Perspective Article

The Electroencephalographic Brainwave Spectrum, Mindful Meditation, and Awareness: Hypothesis

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Abstract

It is hypothesized that being mindfully aware is a spontaneous state of being. It is imbued with joy, peace and happiness. Such a state is periodically revealed during restful attentiveness or presence. It is also associated with spontaneous brain alpha activity of 8–13 Hz. In deep nonrapid eye movement sleep, there is synchronous delta activity at a coherent frequency of 0.1 Hz. Both of these brainwave ground states are spontaneous, calm and effortless. When any physical or mental effort is made, the alpha rhythm is desynchronized, and it is superposed by faster brain waves of beta (13–30 Hz) and gamma frequencies (30–150 Hz). This is associated with a stream of dualistic conscious experiences with contents. During deep sleep, delta activity is superposed by beta and gamma activity with microarousals resulting in dream experiences. During effortless, meditative awareness, the whole family of alpha rhythm is synchronized including (a) *Occipital-parietal alpha* with visual clarity, formless color, and the absence of visual imagery (b) *Frontal eye-field alpha* with relatively motionless eyes, and the absence of voluntary actions or plans to move the eyes in some direction, along with nonactive working memory, (c) *Somatosensory alpha or Mu rhythm* from the somatic motor-sensory cortex with the resultant stillness of the body including head, face, larynx, spine, hands and legs, (d) *Mid-temporal auditory alpha* with vocal quietness and internal verbal silence (*Maunam*) with a feeling of spontaneous silence and serenity, (e) *Cingulate and precuneus alpha* resulting in freedom from autobiographical memories and the sense of agency or ego. The insular cortex serves as a gatekeeper, a hierarchical controller to switch between conscious engagement or disengagement from the internal or the external world. It switches between the default mode network and the executive frontoparietal networks, between the sequential and the parallel modes of functioning. Mindful consciousness is local and dualistic, whereas mindful awareness is nonlocal and nondual.

Keywords: *Bio-synergy, body-mind-world homeostasis, default state of being, electroencephalographic brainwave spectrum, global alpha synchrony, insular cortex, mindful meditation and awareness, optimal flow state, sleep-wake-mind central pattern generator*

Introduction

Bioelectricity is defined as an endogenous electrical signaling mediated by the dynamic distribution of charged molecules in the living organisms. Neuro-electricity is an evolved and specialized form of bioelectricity. Bioelectricity is one of the three major forms of bioenergy, namely biochemical, biomechanical, and bioelectrical. These three forms of bio-energy are instantly integrated in almost all of the biophysical events and life processes. This triune bio-synergy with bio-synchrony, and homeostasis are continuously enactive in all living forms. These bioenergetic forces create dynamic and infinitely variable biopatterns. In this sense, the whole universe is a self-organized biosystem with its own natural laws. Considerable recent research work is available on bioelectricity and biopatterns.[1-8]

The Alpha Rhythm

Since the discovery of human brain's electrical activity by Hans Berger in 1929, extensive research has been done in the human electroencephalography (EEG). Berger used the term "electroencephalography" or EEG for the first time in neuroscience. The great advantage of EEG in studying the human brain-mind activity is that it is fast and precise even in the millisecond range. Other techniques like the functional magnetic

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resonance imaging brain, take several seconds for a single measurement. Most of the human conscious mentation and behavior happens in the sub-second range. As a matter of fact, the EEG microstate is defined as a set of EEG events occurring within 60–120 ms.[9] The duration of one item in working memory can be 25 ms, and one can hold 7 ± 2 items in one's working memory. Human evoked potential studies show the auditory evoked potentials to be about 10 ms, visual evoked potentials 100 ms, and the conscious event-related potential, P300 is about 300 ms for one conscious decision.

The alpha EEG rhythm of 8–13 Hz was initially popularized as the Berger rhythm. The historical aspects of Berger's EEG discovery, his early astute observations and writings have been reviewed recently.[10] Berger observed that the alpha rhythm was suppressed by eye-opening and mental activity. He thought it was a spontaneous, whole cortical rhythm rather than a local phenomenon in the visual cortex.

