Review

On brain criticality in the context of resonance

Gerry Leisman[1,2*]

[1]Movement and Cognition Laboratory, Department of Physical Therapy, University of Haifa, 199 Abba Khoushy Avenue, Eshkol Tower, Rm. 910, Haifa, Israel 3498838

[2]University of the Medical Sciences of Havana, Department of Clinical Neurophysiology, Calle D No. 139 esq. 29, Vedado, Plaza de La Revolución, Habana, Cuba

***Correspondence: Correspondence:** g.leisman@welfare.haifa.ac.il
DOI: https://doi.org/10.56280/1579669390

Received 2 February 2023 Accepted 28 May 2023 Online published 27 June 2023

Abstract

Biofields integrate several physiological levels temporally and spatially. Physiological coherence complements metabolic processes, which preserve animal cellular and physiological function. Coherent physiology involves internal biological system coordination and sensitivity to specific stimuli and signal frequencies. Current research shows that exogenous biologically and non-biologically generated energy entrains human physiological systems. Electrical and magnetic field measurements during physiological activity may occur from metabolic processes or unknown physiological actions. All living things resonate at similar or coherent frequencies; therefore, species will eventually share resonance. Resonance is a term closely related to awareness, interregional connections or disconnection in the brain, and the integratory function of the brain. It can describe synchrony, vibration, or harmony more broadly. The synchronized electrical cycles of the brain have similar resonance patterns. Resonance's significance in fostering integrated brain activity, awareness, awakeness and death are reviewed.

Keywords: Resonance, brain criticality, entrainment, biofield, awakeness, awareness, integrated brain function, death

1. Introduction

We have long wondered how a biologically based machine could be built with billions of neurons that outperform several of the most sophisticated computers. The brain has significant processing capability and nearly infinitely expandable storage (Kang et al., 2020; Leisman, 2022; Leisman & Melillo, 2022). The brain can tune itself to the level where it can be excitable without chaos, akin to a phase transition. The idea that the brain may tune itself to an excitable level without the disorder in a manner analogous to a phase transition has recently been supported (Romanczuk & Daniels, 2023). Our nervous system tends to maintain a balance between rest and chaos. Information processing is optimized when there is a state of flux between quiescence and chaos (Ma et al., 2019). This then leads us to the notion of criticality.

Complex systems on the verge of a phase change between randomness and order are in a critical state (Romanczuk & Daniels, 2023; Fenoaltea et al., 2023). There is a unique improvement in information processing abilities in this kind of system, and we might even speculate that in the brain (Grosu et al., 2023; Olabe et al., 2023). We are starting to identify relationships and connections between criticality, computing, and cognitive processes. We can better grasp the nature of cognition and neural processing by comprehending the concept of criticality. Criticality is a state found in complex systems on the cusp of a phase transition between randomness and order (O'Byrne & Jerbi, 2022). There is a singular enhancement of information-processing capacities, in which we might even think the brain itself may be critical (Romanczuk & Daniels, 2023; Fenoaltea et al., 2023). By understanding the notion of criticality, we can gain a more fundamental understanding of the nature of cognition and neural computation. We are finding associations and linkages between computation, criticality and cognitive processes (Sandvig & Sandvig, 2022). When neurons functionally combine with others, they seek a critical set point and regime (O'Byrne & Jerbi, 2022; Shine, 2023). Criticality is mediated inhibitory neurons, whose function appears to regulate larger brain networks (Liang & Zhou, 2022).

Neurons that fire simultaneously link together, according to Hebb (1948). We now understand that neurons seek a key set point and regime when they functionally join others and the idea that criticality is subject to active regulation (Ma et al., 2019).

Criticality is mediated by inhibitory neurons, see e.g., Koch & Leisman (1990, 2015) and Leisman & Koch (2009). These neurons appear to have a role in controlling larger brain networks. According to Koch & Leisman (2015), the function of criticality is to develop a computational model that may be used to optimize information processing, including storing and transmitting intricate sensory patterns and parts of memory.

Power laws (Palva & Palva, 2011) are the foundation for most measurements in clinical neurophysiology and psychophysics. These power laws are used to separate background activity from noise using a variety of methodologies, such as the Fast Fourier Transform, signal averaging techniques, coherence, dipole source localization, and Hilbert-Huang transforms. The exponent relation is a good substitute for direct use in information processing. We might want to look into biofield physiology to explain the living process, in order to better comprehend the relationship between criticality, resonance, consciousness, "*awakeness*", awareness and integrated brain function.

2. Biofield physiology and information

Biological systems produce a variety of partially distributed fields as a means of self-regulation and efficient physiological organization. Similar to molecular control systems, biofields can change physiological regulatory systems. These biofields, which modify brain synchronization, include magnetoencephalograms (MEG) and electro-encephalograms (EEG) (Kerrick, 2022).

Biofields comprise widely dispersed forces that can encode information (Hammerschlag et al., 2012; 2015). These pressures can control and impact the physiology of tissues and cells. A complementary function for physiological coherence to metabolic processes, frequently considered to sustain cellular and physiological function, biofields coordinate the integration of several levels of physiological activity temporally and spatially (Ho, 2008). In this context, the terms "biofield activity" and "resonance" are synonymous to denote what makes a living object.

Coherent physiology necessitates, among other things, effective coordination and integration of internal biological systems as well as a sizable sensitivity to certain stimuli and hence to particular signal frequencies. Current research indicates that exogenous biologically and non-biologically generated energy is susceptible to and entrains human physiological systems (Kerrick, 2022). Numerous instances have led to this observation being made. Measurements of electrical and magnetic fields can be taken during physiological activity, which may be confusion brought on by metabolic processes or the outcome of physiological action that is not fully understood (Finger & Kramer, 2021; Doelling et al., 2023).

It is recognized that there will eventually be shared resonance, both within and between individual species, because all living things resonate at comparable or coherent frequencies. In neuroscience, resonance theory has been used, see e.g., Koch (2004), and Fries (2005, 2015). According to Fries (2005, 2015), brain synchronization, resonance, or "*communication through coherence*," is a crucial aspect of the nervous systems function.

