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МАТЕРИАЛЫ ЛЕКЦИЙ ШКОЛЫ

BRAIN SYSTEM OF COGNITIVE CONTROL IN MAN

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N.P. Bechtereva Institute of the Human Brain of the RAS, Saint Petersburg, Russia

e-mail: yurykropotov@yahoo.com

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In daily life, we often need to adapt our behavior in unpredictable situations (e.g. Miller, Cohen, 2001). From a "dual mechanisms of cognitive control" hypothesis those adaptive procedures are present in two modes associated with proactive and reactive cognitive control (Braver, 2012).

In research of event-related potentials (ERPs) for disentangling neuronal mechanisms of cognitive control several experimental paradigms have been designed. The most known of them are a task switching paradigm, delayed tasks, inhibition paradigms such as Stop signal task (Logan, 1994) and GO/NOGO task (Simson et al., 1977). ERP studies on proactive cognitive control focused on 1) a late parietal positivity – P3 cue or switch positivity (for review see Karayanidis, Jamadar, 2014), 2) anticipatory-related slow potentials known as the contingent negative variation – CNV (Walter et al., 1964) and 3) the stimulus preceding negativity (SPN) (for review see Brunia, van Boxtel, 2001).

Studies on reactive cognitive control focused on discriminating ERP correlates of conflict detection and action inhibition. The current hypothesis considers the N2 NOGO wave as an index of conflict detection whereas the P3 NOGO wave reflects action inhibition process (Smith, Schmuckler, 2008).

From the predictive coding hypothesis, the human brain operates in a predictive manner and is able to effortlessly generates a pre-potent model of behavior (Picard, Friston, 2014). According to this theoretical view, specific stimuli are mapped onto specific responses and altogether form habitual patterns of behavior – a prepotent model (Isoda, Hikosaka, 2011). The ability to construct the prepotent model makes human and animal life efficient because it liberates restricted resources of cognitive control from the uncountable requirements of routine behavior.

One of the challenges in ERP research is volume conduction – a passive transmission of electrical field trough neuronal tissue from a given electrical current generator. According to the volume conduction a single electrical current dipole produces a potential which critically depends on orientation of the dipole and can be widely distributed (Nunez, 1977). The other challenge in EEG research is an effect of reference electrodes on EEG/ERP pattern (for a recent review see Yao et al., 2019). One way of solving these two problems is converting multi-channel to the current source density (CSD) (Kayser, Tenke, 2010).

The current view considers most of ERP waves as summations of multiple sources distributed over distant cortical areas (Kappenmann, Luck, 2012). Recently, our laboratory developed a new blind source estimation method based on joint diagonalization of covariance matrixes of large collections of individual ERPs (Kropotov, Ponomarev, 2015; Ponomarev, Kropotov, 2013).

In the present paper I am going to talk about our recent study in which we used an advanced technology: 1) an ICA for artifact correction, 2) a current source density montage, 3) a blind source separation method, 4) three modifications of the cued GO/NOGO paradigm for independent modulation of operations of cognitive control in proactive and reactive modes, 5) a large dataset (around 200 subjects) allowing good signal to noise ratio in grand-average ERP and high test-retest reliability in separation latent components.

Those technological developments enabled us to separate sensory-related components and components of proactive and reactive cognitive control.

The two functionally distinct visual-related components include: 1) the occipital component, showing just a transient response to visual stimuli, coding visual category in an early (100–200 ms) package and demonstrating enhancement of response to physical repeated stimuli; 2) the temporal component, showing post-stimulus delayed and pre-stimulus preceding activities, revealing the late package (300–400 ms) in addition to the early package of sensory processing; demonstrating sensitivity to behavioral context during the time window 200–300 ms) between those two packages.

The data are explained as follows. In proactive control the brain constructs a predictive model the sensory world reflected in ERP patterns of delayed and preceding activities. In reactive control the brain compares this model with the current sensory input by generating prediction errors at different levels (physical and semantic) which are exhibiting in the physical and semantic repetition suppression effects (N250) and in the semantic violation effect (N400).

The components of cognitive control include:

The frontal component with the source in local frontal area Fz, Fcz. This component shows a post-stimulus delayed activity (orienting CNV) reflecting a frontally created predictions about forthcoming events, and a transitory N250 response to stimuli that don't match these predictions. The component seems to represent a hub in the anterior cingulate/medial prefrontal cortex that receives inputs form the sensory related components in the context sensitive time window (200–300 Ms) and from the frontal-parietal cognitive control system.

The two components with distinct parietal sources (the parietal – more medial, the parietal central – more lateral) are associated with different hypothetical operations. The parietal central component is related to activation of the cortical-basal ganglia-thalamic-cortical motor-cognitive loop and is reflected in the preparatory activity of proactive control. I reactive cognitive control the transient reactions of the component are reflected in the opponent (push/pull=engage/disengage) responses to GO/NOGO stimuli during 290–370 time window. The parietal component is related to automatic reactivation of sensory-response representations in the dorsal visual stream and is reflected in P400 in both active and passive conditions.

The medial central component is exclusively reactive in NOGO condition and seems to relate to a global inhbition of irrelevant events which is different from a competitive local inhibition effect of the parietal-central component.

The Rolandic component in proactive cognitive control is related to shaping and predicting the plans of possible actions and is expressed in strong negativities reaching extremums (terminal CNV) just before the second stimulus. The Rolandic component in reactive cognitive control is related to reactivation of those plans when the appropriate stimulus is presented and reflected in the strong late positive fluctuations.