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Review

The Origin of Natural Neurostimulation: A Narrative Review of Noninvasive Brain Stimulation Techniques

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Abstract

This narrative review of the literature on noninvasive brain stimulation techniques observes four neurostimulation domains: light therapy, photobiomodulation, a group of techniques within transcranial electric current and magnetic field stimulations, low-frequency sound stimulations, including vibroacoustic therapy, and rhythmic auditory stimulation. The review aims to determine whether or not different brain stimulation approaches rely upon a similar physicochemical sequence of actions. The study identifies relevant hypotheses about processes at the cellular level underlying noninvasive brain stimulation. The data analysis reveals that mitochondria activity will likely play a central role in brain stimulations implemented by different approaches. Additionally, the mother-fetus neurocognitive model analysis gives insight into conditions of the natural neurostimulation of the fetal nervous system during pregnancy. Drawing on these findings, the article supposes the hypothesis of the origin of neurostimulation during gestation. The article presents the requisites of the nature-based brain stimulation technique, called Acoustic Photonic Intellectual Neurostimulation (APIN), derived from studying natural neurostimulation components.

Keywords

Neurostimulation; neuromodulation; acoustic; photonocs; bioengineering; mother-fetus neurocognitive model

1. Introduction

This narrative review of the literature on the noninvasive brain stimulation techniques observes four neurostimulation domains: light therapy (LT) or phototherapy; laser brain stimulation, so-called photobiomodulation (PBM); a group of methods within transcranial electric current and magnetic field stimulations; low-frequency sound stimulations including vibroacoustic therapy (VAT) and rhythmic auditory stimulation (RAS). Because these brain stimulation methods are noninvasive, capable of modulating neuronal plasticity independent of underlying diseases, and can be personalized, they have gained significant interest in the scientific community.

The narrative review is outlined as follows. The Introduction concisely presents each observed approach's definition, treatment scope, and technical characteristics. The 1.5 Subsection presents the research problem of the review. The review method is formulated in the Materials and Methods Section. The Results Section contains theoretical explanations of the therapeutic effect of different noninvasive brain stimulation techniques. This Section tries “cataloging” the relevant hypotheses from the whole topic of noninvasive brain stimulation. In the Discussion section, the current study revises the found hypotheses about the neurostimulation grounds to add their explanation with insight into the essential role of mitochondria in each. Finally, this Section highlights the physicochemical grounds of natural nervous system stimulation and the characteristics of the nature-based brain stimulation technique.

1.1 Light Therapy for Brain Stimulation

Light therapy (LT, also known as Phototherapy or Luxtherapy) refers to the body's exposure to direct sunlight or intensive artificial light at controlled wavelengths to treat various medical disorders, including those associated with the brain:

- Depression. Systematic review studies showed that treatment with LT significantly reduced the rigor of depression [1-4]).
- Chronic pain. Evidence supported the beneficial effect of LT on chronic pain management [1].
- Post-traumatic stress disorder. The recent systematic review revealed promising results in treating PTSD symptoms [5].
- Insomnia. A systematic review showed the effectiveness of sleep care in insomnia disorders [6].
- Cognitive functions. Clinical data support the beneficial effects of LT on cognitive dysfunction [1].

Research also revealed that light therapy may reduce agitation in dementia patients [7, 8]; bright LT is commonly used to regulate seasonal affective disorder and other circadian rhythm-related disorders [9].

1.1.1 Techniques

Concerning brain stimulation, light therapy uses various technologies to irradiate the body with light, such as UVB lamps that emit a spectrum of ultraviolet light with wavelengths ranging from 290–320 nm and a light box that exposes the human body to intense light in a range of 2500–10000

lux of light at a specified distance, with the controlled frequency in the band of 350-750 nm (usually the diapason of the visible light is 400-700 nm) [10].

In brain stimulation, light therapy functions through the visual system of two subsystems and skin irradiation. The image-forming vision pathway involves phototransduction through photoreceptors (rods and cones) responsible for image-forming vision. Another integrator of light information is photoreceptive ganglion cells, which act as rudimentary visual brightness detectors, e.g. [1, 11]. Ganglion cells transduce light stimuli to multiple brain regions that regulate brain functions unrelated to image-forming vision, including the circadian rhythm [12]. Due to melanopsin (a light-sensitive protein), these cells are intrinsically photosensitive. Ganglion cells are integrated with rod and cone input in processing information regarding the light surroundings across a broad spectrum of wavelengths and light levels. The photoreceptive ganglion cells exhibit a spectral sensitivity curve of Gaussian distribution in the 420–590 nm range with a peak spectral sensitivity at about 480 nm.

1.1.2 Limitations and Side Effects

While light therapy is an efficient tool for treating disorders associated with the brain, it can cause side effects of varying severity, including pruritus, blistering, skin erythema, xerosis, altered pigmentation, photoaging, and photocarcinogenesis [13]. Review studies also highlighted that further research is needed to refine the light parameters to develop personalized therapeutics [6].

