4

Physiological Markers for Controlling Active and Reactive BCIs

4.1. Introduction

Despite recent progress achieved in the last few years in the field of functional imaging, identifying significant correlations between a mental task carried out by an individual and measurements of physiological variations in brain activity remains a complex problem. On the one hand, if we suppose that a given mental state is characterized by a particular signal, it is impossible in practice to specifically measure it without interference from the variety of other, non-correlated signals produced by the brain's basic activity. On the other hand, even very specific mental activity generates highly non-stationary signals – this is to say signals whose properties vary in time – due to the fact that they depend on several factors related to the individual's general state of being at the time when measurement is taken. For this reason, in order for the communication channel between the user and the system created by a BCI to be both reliable and well functioning, it is necessary to carefully select the mental tasks that the user performs, as well as the techniques employed to measure variations in his or her brain activity. The objective is to extract a specific activity devoted to communication from the "noisy background" produced by the brain when it is alert.

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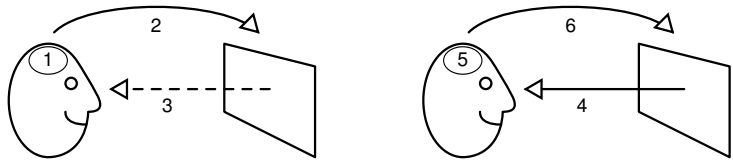
We will focus here on *active* and *reactive* BCIs, which make it possible to establish a direct connection between users and computers in which the user sends messages or commands to the computer. Passive BCIs, in which the connection is not primarily devoted to communication but rather to analyzing the user's mental state, will be studied in the following chapter.

In an active BCI (see Figure 4.1(a)), the user brings about the communication process, which he or she controls by modifying his or her mental state at will. The interface continuously analyzes those variations and decides it has received a command when it identifies a specific kind of mental activity. In a reactive BCI (see Figure 4.1(b)), the interface emits visual, auditory or tactile stimuli to the user to which he or she may or may not pay special attention. The interface decides that a command has been emitted by the user when it detects a specific response from him or her to one or several stimuli.



a) Active BCI b) Reactive BCI

Figure 4.1. *Active versus reactive BCI. a) In an active BCI, the user spontaneously modifies his or her mental state (1). The system detects this variation (2). It then possibly sends informative feedback (3). b) In a reactive BCI, the system stimulates the user (4), whose brain reacts to certain stimuli (5), thus producing a modification in mental state eventually detected by the system (6)*

Choosing between these two approaches, and therefore between given categories of mental tasks, mainly depends on the envisioned BCI application. If the goal is to provide the user with an augmentative and alternative communication device, it is possible to consider using either approach. For example, if the aim is to command a virtual keyboard, an active approach can consist of translating the markers of a kind of spontaneous brain activity into control signals for a mouse pointer [LEE 13], whereas a reactive approach may consist of scanning through the virtual keyboard's keys by successively highlighting each one of them and then asking the user to react to the stimulus corresponding to the highlighted key he or she wants to select [FAR 88]. On

the other hand, when the BCI's objective is to control an effector with several degrees of freedom – for example a prosthesis or an exoskeleton – the reactive approach is ill suited for the task.

Precisely defining a mental task is not enough to have a *marker* of identifiable brain activity that is sufficiently robust for a BCI. In order to be used as a marker, it must be possible to locate a variation in a physiological signal in space, that is to correlate it with a specific phenomenon occurring in a given location of the brain and/or of time, which is to say that it can be associated with the instant in which the user modifies his or her mental state [RAM 06]. More generally, it can be said that very specific successions in activations and deactivations of neuron assemblies, which is characteristic of large-scale integration of information by the different brain regions, represent markers that can be employed by a BCI [KRU 12]. It is also important for the user to be able to exert *voluntary control* on one or several characteristics of a physiological signal in order for it to constitute a marker. The capacity to control a physiological signal can be innate or attained through a learning process for the most part through operant conditioning techniques [BIR 13].