The Family of Alpha Rhythms

The recent research in EEG has discovered a family of at least five alpha rhythms.[11] (A) *Parieto-occipital alpha rhythm* is an ongoing archetypal brain rhythm. It can be suppressed immediately and consistently by eye opening, eye movements, visual imagery, and any mental activity like effortful cognition as in arithmetic calculations. (B) *Frontal alpha rhythm* is based on the activity in frontal eye field, and other frontal areas. This rhythm is suppressed by eye movements and eye movement imagery. (C) *Somatic motor-sensory alpha rhythm*, which is also known as the *Mu rhythm*, follows a somatotopic homuncular pattern of activation. Individual movements of finger, thumb, foot, and tongue selectively suppress the *Mu rhythm* in the corresponding areas in the somatosensory homunculus. (D) *Temporal alpha rhythm*, which is also called the *Tau rhythm*, is present in the midtemporal cortical area. It is suppressed by auditory stimulation, speech and vocalization. (E) *Cingulate alpha rhythm* includes the precuneus and medial temporal lobe areas. These areas showed alpha rhythm especially after neurofeedback training (NFT).[12] These areas are an integral part of the default mode network (DMN).

The DMN shows at least two main rhythmic components, namely a slow 0.1 Hz resting rhythm and an alpha rhythm. The slow rhythm is probably related to the coherent breathing during non-rapid eye movement (REM) sleep and silent meditation. This family of alpha rhythms is mediated by a pacemaker or the reciprocal inhibition mechanism involving the thalamo-cortico-striatal-cerebellar circuit. The locus coeruleus and other monoaminergic brainstem nuclei are involved in such a global sleep-wake-mind central pattern generator (CPG) process as shown in the Figure 1.

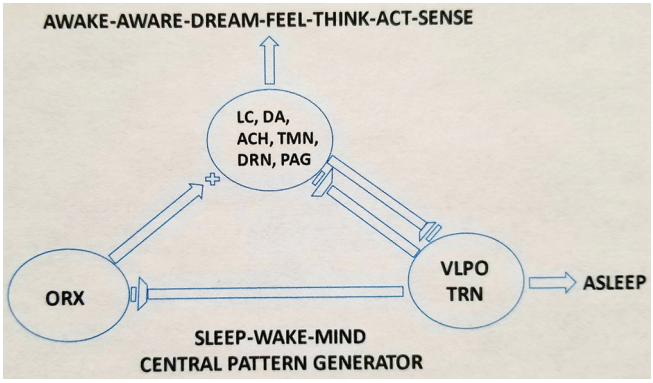

Figure 1: The swmCPG. swmCPG: Sleep-Wake-Mind Central Pattern Generator, ACH: Acetyl choline, DA: Dopamine, DRN: Dorsal raphe nuclei, LC: Locus coeruleus, ORX: Orexin, PAG: Periaqueductal gray, TMN: Tuberomammillary nucleus, TRN: Thalamic reticular nucleus, VLPO: Ventrolateral preoptic area. The arrow with + sign indicates excitation, and the arrow with − sign indicates inhibition

Cortical Excitability and Pulsed Inhibition

The pulsed inhibition theory is about how the alpha rhythm functions as an inhibitory mechanism in the thalamo-cortical-striatal-cerebellar circuit.[13] According to this theory, alpha oscillatory synchrony is associated with pulsed cortical inhibition. Higher alpha amplitude tends to cause cortical inhibition and reduced local excitability. This response also depends on the phase of the alpha rhythm. The local cortical excitability affects the modal cortical functions like vision, audition, touch, movement, cognition, and speech. The best cognitive performance is achieved with optimal conscious arousal and cortical excitability. There is probably a homeostatic phenomenon in the spontaneous organization of this global physiological arousal and cortical excitability. This involves a homeostatic organization of the limbic-autonomic activity, the salience network, and the fronto-parietal executive network. It may be called, the body-mind-world homeostasis. Here the word *world* means *umwelt,* or the world experienced by an individual organism. Such an optimal state of a naturally blissful, self-aware being has been described as a homeostatic feeling, Nirvana or Sthita-Prajñā.

