for a short interval, varied from 1 to 1.5 s. Each presentation alternated with a 3-5 s exhibition of an abstract picture. The time interval between the beginning of the stimulus presentation and the button pressing defined a reaction time (RT) [8].

EEG recording. We recorded 31 EEG signals using a monopolar 10-10 scheme with two reference electrodes on the earlobes and a ground electrode just above the forehead. The noninvasive cup adhesive Ag/AgCl electrodes were placed on the "Tien–20" paste (Weaver and Company, Colorado, USA). Immediately before experiments, we increased skin conductivity using the abrasive NuPrep gel (Weaver and Company, Colorado, USA). As a result, impedance values varied within a range of 2–5 kΩ.

An Encephalan-EEG-19/26 electroencephalograph (Medicom MTD company, Taganrog, Russian Federation) performed acquisition, amplification, and analog-to-digital conversion of

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the EEG signals. This device had a registration certificate from the Federal Service for Supervision in Health Care, No. FCP 2007/00124, dated 07.11.2014, and European Certificate CE 538571 of the British Standards Institute (BSI).

EEG preprocessing. The raw EEG signals were filtered by a band-pass FIR filter with cut-off points at 1 and 100 Hz and by a 50-Hz notch filter. Eye-blinking and heartbeat artifacts were removed by Independent Component Analysis using EEGLAB software. We segmented EEG signals into 400 trials time-locked to the stimuli presentation. Each trial has a 4 s length, including 2 s prestimulus interval. After the preprocessing procedure, we manually inspected trials and excluded those containing high-amplitude artifacts. As a result, we proceeded with 240 trials out of the initial 400. To define the experimental conditions, we divided the whole session into six non-overlapping fragments ($T_{1...6}$) of the equal length. For each fragment, we selected 40 trials

EEG analysis. We analyzed cortical activity on the EEG sensor level. First, we performed a wavelet analysis of EEG signals in the frequency range 4-10 Hz. The obtained spectral power (SP) was averaged across 40 trials for each experimental condition for each subject. For the stimulus-related interval, we performed baseline correction and considered an event-related spectral perturbation (ERSP). Experimental conditions were contrasted via a nonparametric statistical test based on the cluster-based correction for multiple comparisons and a randomization technique. The number of randomizations was set to 2000. A critical α-level was set to 0.05.

III. Result

Contrasting the prestimulus spectral power between the experimental conditions we observed one significant cluster with $p < 0.05$ in the frequency range $4 - 5.5$ Hz. This cluster included occipital (O1, O2, Oz), left-lateralized parietal (P3, Pz) and left-lateralized centro-parietal (CP3, CPz) EEG sensors (Fig. 1, a). Energy of this cluster increased during the experiment (Fig. 1, b) and did not correlate with the reaction time ($r = -.37, p = .1$) (Fig. 1, c).

Contrasting the stimulus-related spectral power between the experimental conditions we observed one significant cluster with $p < 0.05$ in the frequency range $35.7-39$ Hz. This cluster included left-lateralized parietal (P3, Pz), centro-parietal (CP3, CP4, CPz), left temporal (TP7) and left central (C3) EEG sensors (Fig. 1, a). Energy of this cluster decreased during the experiment (Fig. 1, b) and positively correlated with the reaction time ($r = .52, p = .02$) (Fig. 1, c).

IV. Conclusion

We analyzed the reaction times and the sensor-level cortical activity in the group of subjects during a prolonged reaction time task. As a result, we observed that the power of stimulus-related neuronal activity in $35.7 - 39$ Hz positively correlates with reaction time.

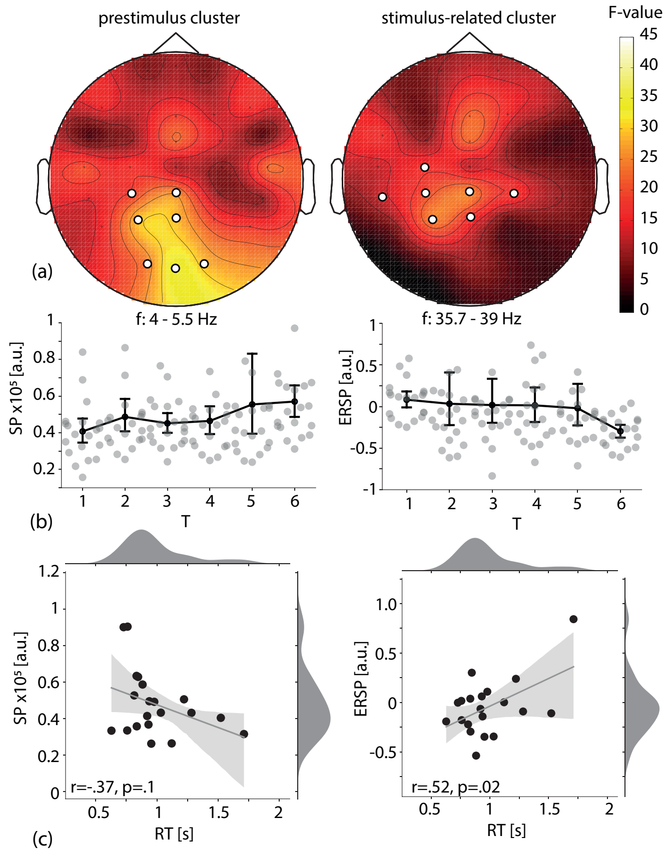

Fig. 1. (a) F-map and EEG sensors cluster representing a significant change of spectral power between conditions $T_{1...6}$. (b) Change of the spectral energy in these clusters (group mean, 95% confidence interval and individual values). (c) Correlation between the cluster's power and reaction time in the group of subjects.

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