In order for a variation in brain activity to be used as a marker for a BCI, it is also necessary for it to be convertible into a signal through a measurement device. A key characteristic for these devices is the resolution they provide in spatial and temporal terms. Good spatial resolution makes it possible to precisely locate the brain region in which activity variations take place. Good temporal resolution makes it possible to precisely correlate variations in physiological activity with those in the user's mental state. Furthermore, if the BCI is meant to be used in *ecological* conditions, this is to say outside the very limited space of a laboratory or a medicine clinic, it is important to also take into account possible blockage of the measuring device, as well as its ease of implementation, fragility, etc.

BCIs are also categorized according to the degree of *invasiveness* they require in order to collect brain measurements. In invasive BCIs, one or several electrodes are implanted in a surgical procedure, whereas in non-invasive BCIs, brain activity measurements – which are here known as surface measurements – are recorded through an external device. In the case of invasive measurements, electrodes are placed as close as possible to the electrophysiological sources, and the measured electrical signals do not cross

the skull, muscles or skin. For this reason, measurements reflect the sources' activity more accurately, which most importantly makes it possible to increase spatial resolution. Moreover, the signal to noise ratio is higher because artifacts generated by the eyes' and jaws' muscular activity can be avoided. On the other hand, invasive techniques require precise knowledge of the location of electrophysiological sources in order to optimize implantation of the electrodes before surgical procedures.

The vast majority of measurement techniques currently available have been employed more or less thoroughly with the objective of implementing BCIs [BIR 06]. Physiological activities, devices enabling their measurement, spatial and temporal resolution levels provided by those devices and the characteristics of the corresponding BCIs are listed in Table 4.1. Note that electrophysiological activity measurements are all capable of being used in an ecological BCI context. On the other hand, although its spatial and temporal resolution are adequate, magnetoencephalography equipment is burdensome, expensive and must be installed in a perfectly isolated environment in terms of electromagnetic disturbances. Functional imaging techniques, which detect variations in brain metabolism through blood oxygen level dependent (BOLD) signals, are characterized by great temporal imprecision related to that signal's dynamic. Furthermore, these measurement devices are currently very bulky, even if it is reasonable to imagine that fNIRS spectroscopy systems, which are inexpensive, of manageable dimensions, and have a good spatiotemporal resolution, will become available in a few years [ZEP 14]. Several authors have thought to overcome the limitations related to using a single measurement technique by employing several of them, thus leading to so-called *hybrid* BCIs, although the description of those techniques goes beyond the scope of this chapter.

Some experiments have been carried out to verify the possibility of using electrical signals gathered on a unique neuron or nerve fiber. For example, Kennedy *et al.* recount their use of neurotrophic electrodes implanted in patients suffering from amyotrophic lateral sclerosis [KEN 04]. Many of those patients have successfully managed to control a spelling interface by modulating the action potential discharge rhythm emitted by a recorded neuron. Very few authors have reported the use of a grid of electrodes chronically implanted in a subject's motor cortex in order to implement a BCI. The most recent experiment to have been attempted was carried out by Hochberg *et al.* on two quadriplegic subjects, within the framework of the

BrainGate 2 clinical project [HOC 12]. Signals gathered by a grid of 96 electrodes were processed in order to bring to light unitary action potentials from a neuron ensemble in the primary motor cortex area controlling the hand. Those signals were then decoded in order to calculate the speed of movement intentions in real time, which were in turn used to control a robotic arm.

Activity, measurement technique	*Spatial res.*	*Temporal res.*	*Invasive*	*Ecological*
Action potential, electrode on a neuron connected to nerve fiber	Excellent	Excellent	Yes	Yes
Local field potential	Good	Excellent	Yes	Yes
Electrocorticogram, epidural or sub dural electrode grid	Adequate	Excellent	Yes	Yes
Surface electroencephalogram	Bad	Excellent	No	Yes
Magnetoencephalogram	Adequate	Excellent	No	No
BOLD signal measured by functional magnetic resonance imaging (fMRI)	Adequate	Bad	No	No
BOLD signal measured by funtional near infrared spectroscopy (fNIRS)	Bad	Bad	No	No (*)

Table 4.1. *Brain activity signals already used in a BCI [BIR 06], with associated measurement techniques, spatial and temporal resolutions, invasiveness and ecological characteristics. BOLD = Blood-Oxygen-Level Dependent; fMRI = functional Magnetic Resonance Imaging; fNIRS = functional Near Infrared Spectroscopy*