Numerous theorists have hypothesized that resonance contributes to conscious states. Dehaene (2014) states that integrated conscious activity results from long-distance connections between synchronous or resonant cortical areas (see also Koch, 2004). By claiming that while consciousness, which is associated with being awake and aware, is a function of resonance, it is not always a property of all resonant states, exemplified by Grossberg (2017) who extended the idea of brain communication-based resonance. Phase changes in resonance were also considered vital for understanding brain function (Freeman & Vitiello, 2006). When Pockett (2000, 2012) proposed an electromagnetic field theory based on synchronization from movement feedback when differentiating between conscious and non-conscious fields, she raised the significance of resonance in understanding integrated brain activity. Others have developed resonance-based brain integration theories, such as Bandyopadhyay et al. (2020), noting EM resonances between clouds of delocalized charges where there is collective delocalization of electrons between benzene rings and aromatic residues of amino acids (Poznanski et al., 2022), or "fractal information theory" (Sahu et al., 2013a, b; Singh et al., 2018). As a result, although theoretical and not yet in practical application, the significance of resonance in understanding brain communication systems has started to acquire momentum.

3. Resonating with life (and death)

One of the numerous hypotheses explaining life and living is the assumption that life function comes from organized computer-like activity in the brain's neural networks connected with mental states (Zhuravlev, 2023; Seymour, 2023). Another notion is that the temporal binding of information in these networks is associated with synchronous oscillations between the cortex and thalamus (Yu et al., 2022; Roelfsema, 2023). How we think consciously may be impacted by the complexity of neural computing (Rolls, 2020; Veit, 2023).

Brain death itself is not noteworthy until a clinical definition is required. Comprehending the mechanisms at play during the lack of consciousness is more important. Although death seems to be a real event and an undeniable state, a corpse, whether human or otherwise, continues life function even after being proven brain dead. There is a minimal disagreement that the person is brain dead despite a few isolated cells, nests, or cell subnetworks that continue to function.

As we continue, the argument becomes more challenging since, although the brain has "died," peripheral body organs like the heart, lungs, liver, and other organs still function due to modern developments. In the past, we had thought that the body perished when the full brain expired, and resultantly physical functions ceased. Nevertheless, the development of modern technology has made it difficult for us to determine the precise moment of death. The constituent components of consciousness or micro-consciousness entities must combine to provide us with the vividness of the conscious experience bringing us to the "*combination problem*" (Young et al., 2022a, b).

3.1. The combination problem

The "combination problem" (Young et al., 2022a, b) poses how lower-level micro-consciousnesses can combine to create higher-level macro-consciousnesses, if at all. The suggested answer in the context of mammalian consciousness proposes that a shared resonance enables various portions of the brain to undergo a phase change in the velocity and bandwidth of information flow between the parts (Young et al., 2022a, b). Richer types of consciousness can emerge due to this phase transition, with the specific set of component neurons determining the character and content of that consciousness at any given time (Pereira et al., 2022). To distinguish this perspective from emergent materialism, we can provide more general insights into the ontology of consciousness and propose that awareness manifests as a continuum of increasing richness in all physical processes. This method called a *meta-synthesis*, can be called a *generic resonance theory* (Grossberg, 2012; Dresp-Langley, 2023).

3.2. All things resonate in some manner

Everything in our universe is constantly moving and developing. Even seemingly immobile objects vibrate, oscillate, or resonate at particular frequencies. Therefore, everything oscillates, and resonance is characterized by coordinated oscillation between two states. When various oscillating processes are close enough in frequency, they frequently begin vibrating at the same frequency (Strogatz, 2003). They "sync" sometimes surprisingly, making information and energy flow richer and faster. Analyzing this phenomenon may yield a profound understanding of the nature of consciousness, both in the context of humans and other mammals and at a more fundamental level. In order to demonstrate the nature of synchrony relative to the experience of consciousness, Strogatz (2003) employed a variety of examples of resonance from physics, biology, chemistry, and neuroscience.

Large-scale neuron firing can occur at precise frequencies in human brains and mammalian consciousness, which are thought to be frequently linked to different types of neuronal synchronization (Crick & Koch, 1990; Koch, 2004; Fries, 2005, 2015; Dehaene, 2014). At this point, it can be helpful to consider how resonance and synchrony differ in our inquiries.

3.3. What are resonance and synchrony

Resonance or synchronization is the propensity for several processes to move in unison — to oscillate — at the same or a similar frequency. Synchrony, also known as harmonic oscillator theory or complex network theory, is the study of how connected oscillators behave about one another.

Numerous instances of resonance raise the following two queries: How do the parts of resonant structures - a term used to denote any collection of resonating parts - communicate with one another, and how do they achieve resonance once they do?

According to Walter Freeman's studies of the brains of rabbits and cats, electrical field gamma synchrony, a specific sort of neuronal synchrony, is accomplished too swiftly to rely just on electrochemical neuronal signalling and must instead depend on electrical field signalling. As Freeman & Vitiello (2006) stated, the beta and gamma ranges of carrier waves periodically re-synchronize in extremely short time lags over very large distances, according to the high temporal resolution of EEG signals, providing evidence for various intermittent spatial patterns. Axodendritic synaptic transmission, the predominant mechanism for brain interactions, should cause the EEG oscillations to experience distance-dependent delays due to finite propagation velocities and sequential synaptic delays. Not at all. Even gap junction coupling cannot fully account for the precise coherence of global brain gamma “synchrony”, according to Craddock et al. (2015). However, the available data strongly suggest that shared resonance is crucial for human and other mammalian consciousness.

3.4. How do resonating structures achieve shared resonance?

How do entities that connect through resonance modify their resonance frequencies to reach resonance with one another? In many circumstances, entities that are initially unsynchronized manage to become entrained. What driving forces are behind these processes?

We may compare the mechanisms that enable firefly synchrony to conscious human activities regarding how fireflies time their flashes. For instance, when we want to lift our finger, a series of neuronal pulses from our brain to our finger causes the desired result, and the motion is made. Like fireflies, it is conceivable to hypothesize that after they plan to flash their lights, an electrical pulse is sent from the fly's brain to its abdomen thereby activating the physiological and chemical mechanisms that cause the fly's bioluminescence to take effect (Strogatz, 2003).

