Progress in Neurobiology 165–167 (2018) 51–65

Contents lists available at ScienceDirect

Progress in Neurobiology

journal homepage: www.elsevier.com/locate/pneurobio

Review article

Uncensored EEG: The role of DC potentials in neurobiology of the brain

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ARTICLE INFO

Keywords:
Electrocorticography
Bioelectrical activities
Electroencephalography
Cortex
Spreading depression
Epileptiform discharges

ABSTRACT

Brain direct current (DC) potentials denote sustained shifts and slow deflections of cerebral potentials superimposed with conventional electroencephalography (EEG) waves and reflect alterations in the excitation level of the cerebral cortex and subcortical structures. Using galvanometers, such sustained displacement of the EEG baseline was recorded in the early days of EEG recordings. To stabilize the EEG baseline and eliminate artefacts, EEG was performed later by voltage amplifiers with high-pass filters that dismiss slow DC potentials. This left slow DC potential recordings as a neglected diagnostic source in the routine clinical setting over the last few decades. Brain DC waves may arise from physiological processes or pathological phenomena. Recordings of DC potentials are fundamental electro-clinical signatures of some neurological and psychological disorders and may serve as diagnostic, prognostic, and treatment monitoring tools. We here review the utility of both physiological and pathological brain DC potentials in different aspects of neurological and psychological disorders. This may enhance our understanding of the role of brain DC potentials and improve our fundamental clinical and research strategies for brain disorders.

1. Introduction

Direct current (DC) potentials have been a subject of research since the first recording of this type of bioelectrical activity from the animal cerebral cortex by Caton in 1875, which allowed recording of brain waves (Haas, 2003). Along with DC potentials, terms such as slow potentials, standing potentials, sustained potentials and steady potentials have been in use. Since the introduction of EEG recordings in clinical and experimental studies, recordings of spontaneous DC brain potentials have been widely neglected. This is due to the fact that electroencephalography (EEG) recordings have been performed in the AC coupled mode with low frequency filters set at 0.5 Hz or higher. This practice was introduced to cancel unwanted noise, such as sweat and motion artefacts. Successful recordings of DC potentials which could be clearly distinguished from artefacts have been performed, showing that spontaneous slow brain potentials can be recorded in scalp EEG (Picton and Hillyard, 1972; Lagerlund and Gross, 2003; Drenckhahn et al., 2012; Hartings et al., 2014; Bastany et al., 2016). However, it is important to note that recordings – as traditionally done with a low frequency filter set at 0.5 Hz – dismiss much of the information that DC potential recording might provide. Recording of DC potentials may improve our understanding of the neurophysiological brain function as well as the pathological mechanisms behind neurological and psychological disorders.

Brain DC potentials refer the whole frequency range of bioelectrical activities of the brain that can be reliably traced by a DC recording system (Caspers et al., 1987). DC potentials cover a broad range of slow alterations of EEG signals, from phasic deflections of a few milliseconds duration to long-lasting tonic oscillations of several minutes. The DC brain waves reflect alterations in the level of excitation and excitability of the cerebral cortices as well as the subcortical brain regions resulting from *physiological* or *pathological* DC brain activity. The origins of the brain DC potentials and their negative and positive DC shifts are mainly neuronal activities arising from membrane potential changes of the apical dendrites of pyramidal neurons. They represent facilitation processes elicited by cortico-petal afferent fiber activity in particular

Abbrevations: BAEPs, brainstem auditory evoked potentials; BOLD, blood oxygenation level-dependent; CNS, central nervous system; CNV, contingent negative variation; DC, direct current; ECoG, electrocorticography; EEG, electroencephalography; EFPs, epileptiform field potentials; ERPs, event related DC potentials; HISD, hypoxic Ischaemic SD-like event; MRI, magnetic resonance imaging; MS, multiple sclerosis; SD, spreading depression; SSEPs, short latency somatosensory evoked potentials; SUDEP, sudden unexpected death in epilepsy; VEPs, visual evoked potentials

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https://doi.org/10.1016/j.pneurobio.2018.02.001
Received 30 August 2017; Received in revised form 24 December 2017; Accepted 3 February 2018
Available online 08 February 2018
0301-0082/