In this chapter, we will describe electrophysiological activities whose variations, when recorded by a surface electroencephalogram (EEG), are analyzed in order to extract a marker. It is important to note that these are the same activities that are studied in invasive interfaces, where signals are recorded by epidural or subdural electrode grids (electrocorticogram), with the slight difference that spatial resolution and the signal to noise ratio are higher in this case. Variation in EEG signals can be extracted either directly in the spatiotemporal domain, or after a frequency transformation. Spatiotemporal analysis is used to detect an event-related potential (ERP), for which there is a correlation between the phase of oscillations appearing as a response to an event and the instant at which it occurs. Increases or decreases as a function of time are studied at different spatial locations, with the instant at which the event occurs taken as the origin. On the other hand, in order to detect an *induced* activity, given that the phase is not locked, it is only possible to analyze variations in oscillation amplitude after the event's occurrence.

In an active BCI, events that bring about a modification in the individual's mental state are *endogenous*, with the individual spontaneously deciding to carry out a specific mental task. Instead, in a reactive BCI, events that can bring about a modification in the individual's mental state are called *exogenous*, which is to say that they are caused by sensory stimulation.

4.2. Markers that enable active interface control

In this section, we first describe a marker for an activity evoked by an endogenous event that has been widely used to implement BCIs, namely slow variations in average cortical potential. We also present a marker related to the realization of a motor imaging task, namely bereitschaftspotential (BP) or readiness potential.

These first two markers are extracted through a spatiotemporal analysis of EEG signals. Next, we describe markers that conform desynchronizations and synchronizations related to an event, especially desynchronization of beta ($f = 13 - 30$ Hz) and mu ($f = 8 - 12$ Hz) waves before and during motor imaging, and the resynchronization of beta waves afterwards. This phenomenon is known as a "beta rebound". In this case, the markers are extracted by an analysis of EEG signal variations in terms of frequency.

4.2.1. *Spatiotemporal variations in potential*

4.2.1.1. *Slow variations of average cortical potential*

A slow evolution of average cortical potential (slow cortical potential [SCP]) is categorized according to the sign of its variation – either positive or negative – with respect to the average or baseline level, as measured on an interval of time in which the user is considered at rest. The measured potential corresponds to the dendrites' level of depolarization in the upper cortex, whose variations are caused by afferent, intracortical or thalamo cortical influxes advancing toward layers I and II of the neocortex. Negative SCPs are the result of very slow synchronized excitatory postsynaptic potentials emitted by the apical dendrites from the pyramidal neurons. Positive SCPs are the result of a decrease in those same potentials, an inhibitive activity in the interneurons, or an excitatory influx coming from the cell bodies in layers IV and V [BIR 00].

The spatial position at which the maximum variations in average cortical potential occurs varies among individuals [HIN 04]. Recordings carried out on several EEG channels during a visual feedback experiment for BCI learning have shown that SCPs with the greatest amplitude tend to appear at or around the vertex, but that variations occurring in a large spatial extension can also be recorded in some subjects [HIN 05].

Slow average cortical potential variations can constitute a useful marker for BCIs because (1) they are easy to detect by comparing the level of average electrical potential at the instant in question – which is measured by using one or several surface EEG electrodes at the instant – with the baseline potential; (2) they manifest themselves in an innate manner due to the fact that they are the product of changes in excitation levels of a cortical network related to the preparation of a cognitive or motor task; and (3) a user can learn to voluntarily modulate these variations in order to increase their amplitude by employing operant conditioning techniques [BIR 00].

The learning technique implemented by Birmaumer to this end is described in detain in section 3.3.1 of Chapter 3 of Volume [CLE 16]. This marker is of interest because SCPs are measurable even for patients suffering from major brain injury, like those caused by an ALS.

4.2.1.2. *BP or readiness potential*

Discovered over 50 years ago, readiness potential manifests itself in two successive phases through a reduction of cortical potential that is at first slow and then fast. BP begins between 1 s and 1.5 s before the execution of a voluntary movement [KOR 65]. Its first component (EBP, early BP) is more visible in the centromidline, whereas the second component (LBP, late BP), which starts about 400 ms before movement, has its maximum amplitude right above the primary motor cortex (see Figure 4.2). The generally accepted hypothesis is that EBP begins in the presupplementary motor area (pre-SMA) without a specific location and in the SMA displaying a somatotopic organization, and then bilaterally continues on to the lateral premotor cortex. On the other hand, LBP is generated specifically in the contralateral primary motor cortex (M1) and the lateral premotor cortex following a precise somatotopy [SHI 06].