The goal of mental training is to achieve an optimal conscious arousal, calm attentiveness, and excellence in physical-mental performance. Some of the researchers have tried to enhance the alpha rhythm in frequency and amplitude by various techniques including neurofeedback (NFT), transcranial alternating current stimulation (tACS), and other practices like multisensory stimulation, nature walk, yoga, and meditation. Both NFT and tACS have shown some improvement in the alpha amplitude, sensory perceptivity, and cognitive performance.[14-24]

Cortical excitability and the associated functions are localized and lateralized. Some examples of these localized functions are the Penfield's map of sensorimotor homunculus, the cortical areas for vision and audition, Broca's expressive speech area, Wernicke's receptive speech area, and the prefrontal executive functions. When

a local cortical area is activated by a sensory stimulus, the local alpha rhythm is desynchronized, and it is superposed by higher frequency beta and gamma frequencies. This has been demonstrated by lateralized visual stimulation in a mirror-hand illusion, and the unilaterally presented, emotionally distractive stimuli. This is not only true for visually perceived events, but also for mentally visualized events as in visual imagery, vocal rehearsals, and internal speech.[25,26]

The Brainwave Spectrum, Breathing, and Mentation

Brain waves are the neuroelectric waveforms of various frequencies ranging from 0.01 Hz to 600 Hz. This wide spectrum of brainwaves has been classified into (a) Infra-slow waves of 0.01–0.1 Hz, (b) Delta waves of 0.1–4 Hz, (c) Theta waves of 4–7 Hz, (d) Alpha waves of 8–13 Hz, (e) Beta waves of 13–30 Hz, and (f) Gamma waves of 30–150 Hz. An extended brainwave spectrum fits well on a natural logarithmic scale with an exponent e = 2.718281.[27]

Various human behaviors and mental activities are associated with specific patterns of brainwaves in certain cortical areas as was highlighted in the family of alpha rhythms. The specifically localized and lateralized cortical areas are also activated by the subcortical arousal system, namely the reticulo-limbic salience network. It is the salience network that instantly decides whether to approach or avoid a new object in the environment. It makes an instantaneous choice that is vital for the organism's survival and psychosocial success.

The tripartite model of cortical neural networks consists of (a) *Reticulo-limbic salience* network, (b) DMN, and (c) *Fronto-parietal executive* network. All of the human conscious and subconscious activities, experiences, and behaviors are mediated by these three neural networks. An action is a meaningful movement with a specific goal. The spontaneous and intentional actions are guided by the multimodal sensory and memory feedbacks. This leads to the predictive control model of body, mind and world. In order to survive and thrive, we constantly struggle to minimize pain or displeasure and enhance pleasure. When we are free of the pressing needs, desires, fears, efforts and the sense of ego, we reach an optimal homeostatic state of wellness, happiness, and self-freedom, also called eudaimonia, Nirvana and Sthita-Prajñā.[28,29]

Human breathing was significantly correlated with alpha rhythm, cortical excitability and perceptual sensitivity.[30] The alpha rhythm phase and the respiratory phase are correlated with sensory-perceptual performance. The moment-to-moment relationship between cortical excitability and the perceptual sensitivity are coupled to the body's coherent respiratory oscillations at 0.1 Hz or 6 breaths/min. The central role of respiration in the synchronization of sensorimotor information-sampling to phases of neural excitability has been shown in animal studies. An interaction between alpha and beta rhythms has been shown as beta oscillations are implicated in mediating top-down signals from the frontal eye field to modulate excitability in the visual cortex during visuospatial attention. The two main sources of respiration-locked neural signaling are the mechanoreceptors of olfactory bulb (OB) and the brainstem respiratory command neurons. The cross-frequency coupling between the alpha and beta bands are of importance in the active sensory sampling (beta rhythm), and the perceived experience (alpha rhythm). The respiration-related changes in both oscillatory power and behavior dissipate during expiration and oral breathing.

