PART II

Event-Related Potentials

I. INTRODUCTION

As was presented in Part I different electroencephalogram (EEG) rhythms are characterized by different neuronal mechanisms. These rhythms are observed in resting states with eyes open and eyes closed and are considered to represent background or spontaneous activities. In response to stimuli or movements alpha and beta rhythms are suppressed (desynchronized) during the first 200 ms. These dynamic characteristics of alpha and low beta rhythms in healthy brain indicate that the beta and alpha rhythms themselves do not participate in signal processing per se but rather modulate the information flow in the brain. Here is the right time to stress the difference between two distinct functions in information processing in the brain: (1) the function associated with flow

of sensory-related and action-related information in neuronal networks of the brain, and (2) the function associated with modulation of the information flow. As was shown in Part I of the book, modulation of information flow is manifested in synchronization and desynchronization of EEG rhythms.

The stages of information flow are measured by event-related potentials (ERPs). In contrast to EEG rhythms the necessary condition for eliciting ERPs is time locking to a certain event, either a stimulus or a movement. The tasks that are used to elicit ERPs cover a big variety of human sensory, motor, and cognitive functions. They include various types of detection and recognition tests in different sensory modalities, delayed response tests for measuring working memory, GO/NOGO tests for assessing executive functions and many, many others. Each task is associated with a group of distinct psychological operations such as detection and recognition of stimuli, updating working memory, initiation of action and action suppression, monitoring the results of actions and so on. Each psychological operation in turn involves temporal activation/inhibition pattern of neurons in a certain brain area. The sum of synchronously generated and event-locked postsynaptic potentials is recorded at the scalp in a form of an ERP component – a potential deflection that is spatially localized and temporally confined.

At the early years of ERP studies the components were associated with peaks and troughs on ERPs themselves or on ERPs difference waves. The difference waves were obtained by subtraction of ERPs in a task condition that presumably did not involve a studied psychological operation from ERPs in another task condition that presumably included this operation[1]. Potential deflections at difference waves could be divided into classes on the basis of their latency and direction of deviation (positive or negative)

[1]A simple example of such task could be a threshold recognition task used in one of our studies (Bechtereva and Kropotov, 1984). In this task visual stimuli (digits) were briefly presented to subjects. The exposition of stimuli was individually tailored so short that approximately in 50 per cent of trials the subjects could not recognize the stimuli, while in other 50 per cent of trial they recognized digits. The subjects had to name the digit or to say NO one second later the digit presentation when a trigger stimulus appeared. It was logical to assume that two categories of stimuli ("recognized," "non-recognized") differ from each other by one psychological operation – object recognition and the difference wave between responses to these categories of stimuli would give us a spatial–temporal correlates of this psychological operation.

such as P100, N100, N200, P200, P300, N400, where P stands for positivity, N – for negativity, and the number stands for the peak latency in milliseconds. However, latency of peaks and troughs does not really capture the essence of a component. For example, the peak latency of a so-called P3b component may vary by hundreds of milliseconds depending on the difficulty of the target–non-target discrimination. Even polarity of a certain components may depend on conditions of recording. For example, the C1 wave, which is generated in area V1 of visual cortex, is negative for upper-field stimuli and positive for lower field stimuli due to the folding pattern of area 17 in the human brain.

Another type of classification of components presumes their functional meaning. There are several ERP components that are elicited in certain type of behavioral paradigms and that have specific names according to their presumed function[2].

ERPs method was introduced in cognitive neuroscience more than 40 years ago – in 1960s. The first attempts to decompose ERPs into separate components were made in 1970 by means of factor analysis and principle component analysis. However these techniques provided only orthogonal (in a strict mathematical sense) components, while it was clear that the ERP components had not necessarily to be orthogonal. Recently emerged methods of objective separation of components (such as independent component analysis) lack this disadvantage of old methods and open a new horizon in this field. Accumulating knowledge shows a diagnostic power of independent ERP components as endophenotypes of brain dysfunctions.

This part of the book is devoted to ERP components, their generation, functional meaning, and diagnostic value[3]. We classify components on the basis of their functional meaning. We presume that the ERP components reflect distinct psychological operations carrying out in distinct systems of the brain.

[2]The most studied of them are the mismatch negativity (MMN) as indicator of change detection in repetitive sound, the processing positivity (PN) as indicator of focused attention to a certain sensory channel, error related negativity (ERN) as indicator of errors in continuous performance task, N2 NOGO component as indicator of motor suppression, P3b components as an index of updating the working memory, P3a components as indicator of involuntary switch of attention.

[3]For introduction to the ERP technique I recommend to read a clear written and detailed description of ERPs methods presented in the recently published book by Steven Luck (2005).