It might seem unusual to attribute intent to fireflies. However, it would make sense that fireflies would have intentions and conscious control over some of their physiological processes - especially important processes involving substantial organs like their light-producing organ. Their actions are intricate and show a variety of "*behavioral correlates of consciousness*." By comparing the different neurological and behavioural similarities between humans and other mammals, we may recognize that fireflies probably only have a basic level of conscious awareness without implying anything close to the depth of human consciousness.

Based on the supposition that fireflies possess a primitive kind of consciousness, at least in comparison to human consciousness, we may provide a high-level explanation for how flashes are synchronized without considering the intricacies of sub-level mechanisms.

However, we can also explain firefly flashing synchrony without intelligence or consciousness. This is Strogatz's method, and he and his colleagues proposed intrinsic biological oscillators that automatically sync with neighbours to explain the mystery of firefly synchrony (Strogatz, 2012).

It would be difficult to argue that individual neurons want to be in synchrony, but there is evidence for some form of neuronal consciousness, however basic it may be compared to whole-brain consciousness. How do neurons synchronize so swiftly and regularly? Although numerous indications point to different field effects, this is still unknown. We do not yet understand how this communication occurs in each neuron in such a way that swiftly modifies each neuron's electrical cycle to match fast-altering macroscopic patterns.

Keppler (2013) focused on the phase changes observed in mammalian brains and how these brains appear to exist generally in a state of "criticality," making them extremely sensitive to tiny alterations. It is possible to think of brain mechanisms underlying conscious activities as a complicated system that functions close to a key point of a phase transition. Any appropriate stimulus can trigger the brain to switch from a disordered phase, which shows spontaneous activity and irregular dynamics, to an ordered phase, which shows long-range connectivities and stable attractors.

The idea of "phase transition" can be significant in the context of macro-consciousness and the combination problem. Neuronal states associated with brain states can likewise oscillate in response to relatively insignificant stimuli. The idea that phase transitions are crucial to mammalian consciousness is supported by Dehaene (2014).

A cognitive frequency trio of particular electrical brain wave combinations is characterized as follows by Fries (2005, 2015) that gamma-band synchronization implements the selective communication of the attended stimuli, beta-band synchronization mediates top-down attentional influences, and a 4 Hz theta rhythm resets gamma regularly. Because nature comprises numerous lawful processes, each will resonate at different frequencies. Additionally, processes close to one another may eventually synchronize and resonate at the same frequency.

4. Criticality of resonating consciousness

Hunt (2011) and Schooler et al. (2011) proposed psychophysical laws describing the relationship between consciousness and physical systems. They elaborate on how resonance is essential for establishing macro-scale awareness by combining several micro-conscious entities at different organizational levels.

Without subscribing to panpsychism or panexperientialism (Hunt, 2011, 2014; Schooler, 2015; Schooler et al., 2011; Goff, 2017), we can state that connected consciousness is significantly primitive in the vast bulk of matter, possibly just a rudimentary humming of simple awareness in an electron or an atom. However, in some collections of matter, like in intricate biological life forms, consciousness can become markedly richer than most matter (Koch, 2014; Tononi & Koch, 2015).

An emergentist perspective contends that consciousness appeared where it had not before existed and arose at a specific period in each species that enjoys consciousness. Panpsychism is the opposing position to this theory.

Panpsychism contends that rather than emerging, the mind is always associated with matter and *vice versa* (they are two equally important sides of the same coin). However, the mind constantly connected to all matter is typically quite primitive. Only a very small amount of consciousness exists within an electron or an atom. However, as matter becomes more complex, the same is true of the mind and vice versa. Nevertheless, in this situation, complexity does not matter in any way. Instead, it is the result of stronger internal and external connections that resonate. With a focus on how resonant connections result in larger-scale conscious entities and how such entities may be described and quantified, Hunt (2011, 2019) developed a mathematical formulation of the concept. Although we will not go into great detail here (see Griffin 1998; Hunt 2011; Hunt 2014; Koch, 2014), supported by others (Schooler, 2015; Schooler et al., 2011; Goff, 2017; Tononi, 2012; Tononi & Koch, 2015).

Hunt (2011, 2014) explained his view of panpsychism in the context of integrated information theory when he indicated that, either elementary particles have a charge or they do not. Consequently, an electron possesses one negative charge, a proton possesses one positive charge and a photon, the carrier of light, possesses no charge. Regarding chemistry and biology, Koch (2014) indicates that charge is an inherent characteristic of these particles. Charge does not emerge from uncharged materials; it is simply present. According to his logic, the same holds for awareness. Consciousness arises from the organization of matter. It is inherent in the structure of the system. It is a property of complex entities that cannot be reduced to the actions of simpler qualities.

When two entities resonate at the same frequency, they bond or join in various ways. Depending on the entities under consideration, such common resonance and binding may occasionally result in blending various cognitive, perceptual and motor counterpart traits into a more cohesive whole (Leisman, 2022). According to quantum mechanics, matter is like a tiny standing wave of concentrated energy at the most fundamental level. Each of these waves is regional in both distribution and time.

It is easy to understand why shared resonance results in faster energy and information flow and, ultimately, macro-consciousness when we consider that matter is wave-like. Since waves of various forms underlie all physical processes, at least in part, when distinct entities resonate simultaneously, the waves cooperate rather than compete. This enables energy and information flow between the components of whatever resonant structure we observe to significantly increase bandwidth and speed. The information flows then combine into a larger entity, a greater harmonic, rather than occurring out of phase, and the resonating wave shapes of the micro-conscious creatures are coherent (decoherently).

Koch (2004) indicated that if the information to the brain is more sustained and amplified by top-down processing, a standing wave or resonance might be produced in the network, with critical contributions from feedback pathways. Local and more global feedback could cause neurons to synchronize their spiking activity beyond the degree of synchronization caused by sensory input alone. This amplifies their postsynaptic impact when they activate independently. On this basis, a significant network of neurons may be developed capable of exerting impact throughout the cortex and between lower brain structures. According to Koch (2004), this would be the slow mode upon which conscious awareness rests.