The voluntary rhythmic nasal respiration is of great importance in shaping of human cortical excitability and the body-brain-mind state in health. The yogic practices of pranayama are fully supported by this research. The pranayamic techniques of Bhastrika, Anuloma-Viloma, Kapala-bhati, Bhramari, AUM recitation, and other breathing techniques are well supported by this research.[31]

The First Breath of Life and the Voluntary Control

Human extrauterine life begins with the first breath. The first breath is preceded by complex bio-synergetic processes. For instance, the clearing of the fluids from the lungs and the expansion of chest cavity. The initial neuroelectric events are an instant activation of the Kölliker–Fuse pontine nucleus, which initiates the first inspiratory action, followed by the direct stimulation of the facial/parafacial nuclear complex, which activates the pre-Bötzinger nuclear complex and thus activates the diaphragm. The initial instantiation of the first breath is probably due to high proton or H + ion concentration, and the high CO_2 at the area postrema and other chemo-sensitive zones. At birth, motor neurons allow for the generation of more substantial movements of the thoracic cage, which can meet the requirements of extrauterine breathing.[32]

Voluntary motor control and its hierarchical network were recently reviewed.[33] The five major neural circuits involved in the voluntary action initiation, maintenance, slowing, and stopping were described. The three neural circuits namely skeleto-motor, oculomotor, and dorsolateral prefrontal cortical networks are parts of the fronto-parietal executive network. The two neural circuits, namely orbitofrontal and the anterior cingulate-insular networks are parts of the limbic-autonomic salience network. This tripartite cortical network system also includes the DMN.

Studying intracranial EEG recordings in patients with epilepsy, a direct correlation was found between the gamma activity and the respiratory rhythm in many cortical areas. In voluntary control, the cortical areas involved were caudal-medial frontal, premotor, orbitofrontal, motor

cortex, insula, superior temporal gyrus, and amygdala. In attentive breath awareness, the structures involved were anterior cingulum, premotor, insula, and hippocampus. This neurophysiological understanding provides a good insight into the key brain mechanisms involved in therapeutic breathing exercises such as pranayama.[34]

Nasal breathing modulates local and long-distance gamma coherence in mice, rats, and cats. The frequency of natural breathing was 2–5 Hz in mice, 1–4 Hz in rats, and 0.1–2 Hz in cats. The modulated frequency ranges corresponded to a faster gamma (90–130 Hz) in mice, an intermediate gamma (60–100 Hz) in rats, and a slower gamma (30–60 Hz) in cats. The respiration-driven modulation of gamma amplitude in both OB and the prefrontal cortex could be causal to prefrontal fast gamma. The gamma rhythm disappears upon olfactory bypassing or deafferentation. The respiration phase has been shown to modulate the occurrence of sharp-wave ripple complexes in the hippocampus, a believed substrate of memory consolidation during non-REM sleep and quiescent awakeness.

The hypothesis of *communication through coherence* postulates that the synchronization of oscillations would be a generic key mechanism aiding information transfer. The piriform cortex is the main hub for passing olfactory information to downstream areas, including the orbitofrontal cortex, the mediodorsal thalamic nucleus, and the prefrontal cortex. From a functional perspective, the observed coordination between networks in OB and the frontal cortex may increase the spike synchrony and contribute to higher-order representations, similar to perceptual binding by neural synchrony. Breathing modulates cortico-cortical gamma synchrony in awake animals and thus is likely to orchestrate long-range communication in the mammalian brain. It was postulated that while hippocampal theta provides an internal clock organizing memory and navigation, respiration-entrained rhythms may serve a similar purpose in timing and integrating externally sampled information.[35]

The Central Pattern Generators and Locomotion

All living organisms are continuously active with variable intensity. The CPGs are ubiquitous and spontaneous in many living organisms from Lamprey to Humans. The main characteristic of CPG is that they have a spontaneous output with optional sensory-cognitive modulation. They have an inside-out or action-centered strategy. The two mechanisms of their functioning are (a) the *pacemaker neurons* with their pulsatile output, as in the cardiac electrical network, and (b) the *reciprocal inhibition* mechanism as in innumerable neuroelectric circuits. The CPGs participate in *multidimensional homeostasis*, which is the fundamental property of all life-forms.