II. GLOSSARY

Affective state is a state of the brain characterized by drives, emotions, and motivations.

Agnosia is a condition of a patient who, when faced with a visual object, is unable to name it, show its use, or sort it into a group of morphologically dissimilar objects with identical functions. Shape, color, and movement agnosias are separated.

Amygdala is a nucleus that receives sensory information from polimodal areas of the temporal and parietal cortex through the hippocampus and sends the results of processing to the prefrontal cortex via the thalamus. Its main function is to express fear and initiate associated with fear behavioral reactions.

Anticipating schemata are cognitive structures that prepare the perceiver to accept certain kinds of information rather than others.

Attention, from psychological point of view, is a cognitive mechanism that enables one to process a selected source of sensory information in more detail in comparison to unselected sources by means of limited resources of the brain processor. Attention could be also defined as a state of readiness to receive a certain stimulus – that is, a state for looking forward for a sensory event. In this definition, attention must be separated from motor preparatory set as a state of readiness to make a movement.

Bottom–up processing is the flow of information from lower to higher centers transferring sensory information in a hierarchical manner. These bottom–up processes are usually accompanied by top–down processes in recurrent neuronal networks of the brain, so that separation of bottom–up processing from top–down processing is only of theoretical significance.

Canonical cortical circuit is a hypothetical neuronal network that enables the cortex to perform complex computations of its input. The circuit was first described by Rodney Douglas and Kevan Martin in 1989. The basic idea of the model is that cortical circuits are organized in recurrent excitatory and inhibitory local pathways and that this organization leads to a number of important emergent properties.

Comparison operations are hypothetical operations performed in sensory cortical areas with the goal of detecting any deviation from the anticipatory schemata and adjusting human behavior for those deviations.

An example of such operation in auditory modality is given by the so-called mismatch negativity – a component of ERPs elicited in response to a deviant acoustic stimulus presented at background of repetitive standard stimulus.

Disengagement operation – a process opposite to the engagement operation, which involves inhibition of prepared resources needed for action execution.

Dorsal and ventral streams in the visual system originate in segregated areas of the primary visual cortex of the occipital lobe and target correspondingly temporal and parietal cortical areas. The ventral stream is involved in recognition of separate objects (mostly defined by shape and color) while the dorsal stream is involved in encoding spatial relationships between objects and in controlling actions with those objects such as manipulating with them and orienting toward them.

Emotion is a behavioral response (change in heart rate, facial expression, speech) to a reward (positive emotion), punishment (negative emotion), or images of those behavioral events. Emotion as a psychological entity can be divided into two parts: emotional response and feeling.

Emotional response is defined by somato-sensory (facial and body) responses as well as endocrine responses to emotion-triggered stimuli-rewards and punishers.

Engagement operation is an operation performed by the executive system and involved activation of cortical–subcortical resources needed for action execution. The engagement operation implies the existence of an active process within the brain that exerts disinhibition of cortical neurons that are preset in a recent past to perform a certain action: either motor or cognitive.

Episodic memory is memory for specific events that are temporally dated. It also includes memory for relationships between different events.

ERPs (event-related potentials) brain potentials associated with information flow in the cortical areas evoked by some event (e.g., a repetitive stimulus presenting sequentially during a sensory discrimination task or repetitive flexing a finger during a simple motor task). ERPs are usually obtained by averaging technique that enhances the signal to noise ratio.

Executive functions refer to operations of control and monitoring of motor, sensory, and cognitive actions in goal-directed behavior. These

functions are mostly attributed to frontal lobes however the basal ganglia and some other subcortical structures are necessarily involved.

Explicit memory (that is, conscious memory) is a memory which is stored and retrieved consciously. This type of memory can be acquired during an episode and declared by the subject afterward. It is often is called declarative memory.

Feeling (or emotional feeling) is a subjective experience of the state produced by emotion-triggered stimuli. Examples of emotions are joy and sadness, courage and fear, anger and happiness, love and hate… The cortical center for mapping emotions into separate activation patterns is the orbito–frontal cortex.

Implicit memory is an acquired skill or knowledge that a subject can demonstrate without explicit awareness of it. It is often is called non-declarative memory or procedural memory.

Information processing in the brain is a broad class of transformations of impulse activity of output neurons of the receptive organs (such as retina) to impulse activity and to slower membrane potentials of neurons within different neuronal networks of the brain. In its turn information processing can be divided into two functions: *information flow* and *information modulation*. These two operations are maintained by two different classes of neuromediators: *fast acting mediators* (such as glutamate and GABA) and *slow acting mediators* (such as dopamine, norepinephrine, serotonin, and acetylcholine).