Fries (2005, 2015) proposed a "*communication through coherence*" theory. Fries (2015) offered the following example of shared resonance concerning neural resonance/coherence: "*Inputs happen at various times during the excitability cycle due to a lack of coherence, and their effective connection will consequently be reduced. However, if inputs coincide with the same excitability cycle, they will propagate more quickly and with a larger bandwidth*."

Organisms benefit from more rapid information sharing through various biophysical information pathways, (Funk, 2022). These faster and richer information flows enable the emergence of more macro-scale levels of consciousness than would be possible in similar-scale structures such as rocks or sand piles, as biological structures have evolving boundary conditions rendering functional interactions to take place (Poznanski et al., 2023). However, the type of functional interconnectivity must be based on resonance processes, which typically result in a phase transition in the rate at which information flows due to the switch from incoherent to coherent structures. Sand piles and rocks can be simply collections of incredibly rudimentary aware entities, as opposed to being combinations of micro-conscious entities that combine into a higher level macro-conscious entity, as is the case with biological life.

We know that gamma synchrony is a main neurological correlate of consciousness in human brains, a notion supported by Dehaene (2014). He focused on numerous "*signatures of consciousness*," including late-onset gamma synchrony (Hameroff, 2010). However, mammalian consciousness is often associated with a mixture of gamma and lower harmonic frequencies (Fries, 2015).

This common resonance creates an electromagnetic field that, through certain neuronal electrochemical firing patterns, might act as the source of macro-conscious information (Jones 2013; McFadden, 2002a, b; Pockett 2000; John, 2001). Gamma synchrony illustrates how additional neurons are absorbed into the common gamma synchrony, referred to as "*the conscious pilot*" by Hameroff (2010). This is backed up by other slower-frequency waves (Fries, 2015). On the other hand, as the shared gamma synchrony moves away from particular neurons, it enables those neurons to revert to their prior state of resonance, which translates into a more localized pattern.

In order to entrain additional neurons, this moving large-scale wave absorbs them into a semi-stable gamma wave pattern. As a result, the information and processing power of the various micro-conscious entities comprised by those neuron clusters can be integrated into a macro-conscious entity, and the pace of information interchange can move from largely electrochemical to electromagnetic. Through this procedure, the smaller-scale harmonics are entrained into the larger harmonic; as a result, all of the constituent

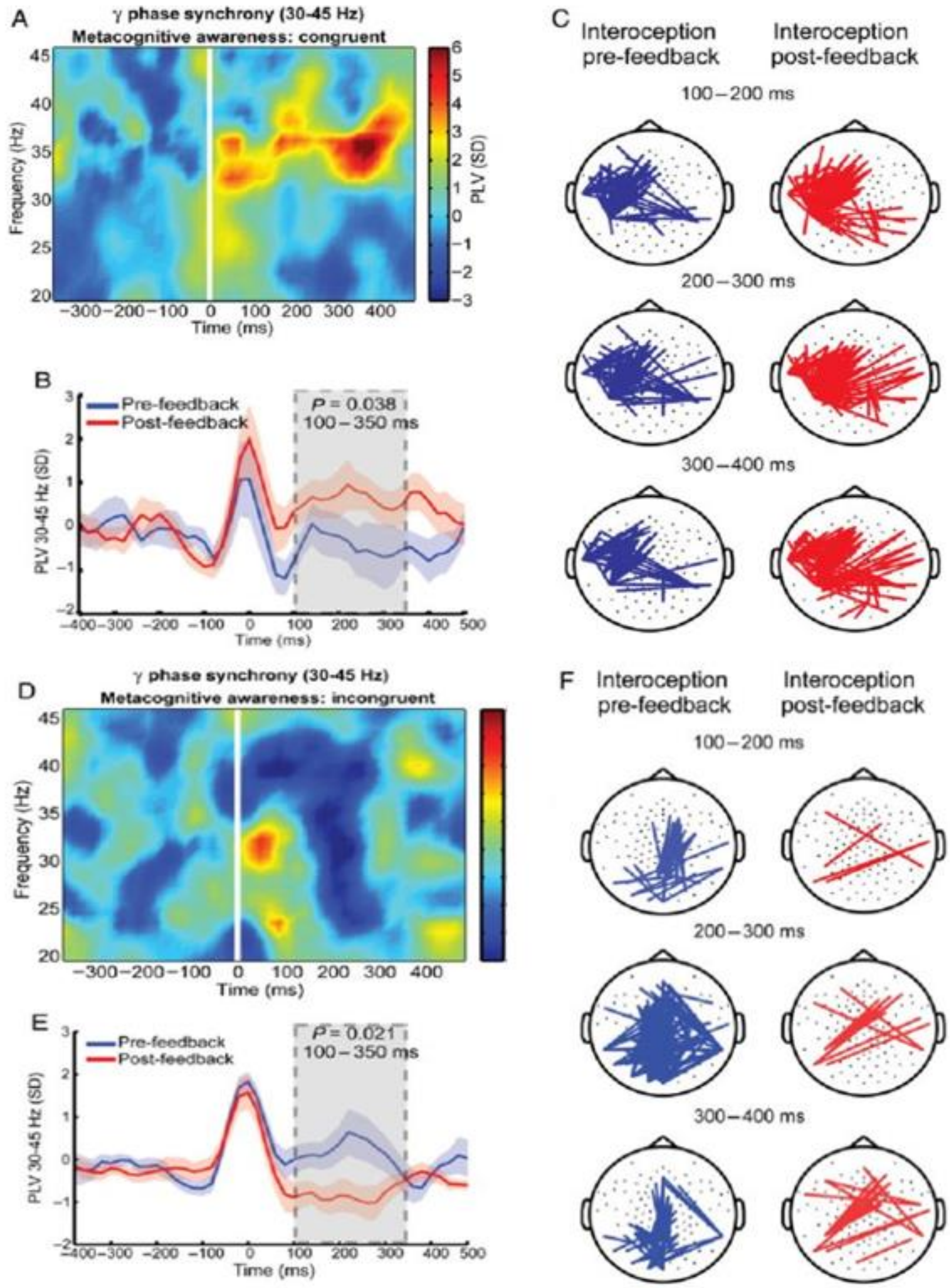

Figure 1 *Metacognitive awareness is modulated by gamma phase synchronization. All values are expressed as standard deviations (SD) to the baseline. (A) All electrodes in the metacognitively congruent and incongruent groups are phase-synchrony locked to the ECG R-peak (D). The difference between the pre-feedback and post-feedback conditions is seen on the time-frequency graph. (B) Gamma phase synchrony between the pre-feedback (blue) and post-feedback (red) conditions in the 30- to 45-Hz frequency range. Phase synchrony in the metacognitively congruent group during pre-feedback (left) and post-feedback (right) situations. Only for substantial changes compared to a comparison condition (P 0.01) was there synchrony between electrode pairs in the blue lines (pre-feedback) and red lines (post-feedback). Distances until the R-peak. (D) (E) (F) The metacognitively incongruent group's results are shown here, but they are the same as those in A, B, and C. (Adapted from Canales-Johnson et al., (2015), with permission).*