The concept and circuitry of CPG was reviewed.[36] The primary function of the nervous system is to move the organism as a whole or partly and more precisely in order to fulfill its behavioral goal depending on its current needs. As Professor Grillner described it,

"The cellular basis of propulsion represents the core of the control system, and it involves the spinal CPGs networks controlling the timing of different muscles, the sensory compensation for perturbations, and the brain stem command systems controlling the level of activity of the CPGs and the speed of locomotion. The forebrain and in particular the basal ganglia are involved in determining which motor programs should be recruited at a given point of time and can both initiate and stop locomotor activity. The propulsive control system needs to be integrated with the postural control system to maintain body orientation. Moreover, the locomotor movements need to be steered so that the subject approaches the goal of the locomotor episode, or avoids colliding with elements in the environment or simply escapes at high speed."

The inside-out strategy of the brain is well described by Professor Buzsaki in his book.[37] His core argument is that "The brain is a self-organized system with preexisting connectivity and dynamics, whose main job is to generate actions and to examine and predict the consequences of those actions." Actions are meaningful, goal-directed movements.

There are multiple CPGs in the spinal cord and the brainstem. The CPGs are mainly associated with motor output from the embryonic basal plate derivatives. They include the somatic motor, branchial motor, and visceral motor nuclei with related cranial and spinal nerves. Some of the brainstem CPGs are named after their behavioral functions, for instance, the CPG for walking, breathing, swallowing, chewing, vocalization, and the head and eye movements.[38,39]

Mindful Meditation and Mindful Awareness: Hypothesis

It is hypothesized that being effortlessly aware is our natural default state. It is being spontaneously joyous, peaceful and happy. Such a state is periodically revealed during restful awakeness. Such mindful awareness is associated with the synchronous, brain *alpha synchrony* of 8–13 Hz in at least five cortical regions as described below. In deep non-REM sleep, there is *synchronous delta* activity at a coherent frequency of 0.1 Hz. Both of these ground states of brainwaves are effortless and calm. But most of us do not notice this fact in their own body-mind-self.

When any physical or mental effort is made in any motor domain, the alpha rhythm gets desynchronized or blocked, and it is superposed by high frequency brain waves like beta rhythm (13–30 Hz) and gamma rhythm (30–150 Hz). This is associated with a multimodal stream of dualistic wake-experiences with varied conscious contents and behavior. During deep sleep, the delta activity is

superposed by high frequency beta and gamma activity with microarousals resulting in dream experiences.

During effortless, meditative awareness, the whole family of alpha rhythm is synchronized including (a) *Occipital-parietal alpha* with visual clarity, formless color, and the absence of visual imagery (b) *Frontal eye-field alpha* with relatively motionless eyes, and the absence of voluntary actions or plans to move the eyes in some direction, along with nonactive working memory, (c) *Somatosensory alpha or Mu rhythm* from the somatic motor-sensory cortex with resultant stillness of the body, head, face, larynx, spine, hands and legs, (d) *Mid-temporal auditory alpha* with vocal quietness and internal verbal silence (*Maunam*) with a profound feeling of spontaneous joy and peace. One may hear a spontaneous *voice of silence* called anāhata nāda in the yogic literature.[40,41] (e) *Cingulate and precuneus alpha* resulting in freedom from random past memories, autobiographical me, and the sense of individual agency or ego. Mindful consciousness is dualistic with contents, whereas mindful awareness is nondual.

"I am joyously present and aware. I am aware of this event. I feel well and happy now. I feel and understand my deep connection with nature. I am happily embedded in nature." These are a few self-observations from my personal journal.

