Chapter 4
Synchronous Physiological Electrical Fields: Function and Interface Potential

J.F. Pagel
University Of Colorado, USA

ABSTRACT

Humans utilize sensory and motor systems developed genetically, physically and socially for interfacing with our external environment. We use these same systems to interface in our interactions with artificial intelligence. There are other functioning central nervous system (CNS) systems, however, involved in cognitive processing for which the function and environmental interface is less clear. The synchronous physiologic electrical field system utilizes broadcast extracellular electrical fields for a wide variety of CNS functions. The operations of this system are usually non-conscious and most apparent during sleep (especially the conscious states of sleep that include dreaming), and un-focused waking. The electrical fields of this system are altered and affected by both internal and external stimuli. These fields can be monitored and analyzed by artificial intelligence (AI) systems, and independently of human input, AI systems can utilize similar frequency based electrical potentials to convey data, communicate, supply power, and to store memory. From both human and AI perspectives, these systems have the potential to function more fully in human/machine interaction. This chapter reviews our current knowledge as to function, current interactive approaches, and interface potential for these physiological electrical fields.

INTRODUCTION

In the first decade after Freud’s publication of the “Interpretation of Dreams,” the alpha rhythm was discovered, the first CNS electrical signal apparent on turn of the century monitoring systems (Berger H, 1931; Freud, 1903). Later and more sensitive equipment detected other physiologic frequencies (sigma, theta, delta, and gamma/beta) using scalp electrodes in humans and implanted electrodes in animal models (Elul, 1971). These specific frequencies were then utilized to define and characterize the various stages of sleep (Rechtschaffen & Kales, 1968). These frequencies, also present during wake, are a background
Synchronous Physiological Electrical Fields

component of any electric or magnetic approach used for CNS monitoring. Recently, other rhythms at frequencies less than 1 Hertz (delta) have been described, occurring in both sleep and wake (Domhoff, 2003). These frequency modulated electrical fields are propagated extracellularly, in most cases apparent on monitoring systems attached outside the actual CNS such as scalp and facial electrodes.

In all species studied, oscillatory (synchronous) brain activity has been shown to be a characteristic CNS property (Cantero & Atienza, 2005). While postulated to reflect CNS the spike potentials of neurons firing, it has been difficult to demonstrate how individual spike potentials might summate to create propagated frequency-based global rhythms (Christakos, 1986; Buzsaki, 2006). It is likely that the specific physiologic frequencies are linked to metabolic oscillators at the neural membrane, occurring secondary to oscillatory opening and closing of ionic gateways and channels (potassium for alpha, calcium for sigma) (Buzsaki, 2005, Pagel, 2005, Steriade, 2001). Such EEG rhythmicity requires many neurons to fire in sequence, most likely secondary to repetitive changes in ion concentrations at the synaptic junction. Oscillation frequency is also modulated by inhibitory neurotransmitter (GABA) activity affecting the chloride channels essential for the synchronization of individual neurons in the CNS (Liu & Reppert, 2000, Buzsaki, 2006).

There was considerable debate as to whether the synchronous electrical fields of the CNS had actual function. It was postulated that these electric fields might rather be a non-functional externally observable side-effect of neural activity (Hobson, Pace-Schott & Stickgold, 2000). Even early after the discovery of this system, however, it was noted that could alter the tendency of individual neurons to form spike potentials (John, 1968). From the electo-neurochemical perspective these fields had the capacity to alter ionic concentrations at the neural membrane affecting any individual cell’s tendency to form a spike potential (Formula 1). Any frequency based change in electrical potential would also affect cellular kinetics though ATP production (Formula 2). There is considerable recent data, indicating functional capacities of this electrophysiologic system in affecting the tendency of neurons to fire, cellular equilibrium, signal-to-noise ratio, neural communication, and cellular messaging systems (Pagel, 2005; Axmaker, Mormann, Fernandez, Eger & Fell, 2006; Anastassiou, Perin, Markam & Koch 2011, Cash, Halgren, Dehghani, Rosetti, Thesen & Wang 2009). EEG synchronization is now viewed by many neuroscientists as an important mechanism utilized by the CNS to attain functional cerebral integration between widely spaced neuronal populations (Singer, 1999; Salinas & Sejnowski, 2001; Cantero & Atienza, 2005). This system affects electrically sensitive neuromessaging systems at the neural cell membrane, potentially affecting expression and access to memory systems stored in electricochemically biological systems including cellular DNA (Pagel, 2005).

Formula 1: The classic Hodgkin, Katz, Goldman equation for the interaction of potassium, sodium, and chloride ions involved in inducing a neural spike potential (Hodgkin & Horowicz 1959). \( \Delta \Theta \) the change in electrical membrane potential alters in a frequency based system inducing a resultant frequency based change at the neural membrane.

\[
\Delta \Theta = \frac{2.3RT \log \left( \frac{P_{k^+} [k^+]_o + P_{na} [na^+]_o + P_{cl} [cl^-]_o}{P_{k^+} [k^+]_i + P_{na} [na^+]_o + P_{cl} [cl^-]_i} \right)}{F}
\]

F= Faraday’s constant
P=ion permeability constraints