Electrophysiology of the expectancy process: Processing the CNV potential

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Abstract. This work reports on the development of a research system and on some experiments that were performed in the area of expectancy potentials. In particular we report on obtaining the CNV potential with no motor action. Discussion related to brain-computer interface research is also provided. This work is a partial report on activities carried out within a collaborative research project between Macedonia and Croatia in 2005-2006.

Introduction: CNV as an expectatory brain potential

Electrophysiology is a study of the electrical properties of biological cells and biological systems including organisms. *Neuroelectrophysiology* is part that is interested in electrical properties of neural systems. Various methods ranging from single neural cell potential recording to magnetic properties of the brain were developed. Most frequently used method in neuroelectrophysiology is electroencephalogram (EEG).

EEG is recording of electrical signals from the brain under various conditions. Various electrical potentials were revealed so far and a possible taxonomy of those potentials (e.g., Bozinovska 1997) is shown in Figure 1. As Figure shows brain potentials are divided into spontaneous and event related. Event related potentials (ERPs) are divided into evoked and anticipatory. Evoked potentials appear after an event, for example after a sound signal. Evoked potentials are divided into exogenous and endogenous. Exogenous evoked potentials appear as a reflex response to an event. They possibly represent the sensory reaction to the event. Examples are visual evoked potentials (VEP), auditory evoked potentials (AEP), etc. Endogenous evoked potentials appear after the exogenous. They are cognitive reaction to the event, and possibly represent pattern recognition effort of the brain related to the event. Example is the P300 potential which appears about 300ms after the event.

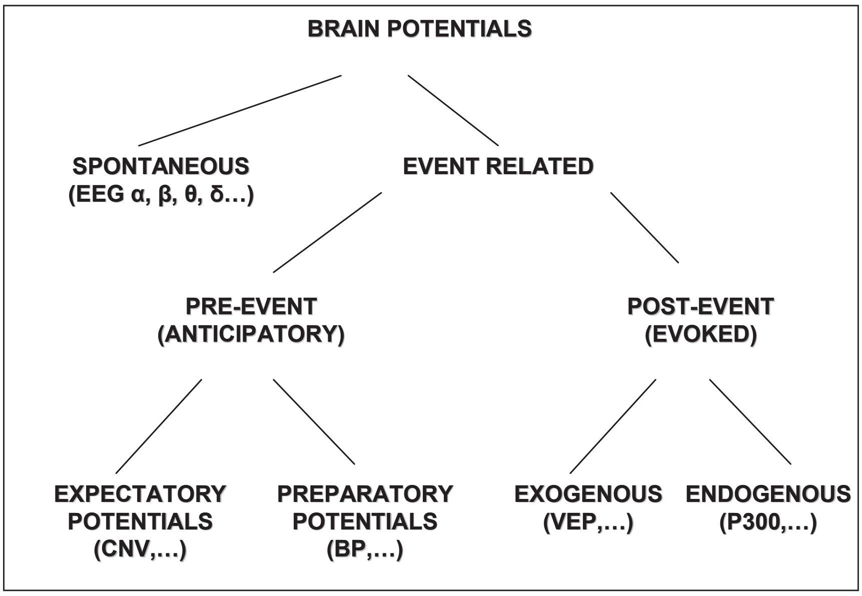

Fig. 1. A taxonomy of brain potentials

Anticipatory brain potentials are divided into expectatory and preparatory. Preparatory potentials are preparation for an action, for example preparation for pressing a piano keyboard; the most well known example is the Beretschaftspotential. Expectatory potentials appear as expectation for some event. The most well known is the Contingent Negative Variation (CNV) potential (Walter et al. 1964) on which this paper focuses.

The CNV potential appears in a CNV experimental paradigm. It is actually a standard reaction time measurement paradigm, in which EEG is measured. Two stimuli are presented to a subject, a warning one, S1, and a imperative one, S2. The first one is short, the second one lasts until the subject stops it by pressing a button. Reaction time (RT) is measured between S2 and pressing the button. If EEG is recorded during this reaction time paradigm, and if ERP is extracted from EEG, a special ERP shape is usually obtained, which is named CNV. Figure 2 shows the CNV potential obtained in our early investigations.