BP also manifests itself when the subject observes movement being carried out by another person, when he or she can predict another person's

movement, and finally when he or she imagines performing that movement. It is this last property that makes it possible to consider BP an electrophysiological marker usable in an active BCI. Either on its own or in conjunction with other markers, BP has been used in several BCI implementations in order to predict when a subject has the intention of carrying out a movement, the direction of that movement and even the limb that will be involved in that movement [AHM 13].

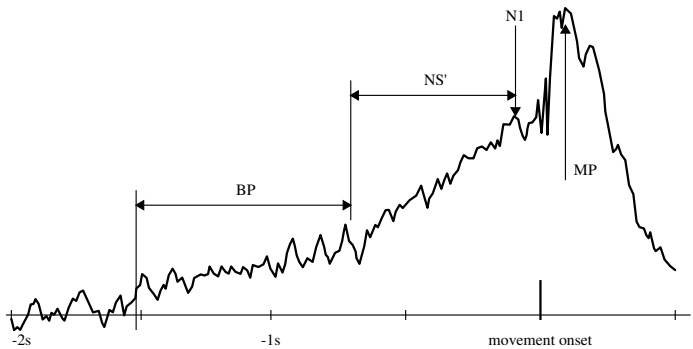


Figure 4.2. *Temporal variation in potential before movement. BP, bereitschaftspotential; NS', negative slope; MP, motor potential*

4.2.2. *Spatiotemporal wave variations*

Some authors consider ERPs to be the superposition of several responses produced by the event, leading to a measurable macroscopic variation. Some other authors consider them a simultaneous zero-reset of a variety of brain waves, which in fact brings about variations in potential that are clearly apparent in the temporal domain [SAU 07]. When the event is endogenous, resynchronization of the phases is not as marked, and its effect on EEG wave oscillations can only be extracted through frequency analysis.

The most frequently used BCI markers of an activity induced by an endogenous event are synchronizations and desynchronizations related to the event (event-related synchronization (ERS), event-related desynchronization (ERD)). In the case of an ERS, variations in activity are manifested in a temporal increase – with respect to its average value – of oscillation

amplitude in a specific frequency range. In the case of an ERD, the opposite result holds: a decrease in the amplitude of those same oscillations can be detected. According to the type and complexity of the endogenous event inducing the variation in brain activity, the spatial location of ERD/ERS and their latency – that is to say the time between the instant they appear and the moment the event was produced – are very variable.

In active BCIs employing ERD/ERS, the endogenous event corresponds in practice to the user beginning a specific mental task. For example, carrying out a mental calculation, which involves the use of working memory, produces an ERS in the gamma range ($f > 25$ Hz) in the prefrontal dorsolateral cortex [RAM 06]. Among the mental tasks that have already been the subject of active BCI experiments employing an ERD/ERS, we can find the following [FRI 12, DEL 02]: rotating an object, cube or more complex shape; associating words, for example those beginning with a given letter; auditory imagination; mental navigation of a known space; imagining faces of known people; motor imaging.

Without a doubt, evidencing ERDs/ERSs produced by a motor imaging task has been the object of the largest number of research devoted to active BCI development. This can be explained by the fact that ERDs/ERSs are produced for this mental task in frequency ranges – mu ($f = 8 - 12$ Hz) and beta ($f = 13 - 30$ Hz) – that can be easily measured by a surface EEG, unlike ERDs/ERSs produced for oscillations at higher frequencies. Moreover, movement-correlated mu rhythm ERDs/ERSs can easily be spatially located given that maximum amplitude variations are recorded on EEG electrodes located right above the primary motor areas in the precentral gyrus [DER 99].

Figure 4.3 represents an EEG signal's power spectrogram as recorded when focusing on the motor area during movement. On this spectrogram, desynchronization (ERD) and then resynchronization (ERS) of the rhythms related to movement execution can be seen clearly. Neuper and Pfurtscheller have shown that the same power variations occur in EEG signals when movement is simply imagined rather than actually carried out [NEU 98]. A motor imaging mental task therefore normally involves a desynchronization of beta and mu rhythms, followed by a resynchronization of the beta rhythm, which can be detected in order to serve as usable active BCI markers.