"windows" are opened to one another, allowing information to flow more freely. The macro-consciousness changes at the same rate as its component neurons and related fields. An example of such a process is provided in **Figure 1**.

Whitehead et al. (2010) indicated that the many become one and are augmented by one. In other words, lower-level entities are employed to create a new, higher-level entities; however, the lower-level entities are not eliminated during the binding process; rather, they are bound into the new entity, increasing the number of entities by one. The many become one and multiply one by one. As the "*conscious pilot*" (Hameroff, 2010) circles the brain, several subsidiary micro-conscious entities are included, combining into a single dominant consciousness while leaving the subsidiary consciousnesses alone.

5. Coherence in resonance

Fries (2015) presents his *Communication Through Coherence* (CTC) model and the function of "selective communication" acts as a function of resonance between different brain components (the "windows" that are open when coherent and resonant and closed when incoherent and not resonant). Additionally, coherence permits the entrainment of specific neurons to the dominant resonance frequency. Fries (2015) concluded that communication requires coherence. Without coherence, inputs will arrive at random phases of the excitability cycle, decreasing effective connectivities. A postsynaptic neural group that receives inputs from many presynaptic groups primarily responds to the presynaptic group with which it is coherent. Thus, selective communication is carried out utilizing selective coherence.

Not only does coherence make communication more effective and precise, but it also makes it more selective. If one group of synaptic inputs collectively creates one *neural representation* (Rule & O'Leary, 2022; Hodassman et al., 2022) that can elicit postsynaptic excitation followed by inhibition, then further synaptic inputs cannot enter the cell because inhibition will have prevented that from happening. Consequently, these additional inputs cannot inhibit themselves and cannot communicate the *neural representation* they generate. In this approach, the winning set of synaptic inputs overcomes the perisomatic inhibition in the postsynaptic neuronal group, entrains it to its rhythm, and establishes a particular or exclusive communication link. Interregional brain communication optimization is exemplified in **Figure 2**.

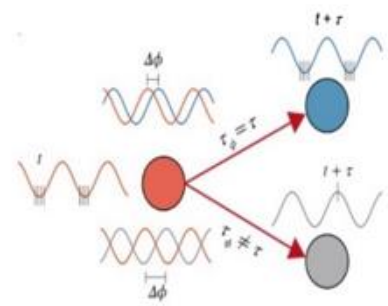

Figure 2 *Schematic demonstrating the principle of rhythmic communication. If neurons preferentially fire at a specific phase of an oscillation, and the oscillations at two regions are coherent with a phase delay matching the conduction delay between them, then spikes fired at the excitable phase in one region will arrive at the excitable phase in the downstream region. These rhythmic bouts of maximum gain can be used to establish an effective communication channel between two coherent regions. Conversely, spikes will arrive away from the excitable phase when the phase does not match the delay and will be less likely to elicit firing. (Adapted from Chapeton et al. (2019), with permission).*

It is now thought that evolution included merging small creatures to generate the organelles (such as mitochondria) of more sophisticated eukaryotic cells, which then fused to form multicellular organisms (Margulis & Sagan, 1990). It is plausible that life acquired the capacity to integrate subjective experiences into nested hierarchies of higher-order conscious individuals, just as it evolved the capacity to combine distinct living units into more complicated solitary life forms. The hypothesis was suggested by Zeki & Bartel (1999) and Zeki (2003) to explain how consciousness develops, from neuronal activity in the brain, relies on this hierarchical view of awareness.

Using differences in the processing rates of different areas of the visual system, Zeki (2003) argues that the brain engages in a hierarchical arrangement of distinct conscious experiences resulting in a single, unified experience. He proposes that consciousness exists on three distinct hierarchical levels within the brain: micro-consciousness, corresponding to the different levels of the visual system that process distinct attributes (e.g., V5 processes motion and V4 processes color); macro-consciousness, which integrates multiple attributes of a system (e.g., binding color to motion); and unified consciousness, which corresponds to the experience of the person who is perceiving. In addition, Zeki (2003) proposes that each of these nested levels of consciousness occurs in a particular temporal order, with the lower order levels occurring before and feeding into the higher order levels. The reason for this is that the lower-order levels are more fundamental. Zeki (2003) model can be explained according to three hierarchical levels of awareness: micro-, macro, and unified consciousness. One level must depend on the presence of the level below it. One might imagine a temporal hierarchy at each level. This has been established for the micro-consciousness level because color and motion are sensed at distinct periods. It has also been demonstrated at the level of macro-consciousnesses, according to Zeki (2003), as binding across characteristics requires more time than binding inside attributes. Individual temporal hierarchies of micro- and macro-consciousnesses lead to a final, united consciousness, resulting in "myself" as the seeing individual.

At the atomic and molecular level, the inorganic world may contain only the smallest conscious observers. In contrast, life may have evolved the ability to build hierarchies of conscious observers inside conscious observers, with each level subsuming a more macroscopic perspective, based on the (rudimentary) level of awareness intrinsic to atoms and molecules. This process reaches its greatest level when the organism's unified dominating experience occurs.

Zeki (2003) distinguishes his proposed levels by the chronological sequence in which they occur, with higher-order experiences occurring later. In other words, according to Zeki's theory, distinct conscious elements in the brain may experience the same events at slightly different times and for varying durations, with the ultimate unified awareness involving the longest moments/duration of the experience.