As we can see from Figure 2, the CNV feature is a ramp-like shape between S1 and S2, with ceasing after S2. It is a rather complex potential containing components both exogenous and endogenous components to both S1 and S2.

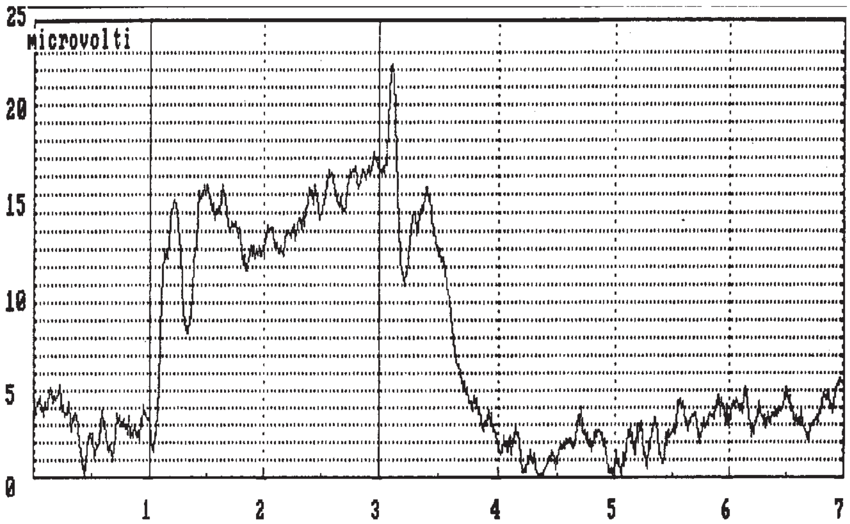

Fig. 2. Morphology of the CNV potential

CNV flip-flop paradigm

In our research we introduced a feedback loop on the CNV paradigm. The paradigm is computer controlled and Figure 3 shows the modified CNV paradigm we use in this research.

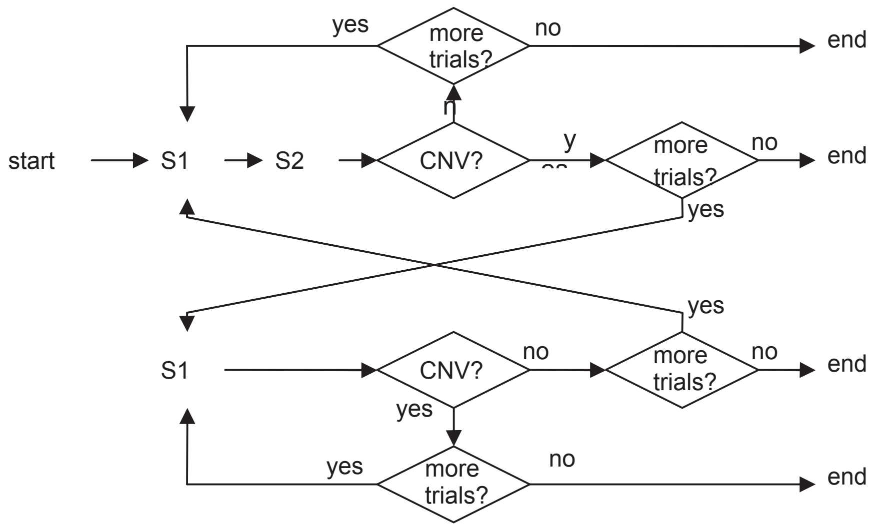

Fig. 3. The CNV flip-flop paradigm

As Figure 3 shows, after the classical part of the CNV paradigm in which S1-S2 pair of stimuli is administrated and CNV appears, the computer turns off the stimulus S2. As experiment goes on, since S2 is no more present, expectancy on S2 ceases and CNV shape degrades into some other ERP shape. The computer recognizes the CNV is not present, and turns on the signal S2 again. In such a way we obtain an experimental paradigm in which CNV potential repeatedly appears and disappears. We named this CNV flip-flop paradigm (Božinovski 2005) after a basic memory device known in digital circuits.