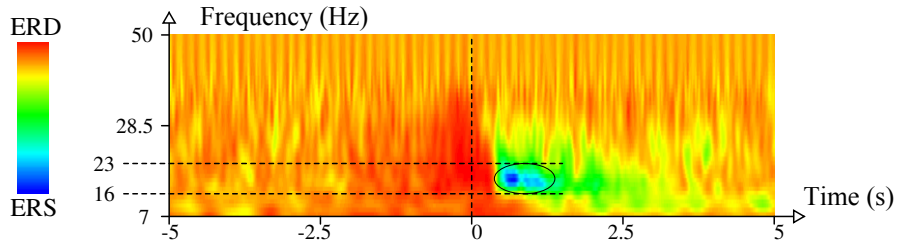


Figure 4.3. *Desynchronization and synchronization related to the event. Spectrogram (time-frequency representation) of an EEG signal recorded directly above the motor area during movement. Event-related desynchronization (ERD) begins both in the mu (8–12 Hz) and beta (13–30 Hz) ranges. ERD in the mu range is produced for about 1 s after the end of movement. On the other hand, only 500 ms after the end of movement an event-related synchronization appears in the beta range. This "beta rebound" is located in the figure's ellipse. For a color version of this figure, see www.iste.co.uk/clerc/interfaces1.zip*

However, imagining movement without actually carrying it out is not a trivial mental task, and the cognitive strategies employed by subjects that perform it are in practice very variable, even in the case of people suffering from paralysis [MUL 07]. Several studies have shown that short duration movement imagination is a strategy that produces straightforward desynchronizations in beta and mu rhythms at the beginning of the task [MOR 08, JEO 11]. On the other hand, when the subject imagines movements for a longer period of time or for a variable length of time, ERDs are less marked at the beginning of the task [JEO 11]. In this case, the motor imaging task is more easily captured by the resynchronization of mu and beta rhythms that appear in EEG signals when it ends.

A subject's capacity to voluntarily modify the amplitude of his or her sensorimotor rhythms with the purpose of controlling an active BCI can also be improved by an operant conditioning technique. Wolpaw *et al.* were the first to relate this approach, initially for controlling the vertical position of a cursor (just one degree of freedom [WOL 91]), and then on two screen dimensions (two degrees of freedom [WOL 94]). In this work, BCI control signals are determined by measuring the power of EEG signals recorded directly above the primary motor area, in the frequency range corresponding to the mu rhythm, while respecting motor somatotopy.

4.3. Markers that make it possible to control reactive interfaces

In cases qualified as reactive, a BCI sends the user repetitive stimulations whose spatial and/or temporal characteristics encode two or more options which he or she must choose from. The user therefore has the task of focusing, or not focusing, his or her attention on the stimulations associated with the option he or she wishes to select in order to communicate with the interface. The very perception of stimulation produces a potential, which is qualified as exogenous. If the perception moreover brings about a specific cognitive reaction in the subject, other potentials can also be produced later, like P300. Among the exogenous potentials that are employed as markers in BCIs, we can mostly find stationary sensory evoked potentials (SEPs), which are produced by a visual, auditive or tactile stimulation and which are locked in phase with this stimulation. P300 is the cognitive evoked potential brought about by a stimulation that is most commonly used as a marker in BCIs. We will therefore describe it in detail.

4.3.1. *Sensory evoked potentials*

SEPs appear in EEG signals only when the subject receives sensory stimulation of some type. In this sense, they are different from spontaneous potentials and ERPs that are not related to perception, for example the spontaneous decision to perform a given movement. SEPs are locked in phase with stimuli and can be determined with a high degree of precision. This property makes it possible to easily extract them by repeating the simulation a large number of times and averaging EEG readings, but also, in the case of a single reading, to acquire good *a priori* knowledge of characteristic variations that are being studied in the signals. In order to use an SEP as a marker in a BCI, it is in practice necessary for it to be identified and located in the EEG signals by using a very limited number of simulation repetitions, so as to obtain rapid communication.