6. Integrating consciousness through resonance

There is evidence that shared electrical resonance is probably the origin of the combination problem (Fries, 2005, 2015). A shared quantum entanglement resonance could likewise precede and lead to this shared electrical resonance.

Due to the ever-changing energy/information fluxes that supervene the usually stable physical structures, the energy/information fluxes can serve as the foundation for many *dispositional states of consciousness* (Poznanski et al., 2023). This is contra to that indicated by Fries (2015), who refers to stable structures as the "backbone" of conscious processes when he questions if neural communication is dependent on neuronal synchronization, then dynamic changes in synchronization could adapt the communication pattern. Such adaptable alterations in the brain's communication network, which are supported by the more rigid anatomical structure, lie at the core of cognition, according to Fries (2015).

If the shared resonance states remain confined, physical materials may fail to form macro-consciousness. Disordered, non-resonant situations prevent the spatial interchange of information. Large-scale shared resonance is crucial to dominant consciousness, such as the awake consciousness enjoyed by humans. In brain networks, there is a hierarchy of resonance (Steinke & Galán, 2011; Riddle & Schooley, 2019). Lower-level resonance (involving less information integration) can exist even when higher-level resonance (representing more degrees of integration) is momentarily (sleep, seizure, etc.) or permanently (death) missing (death, in which case lower-level resonances may continue for some time but will also, before too long, dissipate). Confined, physical materials may fail to form macro-consciousness. Disordered, non-resonant situations prevent the spatial interchange of information. Large-scale shared resonance, such as the awake consciousness, is crucial to dominant consciousness. In brain networks, a resonance hierarchy exists (Steinke & Galán, 2011; Riddle & Schooley, 2019). Lower-level resonance (involving less information integration) can exist even when higher-level resonance (representing more degrees of integration) is momentarily (sleep, seizure, etc.) or permanently (death) missing (death, in which case lower-level resonances may continue for some time but will also, before too long, dissipate).

These dynamics may explain why, during seizures, significant regions of the brain can be synchronized at regional levels without global consciousness. Lower-level systems (individual and local clusters of neurons) are in synchrony during absence seizures, but higher levels of organization lose their characteristic synchrony, making conscious states not infrequently difficult to describe (Koch & Leisman, 1990; Leisman & Koch, 2009; Jiruska et al., 2012). Resonance mirrors the dynamics of the physical structure. Therefore, the physical structure can remain stable even when resonance and awareness states vary.

7. Resonance signatures allow us to adapt and effectively interact with our environment

Each part of our brain and body probably has its individual resonance signature. These signals can fluctuate subtly from moment to moment, possibly fluctuating around the average frequency value. It has been hypothesized (**Myllylä & Saariluoma, 2022; Graziano, 2022**) that the major cause of conscious experiences is how our brains learn new knowledge about an ever-changing reality during our lives. These processes include learning top-down expectations, matching against bottom-up data, attentional focus on the expected clusters of information, and developing resonant states between top-down and bottom-up processes as they reach an attentive consensus between what is expected and what exists in the outside world. Each conscious state in the brain is a resonant condition and that these resonant conditions are responsible for learning sensations and the corresponding cognitive representations (see **Grossberg, 2012**). Accordingly, our sensory and cognitive representations of the world can maintain their integrity as we learn more about it. As our bodies grow from infancy to adulthood, our spatial and motor representations can unlearn irrelevant learned maps. This occurs as the brain attempts to keep up with the changes occurring in the body. The inhibitory matching processes that underlie spatial and motor activities cannot result in resonance, leading to the conclusion that procedural memories are not conscious. Thus, resonance is the language that facilitates successful communication with our inner and exterior worlds and with others.

References

Bandyopadhyay, A. (2020) *Nanobrain: The Making of an Artificial Brain from a Time Crystal*. CRC Press, Taylor & Francis Group, Boca Raton, FL.

Bianconi, G., Arenas, A., Biamonte, J., Carr, L. D., Kahng, B., Kertesz, J. *et al.* (2023) Complex systems in the spotlight: next steps after the 2021 Nobel Prize in Physics. *Journal of Physics: Complexity* **4**, 010201.

Bianconi, G., Arenas, A., Biamonte, J., Carr, L. D., Kahng, B., Kertesz, J. *et al.* (2023) Complex systems in the spotlight: next steps after the 2021 Nobel Prize in Physics. *Journal of Physics: Complexity* **4**, 010201.

Canales-Johnson, A., Silva, C., Huepe, D., Rivera-Rei, Á., Noreika, V. *et al.* (2015) Auditory feedback differentially modulates behavioral and neural markers of objective and subjective performance when tapping to your heartbeat. *Cerebral Cortex* ***25***, 4490-4503.

Chapeton, J. I., Haque, R., Wittig, J. H., Inati, S. K. & Zaghloul, K. A. (2019) Large-scale communication in the human brain is rhythmically modulated through alpha coherence. *Current Biology* **29**, 2801-2811.

Craddock, J. A., Hameroff, T. R., Ayoub, S. T., Klobukowski, M. & Tuszynski, A. (2015) Anesthetics act in quantum channels in brain microtubules to prevent consciousness. *Current Topics in Medicinal Chemistry* **15**, 523-533.

Crick, F. & Koch, C. (1990) Towards a neurobiological theory of consciousness. *Seminars in the Neurosciences* **2**, 263–275

Dehaene, S. (2014) *Consciousness and the Brain: Deciphering How the Brain Codes Our Thoughts*. Penguin books, New York.

Doelling, K., Herbst, S., Arnal, L. & van Wassenhove, V. (2023) *Psychological and neuroscientific foundations of rhythms and timing*. London, Oxford.

Dresp-Langley, B. (2023) The Grossberg code: universal neural network signatures of perceptual experience. *Information*, **14**, 82.

Fenoaltea, E. M., Meng, F., Liu, R. R. & Medo, M. (2023) Phase transitions in growing groups: How cohesion can persist. *Physical Review Research* **5**, 013023.

Finger, A. M. & Kramer, A. (2021) Mammalian circadian systems: Organization and modern life challenges. *Acta Physiologica* **231**, e13548.