Brain-computer interface

We understand the brain-computer interface (BCI) is a system which can derive meaningful information directly from the human brain in real time or near real time and possibly use that information for control purposes.

The brain communicates with its environment usually through peripheral nerves and muscles. In a brain-computer interface paradigm brain uses direct bioelectric communication with external world without its normal output through peripheral nerves and muscles. Messages are conveyed by an EEG activity rather than by muscle contractions. Subjects with neuromuscular disorders benefit greatly from a BCI since it offers them basic communication abilities, such as control of a spelling program or control of a neuroprosthesis.

Here we would mention some milestone events in the BCI research. Possibility of controlling devices using EEG was mentioned by Vidal (1973). Alpha rhythm was proposed to be used by Osaka (1984). The concept of mental prosthesis was introduced by Farwell and Donchin (1988). The first control of a mobile robot using EEG alpha rhythm took place in Macedonia (Bozinovski et al. 1988)

In 1990s (Keirn and Aunon 1990), BCI experiences its renaissance. Wolpaw et al. (1991) moved a computer screen cursor using EEG. The term Brain-computer interface was introduced by Pfurtscheller et al. (1993). The importance of digital signal processing in BCI was emphasized by McFarland et al (1997). Alpha rhythm was again used as a mind switch (Craig et al., 1997). A signal processing technique named autoregressive classification techniques were introduced by Anderson et al (1998). The concept of imaginary voluntary movement-related potentials (IMMRP) was introduced by Mason and Birch (2000).

Cognitive processes based BCI were introduced starting 2000. A P300 based BCI was proposed by Donchin et al (2000) and a CNV based BCI was introduced by Bozinovski (2005).

In addition to the scalp recording EEG-based BCI, today invasive methods are used on animals. Open-brain BCI with recordings directly from brain tissue was used to show ability of a brain to control a robot arm (e.g., Nicolelis and Chapin, 2002).

The block diagram of the basic components of a BCI is shown in Figure 4 (Bozinovski et al. 1988). Since BCI must operate either in real-time or near-real-time it is important that the signal processing does not introduce unacceptable time delays (Soernmo and Laguna, 2005).

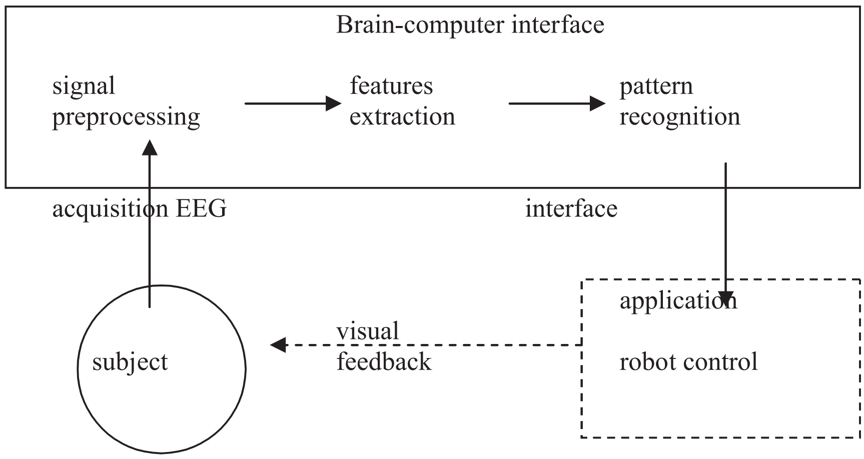

Fig. 4. Block diagram of a brain-computer interface

The Figure 4 shows the BCI components for a robot control (Bozinovski et al 1988). Other application might be considered such as spelling program, cursor movement, wheelchair movement, TV on/off, etc.

The following interrelated steps are fundamental to the design and use of a BCI (Soernmo and Laguna, 2005): 1) The mental process of the user which encodes commands in the EEG signal and 2) the BCI which, by employing signal processing techniques, translates the EEG signal characteristics into commands which control a device.