4.3.1.1. *Visual evoked potential*

Just after the perception of a visual stimulus with a very short duration – generally a flash of light – it is possible to record several SEPs of different latencies directly above the primary visual area. In this case, the visual evoked potentials (VEPs) with the highest amplitude are N2, with a latency of 90 ms, and P2, with a latency of 120 ms. When stimulation is produced by a

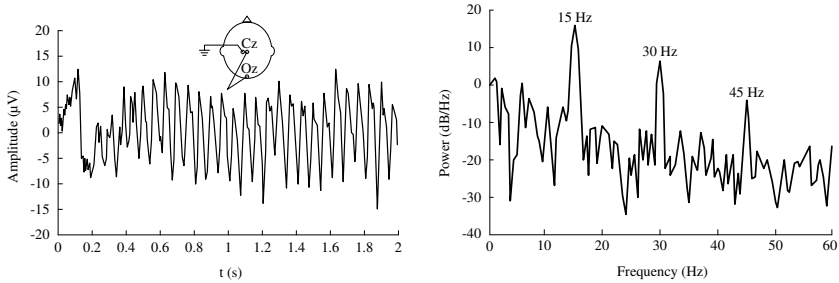
mechanism whose luminescence remains constant, but whose contrast is suddenly modified – for example by changing the black and white tiles of a checkerboard – the most marked VEPs are N75, P100 and N135 potentials [VIA 10]. In those simulation conditions, that is considering a response to a single stimulus, it is extremely difficult to extract VEPs in EEG signals in a single attempt. For this reason, their use as BCI markers is unlikely [ZHU 10].

On the other hand, however, when simulations are repetitive, a permanent functioning state is established in the visual perception chain, leading to the emergence of steady-state visually evoked potentials (SSVEPs). SSVEPs, which were first studied in humans by Regan in 1966 [REG 66], are characterized by their amplitude and phase. The phenomenon's phase constitutes the reference stimulus. These characteristics are generally measured through a frequency transformation of the EEG content, much like that used to analyze cortical rhythms. Even if the question has not been definitively determined, it is considered that the stimulation frequencies that allow for SSVEP evocation are between 3 and 40 Hz [VIA 10]. Below 3 Hz, the stimuli's cadence is insufficient for a steady-state protocol to set up. Brain responses therefore become equivalent to a succession of unitary responses. Beyond 40 Hz, the SSVEP's amplitude becomes too small to be detected and processed, especially from surface EEG signals. Figure 4.2 provides an example of an SSVEP measured by an occipital electrode placed in Oz, with the reference taken at the vertex.

SSVEPs are interesting markers for BCI implementation because (1) they are easy to extract with basic processing of EEG signals, for example narrowband filtering centered on the stimulus' frequency; (2) their characteristics are relatively independent of the subject, with the condition of specifically selecting electrode positions providing maximum amplitude; and (3) they are little affected by muscular artifacts such as blinking and facial muscles' EMG [PER 03].

In the majority of BCIs employing SSVEPs, the subject chooses an option by directing his or her gaze toward one of the available targets, each flashing at a different frequency. For this reason, the resulting BCI is qualified as *dependent*, since the subject must at least be in control of some residual movement allowing him or her to change the direction of his or her gaze. Recent studies have talked about *independent* BCIs employing SSVEP

evoked by spatially combined stimulations, for example a checkerboard whose two types of tiles are colored differently and flash at two different frequencies [ALL 08, LES 14]. In those BCI arrangements, the SSVEP amplitude is determined by the attention that the subject pays to one or another of the stimulations, and not by a change in the gaze direction.



a) b)

Figure 4.4. *EEG measured on a bipolar derivation on positions Oz and Cz during visual stimulation at a frequency of 15 Hz. a) Signal averaged on 10 experiments synchronized at the beginning of the stimulus. The transitory phase is clearly visible before the emergence of the steady-state protocol. b) Power spectrum for that same signal, showing a peak for the fundamental frequency – which is identical to that of the stimulus – and several other peaks for its harmonics. Figure reproduced from [ZHU 10]*

4.3.1.2. *Other steady-state potentials: steady-state auditory evoked potential, auditory steady-state response and steady-state somatosensory evoked potential*

Repetitive stimulation of a sensory modality other than vision also makes it possible to evoke steady-state SEPs. Somatosensory evoked potentials can therefore also be detected for repetitive tactile stimulation (steady-state somatosensory evoked potentials) as can auditory evoked potentials for repetitive auditive stimulation (steady-state auditory evoked potential (SSAEP), or auditory steady-state response). As for SSVEPs, these steady-state potentials can be extracted from EEG signals through narrowband filtering centered on the stimulation frequency or one of its harmonics. Indeed, the possibility of using those steady-state SEPs as markers in a reactive BCI is still being debated by the community, especially in the case of SSAEPs. The problem has to do with the fact that very little research

has been able to demonstrate a user's capacity to adjust his or her SEPs by selectively focusing attention on a specific stimulus [HIL 12, MUL 06].