Freeman, W.J. & Vitiello, G. (2006) Nonlinear brain dynamics as macroscopic manifestation of underlying many-body field dynamics. *Physics of Life Reviews* **3**, 93-118.

Fries, P. (2005) A mechanism for cognitive dynamics: neuronal communication through neuronal coherence. *Trends in Cognitive Sciences* **9**, 474-480.

Fries, P. (2015) Rhythms for cognition: communication through coherence. *Neuron* **88**, 220-235.

Funk, R. H. (2022) Understanding the Feedback Loops between Energy, Matter and Life. *Frontiers in Bioscience-Elite* **14**, 29.

Goff, P. (2017) *Consciousness and Fundamental Reality*. Oxford University Press, Oxford.

Graziano, M. S. (2022) A conceptual framework for consciousness. *Proceedings of the National Academy of Sciences* (USA) **119**, e2116933119.

Griffin, D. R. (1998) *Unsnarling the World-knot: Consciousness, Freedom, and the Mind-body Problem*, University of California Press, Los Angeles.

Grossberg, S. T. (2012) *Studies of mind and brain: Neural principles of learning, perception, development, cognition, and motor control*. Springer, New York.

Grossberg, S. T. (2017) Towards solving the hard problem of consciousness: The varieties of brain resonances and the conscious experiences that they support. *Neural Networks* **87**, 38-95.

Grosu, G. F., Hopp, A. V., Moca, V. V., Bârzan, H., Ciuparu, A., Ercsey-Ravasz, M. *et al*.(2023) The fractal brain: scale-invariance in structure and dynamics. *Cerebral Cortex* **33**, 4574-4605.

Hameroff, S. (2010) The "conscious pilot"—dendritic synchrony moves through the brain to mediate consciousness. *Journal of Biological Physics* **36**, 71-93.

Hammerschlag, R., Jain, S., Baldwin, A.L., Gronowicz, G., Lutgendorf, S. K., Oschman, J. L. & Yount, G. L. (2012) Biofield research: A roundtable discussion of scientific and methodological issues. *The Journal of Alternative and Complementary Medicine* **18,** 1081-1086.

Hammerschlag, R., Levin, M., McCraty, R., Bat, N., Ives, J.A., Lutgendorf, S.K. & Oschman, J.L. (2015) Biofield physiology: a framework for an emerging discipline. *Global Advances in Health and Medicine* **4**, 35-41.

Hebb, D. (1948) *The Organisation of Behavior: A Neuropsychological Theory*.Wiley, New York.

Ho, M. W. (2008) *The Rainbow and the Worm: The Physics of Organisms*. World Scientific, Singapore.

Hodassman, S., Vardi, R., Tugendhaft, Y., Goldental, A., & Kanter, I. (2022) Efficient dendritic learning as an alternative to synaptic plasticity hypothesis. *Scientific Reports* **12**, 6571.

Hunt, T. (2011) Kicking the psychophysical laws into Gear a new approach to the combination problem. *Journal of Consciousness Studies* **18**, 96-134.

Hunt, T. (2014) *Eco, Ego, Eros: Essays in Philosophy, Spirituality and Science*. Aramis Publications.

Hunt, T. (2020) Calculating the boundaries of consciousness in general resonance theory. *Journal of Consciousness Studies* **27**, 55-80.

Kang, C., Li, Y., Novak, D., Zhang, Y., Zhou, Q. & Hu, Y. (2020) Brain networks of maintenance, inhibition and disinhibition during working memory. *IEEE Transactions on Neural Systems and Rehabilitation Engineering* **28**, 1518-1527.

Jiruska, P., De Curtis, M., Jefferys, J. G., Schevon, C. A., Schiff, S. J. & Schindler, K. (2013) Synchronization and desynchronization in epilepsy: controversies and hypotheses. *The Journal of Physiology* **591**, 787-797.

John, E. R. (2001) A field theory of consciousness. *Consciousness and cognition* **10**, 184-213.

Jones, M. (2013) Electromagnetic-field theories of mind. *Journal of Consciousness Studies* **20**, 124-149.

Keppler, J. (2013) A new perspective on the functioning of the brain and the mechanisms behind conscious processes. *Frontiers in Psychology* **4**, 242.

Kerick, S. E. (2022) Literature Review on Human Bioeffects of Electromagnetic Energy: A Complex Systems Perspective. DEVCOM US Army Research Laboratory Technical Report ARL-TR-9415

Koch, C. (2004) Qualia. *Current Biology* **14**, R496.

Koch, C. (2014) Ubiquitous minds. *Scientific American* **25**, 26-29.

Koch, P. & Leisman, G. (1990) A continuum model of activity waves in layered neuronal networks: computer models of brain-stem seizures. In: *Proceedings. Third Annual IEEE Symposium on Computer-Based Medical Systems* (pp. 525-531). IEEE.

Koch, P. & Leisman, G. (2015) Cortical Activity waves are the physical carriers of memory and thought. In *2015 7th International IEEE/EMBS Conference on Neural Engineering (NER)* (pp. 364-367). IEEE.

Leisman, G. (2022) On the application of developmental cognitive neuroscience in educational environments. *Brain Sciences* **12**, 1501.

Leisman, G. & Koch, P. (2009) Networks of conscious experience: computational neuroscience in understanding life, death, and consciousness. *Reviews in the Neurosciences* **20**, 151-176.

Leisman, G. & Melillo, R. (2022) Front and center: Maturational dysregulation of frontal lobe functional neuroanatomic connections in attention deficit hyperactivity disorder. *Frontiers in Neuroanatomy* **16**, 936025.

Liang, J. & Zhou, C. (2022) Criticality enhances the multilevel reliability of stimulus responses in cortical neural networks. *PLoS Computational Biology*, **18**, e1009848.

Ma, Z., Turrigiano, G. G., Wessel, R. & Hengen, K.B. (2019) Cortical circuit dynamics are homeostatically tuned to criticality *in vivo*. *Neuron* **104**, 655-664.

McFadden, J. (2002a) Synchronous Firing and its influence on the brain's electromagnetic field. *Journal of Consciousness Studies* **9**, 23-50.