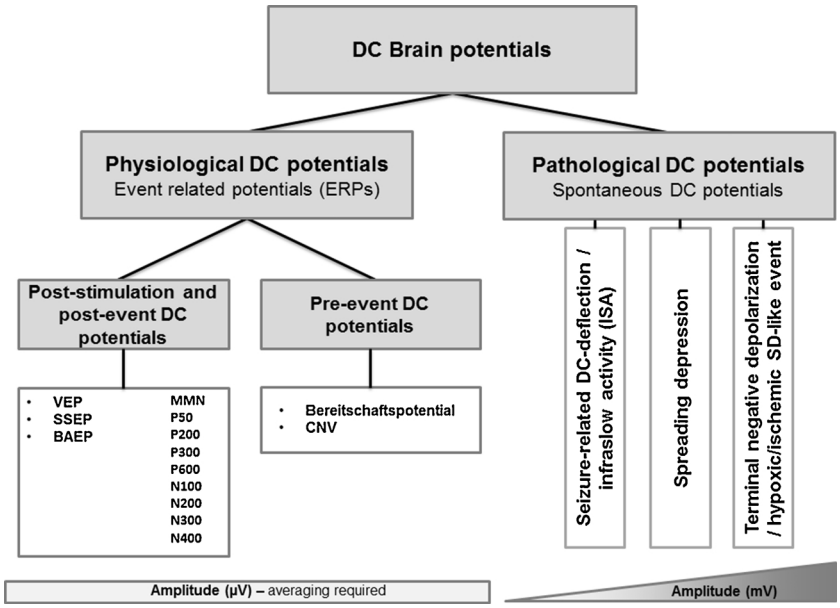

Fig. 1. Overview of brain DC potentials. Brain DC potentials can be divided to physiological DC potentials (event related DC potentials; ERPs) and pathological DC potentials (spontaneous DC potentials). ERPs are small in amplitude and strictly time locked to a stimulus or event and spontaneous large DC potential shifts have been largely linked to pathologies of the brain. Changes in normal patterns of ERPs can be used as diagnostic, prognostic, and treatment monitoring in different neurological or psychological disorders. Spontaneous brain DC potentials were recorded in the brain of patients suffering from different neurological disorders, such as epilepsy, stroke, and traumatic injury. BAEP, brainstem auditory evoked potentials; CNV, contingent negative variation; MMN, mismatch negativity; SSEP, short latency somatosensory evoked potentials; VEP, visual evoked potentials.

from thalamic nuclei and unspecific afferent systems (Caspers et al., 1984; Speckmann et al., 2011). A plethora of both physiologic and pathologic phenomena have been associated with DC brain potentials and thus DC potentials are of interest of scientists and clinicians in various scientific fields, including basic and clinical neuroscience.

Two conceptually different types of DC potentials exist; physiological DC potentials (event related DC potentials; ERPs) and pathological DC potentials (spontaneous DC potentials). ERPs are DC potentials small in amplitude and strictly time locked to a stimulus or event. These potentials have been used for diagnostic purposes, mainly in the field of neurology, neurosurgery, and neuroscience. On the other hand, there is evidence of spontaneous DC potential shifts in the human brain, such as spreading depression or spreading depolarization (SD). Those spontaneous large DC potential shifts have been largely linked to pathologies of the brain, but are not recorded in the routine clinical setting (Fig. 1).

Currently, both ERPs related and spontaneous DC potential measurements are clearly underutilized in the clinical context and for many clinicians the use of EEG is restricted to very few clinical scenarios, such as epilepsy, prognostication in the intensive care unit, and facilitating the diagnosis brain death. This leaves the EEG and particularly DC potential recordings as a neglected diagnostic source. For spontaneous DC potentials, this is due to the fact that traditional use of filter settings prohibits their recording in the routine clinical setting, whereas the utilization of evoked potentials in the work up of brain diseases has suffered due to the rise of imaging techniques.

This review aims to summarize current knowledge on DC potentials in the physiological setting and more importantly in diseases of the central nervous system. This will provide both scientists and clinicians with an up-to-date view on DC potentials and thus may promote their use both in a research and in a clinical setting.

1.1. Physiological DC potentials

A fascinating correlation exists between DC potentials and brain functions and processes. DC potentials are correlated with states of high alertness (Bachmann, 1984), transition between wakefulness and sleep as well as between different stages of sleep (Marshall et al., 1998), awareness of muscle movements (Deecke et al., 1976; Cui and Deecke, 1999), consciousness during decision making (Guggisberg and Mottaz, 2013), task demand and performance (Trimmel et al., 2001), consummatory behaviours (Hallschmid et al., 2001), behaviour and arousal state (Pirch et al., 1967; Haider et al., 1981), attention (Rösler et al., 1997), blood-brain barrier disruption (Kiviniemi et al., 2017), and several other complex functions in the healthy brain.

ERPs are DC waves which are small in amplitude and which are evoked in specific brain areas to evaluate sensory, motor, or specific cognitive processes. There has been much confusion around the term “ERPs”; some people have used this term exclusively for endogenous potentials. For the purpose of this review we are using the term in its original meaning for all potentials which occur in the aftermath of an event or which occur prior to an event, i.e. potentials which are linked to an event (Vaughan, 1969). ERPs can be divided into two groups: (*i*) post-stimulation (evoked) and post-event DC potentials: post-stimulation DC potentials are evoked in response to a stimulus and are usually used to measure sensory perceptions whereas post-event DC potentials occur during or after a cognitive process; (*ii*) pre-event DC potentials: these potentials are related to activity in specific regions of the brain leading up to voluntary muscle movement or cognitive processes (such as attention, expectancy, decision making, and speech; Fig. 1).

Post-stimulation ERPs potentials are further subdivided into exogenous or endogenous depending on whether the stimulus is mainly determined by the physical properties or by the psychological effects of the stimulus (Picton, 1995). This subdivision is also reflected in the timeline. The early responses are often determined by the physical properties of the stimulus, hence termed early ERPs, stimulus-dependent (i.e. within ~100 ms after stimulus) ERPs and sensory responses. In contrast, later components of ERPs, i.e. the endogenous part of the response, represent the condition in which the subject pursues the stimulus and are termed cognitive response (Blackwood and Muir, 1990; Sur and Sinha, 2009). Post-stimulation ERPs are named by a letter indicating the polarity of DC waves (i.e. negative, N; or positive, P), followed by a number indicating either the ordinal position of the component in the evoked wave or the latency of the component in millisecond (Fig. 2, Table 1). Of note, due to their small amplitude, all ERPs cannot be discerned within the much larger background EEG and are only visible after averaging of multiple single-trial waveforms. ERPs reflect the summation of the post-synaptic potentials induced by synchronized activation of multiple cortical pyramidal neurons (Peterson et al., 1995).

Two main pre-event ERPs which have been studied intensively are the readiness potential (Bereitschaftspotential) and the contingent negative variation (CNV). These potentials are low negative EEG activities generated over several seconds preceding an event. The readiness potential is a slow wave preceding voluntary movements lasting