Lateral inhibition is a type of connectivity in neuronal networks in which neurons inhibit the surrounding neurons and thus unable the spreading of activation in the lateral direction. Lateral inhibition was first described in retina of the eye in 1950s. The function of the lateral inhibition in the visual system is to emphasize the highest gradients of luminosity in visual images (such as Mach bands).

Leukotomy is a procedure of psychosurgery by which a leukotome (a special knife) is inserted through the eye socket and the inferior/ventral part of the prefrontal cortex is disconnected from the rest of the brain. This operation was started by a Portuguese neurologist Egas Moniz and was very popular in 1950 until the discovery of anti-psychotic drugs.

Limbic system – the term was coined by Paul Broca to define under the same name a group of structures that form a border around the brain stem. Limbic system plays an important part in emotional reactions.

Long-term potentiation (LTP) is an enduring increase in the amplitude of excitatory postsynaptic potentials as a result of high frequency (tetanic) stimulation of afferent pathways. LTP is considered to be a cellular model of learning and memory.

Memory consolidation at neuronal level is a process of developing irreversible changes in synaptic transmission. At psychological level, memory consolidation is associated with forming of long-term memory which decays very slowly (comparable with a life span).

Monitoring as a new concept defines a hypothetical psychological operation that enables the brain to evaluate the quality of action execution and alerts the executive control mechanisms to allocate resources for compensating the conflict between intended and executed actions.

Motivation is desire or drive that steer the behavior by determining goals.

Motor preparatory set is a cognitive mechanism that enables one to focus on performing a certain motor action while suppressing all other irrelevant actions. It is expressed in preparation to make a movement. Attention and motor preparatory set are elements of working memory.

Negative reinforcer (or punisher) is a stimulus that increases behavior pattern directed to avoid the punisher.

Neglect is a neurological syndrome in which patients with brain lesions show a marked deficit in the ability to attend to sensory information presented in the contralesional field. Neglect is often associated with lesions in the right parietal lobe, however lesions in subcortical structures (such a thalamus, basal ganglia, and superior colliculus) can be also responsible for neglect.

Neuromodulator is a slow acting neuromediator that modulates (slowly changes) the information processing.

Neuronal network is a net of neurons in the brain that maintains a distinct function. In this book we distinguish this concept from the notion of *neural net* that stands for a model of the real neuronal network.

Neurotransmitter is a fast acting neuromediator that provides the flow of information within neuronal networks.

Orbitofrontal cortex is a part of the prefrontal cortex that receives strong inputs from all sensory systems and maps rewards and punishers into separate spatially temporal patterns. Patients with damage of the orbitofrontal cortex (such as famous Phineas Cage) lost the ability to map effectively rewards and punishers and consequently lost their ability to

make appropriate decisions between selecting appropriate rewards and avoiding punishers.

Positive reinforcer (or reward) is a stimulus that increases the frequency of a behavior pattern leading to acquisition of reward.

Priming is the facilitation of recognition, reproduction, or biases in the selection of stimuli that have recently been perceived.

Receptive field of a cell in the sensory system is a discrete area in the extrapersonal space (for vision and audition) and in the intrapersonal space (in somato-sensory modality) where the presentation of a corresponding stimulus causes activation or inhibition of the cell. Stimuli presented outside of this receptive field do not affect activity of the neuron.

Representation is a localized or distributed neuronal network which stores particular information (memory) and when activated, enables access to this information. Representations can be genetically determined or formed during learning.

Scotomas is a loss of visual perception in a local part of the visual field due to a localized damage in the primary visual areas.

Selection operation is a process of activation of a representation. In temporal domain the selection operation seems to be accompanied by synchronous oscillations in theta (4–8 Hz) and gamma (around 40 Hz) frequency bands. These synchronous oscillations form an optimal mode of recall from memory.

Semantic memory is a memory for factual information about the world, concepts, and word meaning.

Sensory modality refers to a sensory system that processes a certain type of receptor information. The most well-studied sensory systems are: visual system (seeing form, color, depth, motion, spatial relationships of visual objects), auditory system (hearing and localizing sounds), somatic sensory or somato-sensory system (feeling touch, pain, thermal sensations, mechanical displacement of muscles and joints).

Sensory systems include receptor organs and subcortical and cortical neuronal networks that specifically respond to activation of the corresponding receptors.

Top–down processing is a flow of information from "higher" to "lower" centers within hierarchy of sensory systems, controlling (modulating)

sensory information processing in lower levels by extracting memories from the higher levels.

Working memory implies an active manipulation with the temporary stored information in order to perform sensory-motor and cognitive actions such as language, planning, decision making, etc.