McFadden, J. (2002b) The conscious electromagnetic information (Cemi) field theory: the hard problem made easy? *Journal of Consciousness Studies* **9**, 45-60.

Margulis, L. & Sagan, D. (1990) *Origins of Sex: Three Billion Years of Genetic Recombination*. Yale University Press, New Haven.

Myllylä, M. T., & Saariluoma, P. (2022) Expertise and becoming conscious of something. *New Ideas in Psychology* **64**, 100916.

O'Byrne, J. & Jerbi, K. (2022) How critical is brain criticality? *Trends in Neurosciences* **45**, 820-837.

Olabe, J. C., Basogain, X. & Olabe, M. Á. (2023) Computational model of the mind: How to think about complex systems in nature. In *Brain, Decision Making and Mental Health* (pp. 553-573). Cham: Springer International Publishing.

Palva, J. M., & Palva, S. (2011) Roles of multiscale brain activity fluctuations in shaping the variability and dynamics of psychophysical performance. *Progress in Brain Research* **193**, 335-350.

Pereira, M., Perrin, D. & Faivre, N. (2022) A leaky evidence accumulation process for perceptual experience. *Trends in Cognitive Sciences* **26***, 451-461.*

Pockett, S. (2000) *The Nature of Consciousness: A Hypothesis*. iUniverse, Lincoln, NE.

Pockett, S. (2012) The electromagnetic field theory of consciousness a testable hypothesis about the characteristics of conscious as opposed to non-conscious fields. *Journal of Consciousness Studies* **19**, 191-223.

Poznanski, R.R., Cacha, L.A., Holmgren, J. & Brändas, E.J. (2022) What a feeling - the underpinnings of physical feelings as molecular level holonomic effects. *Journal of Multiscale Neuroscience* **1**, 11-40.

Poznanski, R.R., Holmgren, J., Cacha, L.A., Alemdar,E. & Brändas, E.J. (2022) The act of understanding uncertainty is consciousness. *Journal of Multiscale Neuroscience* **2**, 280-291.

Riddle, J. & Schooler, J. W. (2019) *Nested Observer Windows (NOW): A Theory of Scale-Free Cognition.* University of North Carolina Press, Chapel Hill.

Roelfsema, P. R. (2023) Solving the binding problem: Assemblies form when neurons enhance their firing rate—they don't need to oscillate or synchronize. *Neuron*, **111**, 1003-1019.

Rolls, E. T. (2020) Neural computations underlying phenomenal consciousness: a higher order syntactic thought theory. *Frontiers in Psychology* **11**, 655.

Rule, M. E., & O'Leary, T. (2022) Self-healing codes: How stable neural populations can track continually reconfiguring neural representations. *Proceedings of the National Academy of Sciences (USA)* **119**, e2106692119.

Romanczuk, P. & Daniels, B. C. (2023) Phase Transitions and Criticality in the Collective Behavior of Animals—Self-Organization and Biological Function. In *Order, Disorder and Criticality: Advanced Problems of Phase Transition Theory* (pp. 179-208).

Sahu, S., Ghosh, S., Ghosh, B., Aswani, K., Hirata, K., Fujita, D. & Bandyopadhyay, A. (2013a) Atomic water channel controlling remarkable properties of a single brain microtubule: correlating single protein to its supramolecular assembly. *Biosensors and Bioelectronics* **47,** 141-148.

Sahu, S., Ghosh, S., Hirata, K., Fujita, D. & Bandyopadhyay, A. (2013b) Multi-level memory-switching properties of a single brain microtubule. *Applied Physics Letters* **2013**,123701.

Sandvig, I. & Sandvig, A. (Eds.). (2022) Editorial: Criticality in neural network behavior and its implications for computational processing in healthy and perturbed conditions. *Frontiers in Neural circuits* **16**, 1041250.

Schooler, J. W., Hunt, T. & Schooler, J. N. (2011) Reconsidering the metaphysics of science from the inside out. *Neuroscience, Consciousness and Spirituality*, In: H. Walach et al. (eds.), Neuroscience, Consciousness and Spirituality 1, Springer, 157-194.

Seymour, K. (2023) Consciousness, evolution, and the self-organizing brain. *Journal of Conscious Evolution* **19**, 5.

Shine, J. M. (2023) Neuromodulatory control of complex adaptive dynamics in the brain. *Interface Focus*, **13**, 20220079.

Singh, P., Ray, K., Fujita, D. & Bandyopadhyay, A. (2019) Complete dielectric resonator model of human brain from MRI data: a journey from connectome neural branching to single protein. In: *Engineering Vibration, Communication and Information Processing*: (pp. 717-733), Springer, New York.

Steinke, G. K. & Galán, R. F. (2011) Brain rhythms reveal a hierarchical network organization. *PLoS Computational Biology* **7**, e1002207.

Strogatz, S. H. (2012) *Sync: How Order Emerges from Chaos in the Universe, Nature, and Daily Life*. Hachette, UK.

Tononi, G. & Koch, C. (2015) Consciousness: here, there and everywhere? *Philosophical Transactions of the Royal Society B: Biological Sciences* **370**, 20140167.

Veit, W. (2023) Complexity and the evolution of consciousness. *Biological Theory* **18** (*in press*).

Young, A., Robbins, I. & Shelat, S. (2022a) From micro to macro: the combination of consciousness. *Frontiers in Psychology* **13**, 755465.

Young, A., Hunt, T. & Ericson, M. (2022b) The slowest shared resonance: A review of electromagnetic field oscillations Between central and peripheral nervous systems. *Frontiers in Human Neuroscience*, **15**, 833.

Yu, Y., Han, F. & Wang, Q. (2022) Exploring phase–amplitude coupling from primary motor cortex-basal ganglia–thalamus network model. *Neural Networks* **153**, 130-141

Zeki, S. (2003) The disunity of consciousness. *Trends in Cognitive Sciences* **7**, 214-218.

Zeki, S. & Bartels, A. (1999) Toward a theory of visual cconsciousness. *Consciousness and Cognition* **8**, 225-259.

Zhuravlev,A. V. (2023) Three levels of information processing in the brain. *Biosystems* **229**, 104934.