One of the techniques used is the imagination of different simple hand and feet movements which are associated with different EEG patterns. The related mental process (motor imagery) is identical to the process that results in an actual physical (muscle) movement, except that the motor activity is blocked.

The most common technique for extracting features from an EEG signal is to analyze spectral power in different frequency bands. In many cases single channel spectral analysis is sufficient, although multichannel analysis is preferable. The frequency bands are selected so that they reflect the EEG rhythms of interest: in addition o classical alpha rhythm, the mu rhythm and the beta rhythm has been found useful for BCI. While alpha rhythm is recorded from close to visual cortex, the mu and beta rhythms are recorded close to sensorymotor cortex, i.e., the area which is primarily responsible for the control of hand and foot movement.

In a BCI paradigm, the user (subject) must develop and maintain good correlation between her/his intent and the signal features used in BCI. On the other side, the BCI system must extract signal features that the user can control and then translate correctly those features into commands to a device.

CNV flip-flop as a brain computer interface paradigm

The CNV flip-flop paradigm can be considered in the framework of BCI paradigms (Božinovski 2005). Figure 5 shows that framework.

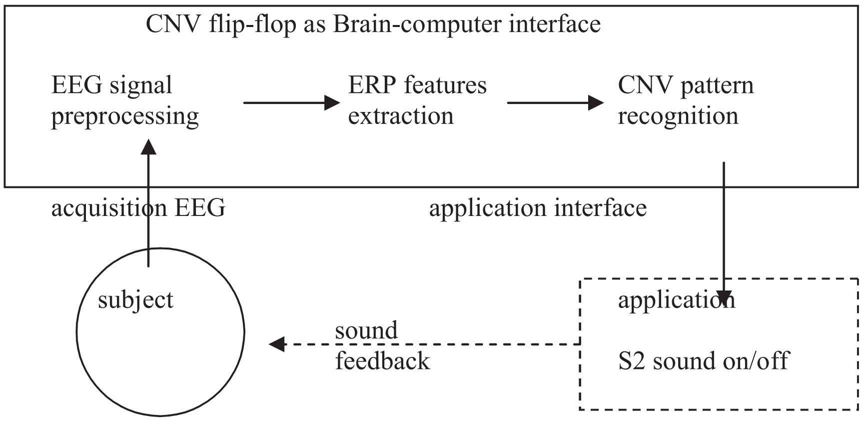

Fig. 5. CNV flip-flop as a BCI paradigm

In this BCI paradigm what is moved by an EEG is the switch on and off of a sound generator. ERP is extracted from an EEG recording and features such as slope and amplitudes of ERP are extracted. The CNV pattern recognition algorithm uses ERPslope(S2-S1) threshold and/or amplitude difference ERP(S2)-ERP(S1) threshold.

Material and methods

The basis of our methodology is a software tool (Božinovski 2007) that performs as a BCI in our research. Figure 6 shows the user interface part of the system.

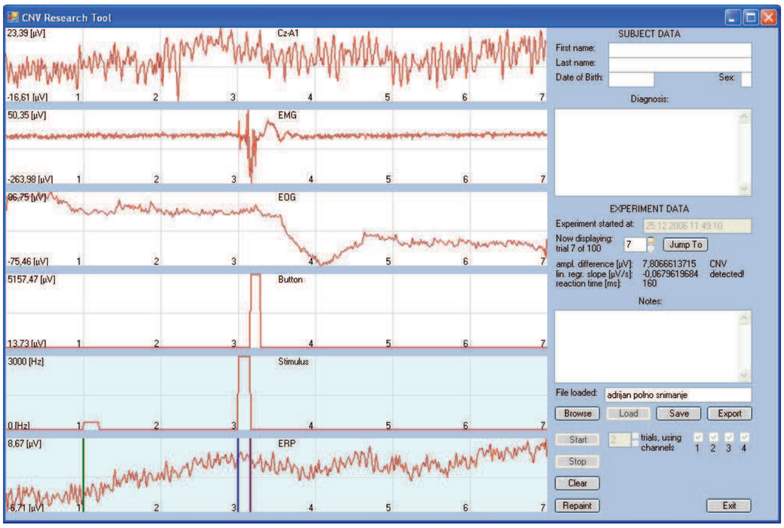

Fig. 6. User interface screen of the research system used

The system records from 4 channels. The first channel is the EEG channel, the second channel is the EMG channel, the third channel is the EOG channel, and the fourth channel is the press-button sensing channel. Channel 5 computes and shows the S1-S2-RT relation by vertical bars. Channel 6 shows the ERP extracted from EEG and also mirrors the S1-S2-RT relation using vertical lines. The user interface also contains information about the subject as well as information and control of the experiment.