Such a *global alpha synchronization* reveals an effortless, mindful awareness. It is strengthened by frequent meditative realizations and insights. We drift away from it by making effort for example by recalling our past experiences, imagining the future, talking unnecessarily to ourselves or others, and planning endlessly, with effortful cognition and persistent action. One has to finish one's narration, and stay calm, alert, attentive, and disengaged from the ego-centered, intentional choice, action, plan, and distraction. One has to let go momentarily, all personal mental activity in order to return to the naturally effortless, default state of our blissful, aware being.

Brief Review of the Electroencephalography Research on Meditation

The occurrence of transient alpha: theta ratio of 2:1, a harmonic relationship that increases linearly from a meditative to an active cognitive processing state. Brain oscillations at alpha (8–14 Hz) and theta (4–8 Hz) frequency bands have been shown to play a key role in a wide variety of cognitive tasks involving memory and executive control. While alpha oscillations have been associated with the storage and retrieval of information, theta oscillations have been associated with the manipulation of such information. The neural correlates of meditative states can be characterized in opposition to effortful cognitive processing, when studied from an EEG *cross-frequency dynamics* perspective.[42]

Focal attention (FA), open monitoring (OM), transcendental meditation, and loving kindness meditation are associated with global increases in oscillatory activity in meditators compared to meditation-naïve adults, with larger changes occurring as the length of meditation training increases. While FA and OM are related to increases in anterior theta activity, only FA is associated with changes in posterior theta oscillations. Alpha activity increases in posterior brain regions during both FA and OM. In the anterior regions, FA shows a bilateral increase in alpha power, while OM shows a decrease only in left-sided power. Gamma activity in these meditation practices is similar in frontal regions, but increases are variable in parietal and occipital regions.[43] Meditation training increased mindful awareness, deepening mental calm, and attentional focus. The dynamic sequencing of EEG microstates were associated with daily increases in felt attentiveness and serenity during training.[44] The effectiveness of meditation as a stress management tool in college students was shown using EEG studies.[45] The state of *open presence* in experts is characterized by increased sensory monitoring and reduced perceptual inferences compared to FA. This study attempted to describe the impact of nondual meditation states on the regulation of brain's automatic predictive processes.[46]

The flow state of mind represents an optimal state of personal experience and skillful peak performance. Considerable research is being done on the preparation, entry into, and exit from the flow state especially in athletes and musicians.[47] In the relaxed preparatory state, there is a development of higher alpha power of 10–12 Hz in the right posterior parietal area, which is a well-known site for global attention and its regulation. An enhanced fronto-parietal connectivity leads to the generation of more creative ideas.[48] In the flow state, there is an activation of Locus Coeruleus-Norepinephrine system, which leads to more alertness and attentiveness. For the best performance, one has to achieve a balanced state of optimal, calm alertness in the preparative phase, followed by an effortless, fully immersed, self-unaware, masterly performance in sports, music, and meditation.[49,50]

Two Fundamental Modes of Conscious Being and Behavior

There are two fundamental modes of our conscious being and behavior, namely sequential and simultaneous. This has been expressed in many complimentary ways as rest-activity, excitation-inhibition, engaged-disengaged, explore-exploit, approach-avoid, sympathetic-parasympathetic, act-pause, appetite-satiety, phasic-tonic, timed-timeless, effortful-effortless, egocentric-selfless, global-local, dual-nondual, individual-universal, sleep-wake, riverlike-oceanlike. The insular cortex serves as a gatekeeper, a hierarchical controller to switch between conscious engagement or disengagement from the internal or the external world. It switches between the DMN and the executive

frontoparietal networks, between the sequential and the parallel modes of functioning.[51,52] My poem titled, "River and Lake" expressed this *complimentary principle* as follows:

> "A skillful mind can flow like a river,
> Or standstill like a lake.
> It depends on the terrain it faces at present.
> It lives with a spontaneous joy,
> Sometimes like a river,
> And sometimes like a lake."

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Conflicts of interest

There are no conflicts of interest.

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