4.3.2. *Endogenous P300 potential*

When an individual receives an unexpected sensory stimulus, or one that is different from what he or she expected to perceive, the standard SEP is followed by one or several other, very specific evoked potentials, whose latencies are greater [DES 65, SUT 65]. If the unknown stimulus's perception captures the individual's attention, that is to say it elicits a cognitive reaction from him or her, an endogenous potential called novelty P3 or P3a appears. The latency of P3a falls somewhere between 250 and 280 ms. Its spatial distribution is frontocentral, and its amplitude is correlated with the strength of the surprise effect caused by the stimulus. However, if the initially unknown stimulus appears several times, the individual becomes accustomed to it quickly and the amplitude of P3a greatly decreases.

P3b, which is sometimes referred to as target P3, is also evoked in response to an unexpected sensory stimulus. In this case, the stimulus is known beforehand by the individual, who must be involved in a cognitive task consisting of reacting when he or she perceives that particular stimulus in a sequence of other stimuli. The latency of P3b is for the most part greater than that of P3a, between 250 and 500 ms, or greater according to the complexity of the cognitive task performed by the individual. Moreover, the spatial distribution of P3b is more posterior than that of P3a.

In some reactive BCIs, P3b endogenous evoked potential, called P300 in that case, is detected by EEG signals processing in order to determine the specific stimulus on which the user focuses his or her attention. In the "oddball" paradigm, a succession of stimuli containing at least two different types of stimuli is presented, usually at a relatively fast rate [SQU 75]. The user is asked to react each time the target stimulus appears, for example by counting the number of times it appears. The other stimuli are considered distractions (standard stimuli). The frequency with which they appear must be greater than that of the target stimuli in order for the amplitude of P300 to be large enough.

P300 is the evoked potential that has most commonly been used in reactive BCIs since Farwell and Donchin's publication [FAR 88]. It represents an especially relevant marker because (1) it can be measured in the first session of BCI use due to the fact that it results from an innate learning process; (2) it is often possible to detect it in a single test, especially when the space–time detection filter's settings are well adapted to the user; (3) the paradigms used in P300 BCIs make high-speed stimulations possible – going as high as 10 stimuli per second – which makes it possible to attain adequate communication lags.

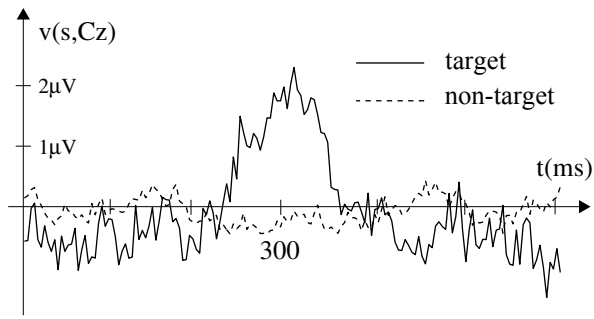


Figure 4.5. *Endogenous P3b potential. EEG readings recorded on a Cz electrode in response to target stimuli (continuous line) and to standard stimuli (dotted line), averaged over 60 recording in each case. We can observe an increase in potential in the neighborhood of 300 ms after a target stimulus*

4.4. Conclusions

In this chapter, we have described the main physiological markers that can be used in order to control an active or reactive BCI. In the case of active BCIs, we have presented the markers of an evoked activity through an endogenous event: slow variations in average cortical potential, BP, synchronizations and desynchronizations resulting from an event. In the case of reactive BCIs, we described the markers of an activity evoked by an exogenous event, in this case a stimulation emitted by the BCI: steady-state somatosensory evoked potentials, especially visual (SSVEP) and cognitive (P300) evoked potentials.

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