Experiments were carried out in Laboratory of Neurophysiology, Institute of Physiology, Medical Faculty in Skopje, Macedonia. Students were used as subjects. An experiment usually lasts more than 30 trials. Figure 6 in particular shows the trial 7 of total 100 trials in this experiment. The slope of the ERP is sufficiently high so that the computer recognizes it as a CNV, and writes that on the experimental data part of the screen.

Obtaining CNV with no motor action

The CNV is a potential with complex morphology and since the paradigm includes pressing a button it is not clear that CNV is solely an expectatory potential. It might be considered as both expectatory and movement-preparatory potential. We experimented with paradigm in which no press button is involved. We proved

(Božinovski 2007) that CNV can be obtained with no press button movement. Figure 7 shows such a case.

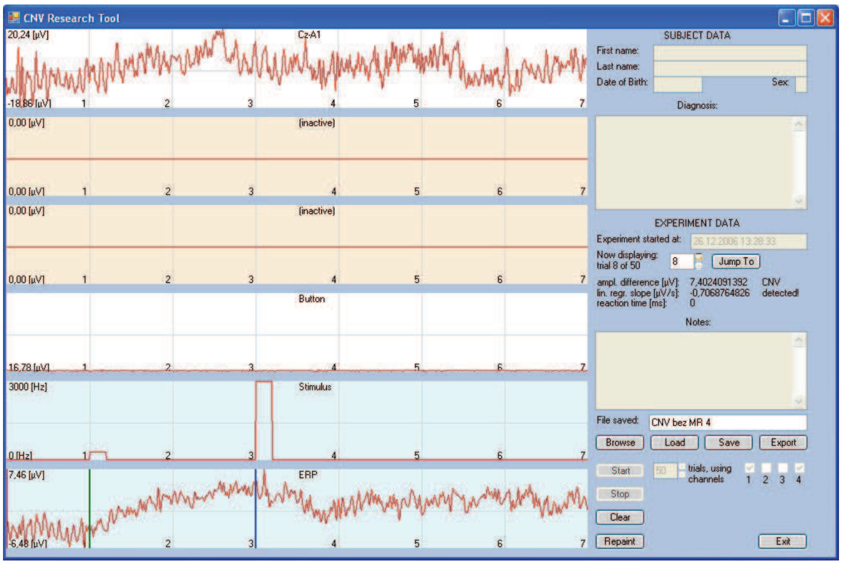

Fig. 7. Obtaining CNV with no motor action

In this modified paradigm, both S1 and S2 are presented with fixed length. No press button is included in the paradigm and consequently no reaction time is measured. As Figure 7 shows we did not recorded from EMG, EOG, and press button channels. It also shows that after 8 trials we were able to obtain the CNV signal. We should note however that this is obtained from a subject already experienced with the CNV paradigm. So we would say that a no-press-button CNV paradigm with experienced person generates CNV as fast as classical CNV paradigm.

It is open question for us whether we imagined the motor movement. In fact we did not. So we believe that CNV is a truly expectatory signal.

Conclusion

Here we gave an unofficial report of the work carried out within the Macedonian-Croatian collaborative project on brain potentials in the period 2005-2006. We continued work on a closed loop CNV paradigm and introduced the concept of flop-flop paradigm. Also we considered the CNV flip flop paradigm as a brain-computer interface paradigm. We developed a software research tool for this paradigm. Using that software tool we were able to show how a CNV can be obtained with no motor component in the CNV paradigm. We believe this work contributes to the research effort related to the electrophysiological phenomena contingent to expectancy and learning.

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