1.2 Photobiomodulation for Brain Stimulation

Photobiomodulation (PBM) or low-level light therapy refers to directional low-power and high-fluence monochromatic or quasimonochromatic light [14]. This technique is used in the treatment of various disorders; the list below shows the areas of application:

- Cognitive functions. Laser transcranial PBM may improve the function of traumatically injured brains [14-19] and diseased or normal brains [20-26]. Clinical data showed improvements in cognition, quality of life, and clinical signs of neurodegenerative conditions, such as dementia, Alzheimer's disease, and Parkinson's disease [14, 27-35].
- Depression. Research studies reported reduced depression symptoms [14, 32-35].
- Chronic pain. A literature review revealed photobiomodulation benefits chronic pain [36, 37].
- Post-traumatic stress disorder. A review revealed significant results in PTSD symptom management [38].
- Insomnia. Clinical research showed that intravascular laser irradiation of blood is a beneficial and feasible treatment for insomnia [39].

Research has shown that laser transcranial PBM may lead to vasodilation and increased cerebrovascular oxygenation [20-26] and exert a neuroinflammatory suppressive effect [26, 27]. Photobiomodulation is also an efficient treatment in inflammation management [36]. Increased cerebral oxygenation significantly impacts cognitive tasks such as memory and attention [20].

1.2.1 Techniques

This neurostimulation approach exerts its function of treating brain tissue with light using lasers (the acronym of Light Amplification by Stimulated Emission of Radiation) or light-emitting diodes

(LEDs) generally in the red to near-infrared wavelengths 600–1100 nm. The laser beam has a narrow spectral width (around 1 nm), emitting the coherent light of a single wavelength. The LED's light is non-coherent and non-monochromatic; it has a spectral width of up to 80 nm., which results in a more broad, Gaussian-like spectrum of emitted light [40].

Laser devices emit coherent light with various coherence lengths depending on the bandwidth of the specific laser. Laser-coherence lengths can vary from meters for the He-Ne laser to only a few mm for diode lasers [41]. Laser and light-emitting diodes are different techniques. They don't work the same way. While laser diodes emit focused light with a narrow beam, LED light is dispersed and multidirectional. Lasers for photobiomodulation are presented within a range of beam size, power density, and wavelength characteristics that provide tissue penetration within the method's scope [41]. For example, a laser known as HD Laser™ CG5000 has a beam size of 45 mm, a power density range of up to 1.6 W/cm^2 and a 1064 nm wavelength [41].

1.2.2 Limitations and Side Effects

A review reported that clinical studies are heterogeneous in populations and therapy settings, and most lack sufficient control [38]. The literature contains poor data on the side effects of this method. Research reported changes in patients' weight and systolic blood pressure, which were insignificant; only diastolic blood pressure increased and reached statistical significance, but not clinical one [42]. Another potential side effect should become a subject of long-term research. The target, frequency, and dose of the laser beam in transcranial PBM radiation are still questions that need to be defined [43]. In brain stimulation, PBM stimulation targets relatively large areas (relatively the neuronal scale) of poorly characterized brain tissue. One cannot be sure that the target, frequency, and intensity do not give an excessive irradiation dose to healthy neurons when treating brain tissues, the outcome of which would emerge later [43].

1.3 Transcranial Current and Magnetic Therapy for Brain Stimulation

This noninvasive brain stimulation approach applies electromagnetic properties of the brain activity to provide neurostimulation by non-invasive means. It encompasses a cohort of methods, such as Cranial Electrical Stimulation (CES), Electroconvulsive therapy (ECT), Transcranial Alternating Current Stimulation (tACS), Transcranial Direct Current Stimulation (tDCS), Transcranial random noise stimulation (tRNS), and Transcranial Magnetic Stimulation (tMS). In the literature, tDCS, tACS, and tRNS are usually noted as a group with the unique name Transcranial Electrical Stimulation (TES).

The growing body of literature shows the application of all these brain stimulation methods in treating similar brain disorders. The list below shows the areas of application (for further reading, the links present all the above techniques in the order listed):

- Depression [44-49],
- Chronic pain [50-55],
- Post-traumatic stress disorder [44, 56-58],
- Insomnia [44, 59-62],
- Cognitive functions [63-68].

Interestingly, the current study found controversy in reporting the results of treatment. On memory: While Brunyé and colleagues [63] reported that CES selectively increases performance on

a recognition memory test, Michals and colleagues [69] did not. Pain relief: The experiments by Alwardat and colleagues 2020 did not support the clinical use of tDCS to reduce pain; meanwhile, the systematic review by Moshfeghinia and colleagues [53] highlighted the potential effect of tDCS in pain treatment. Some researchers, such as Saccenti and colleagues [57], Moo-Estrella and Pérez-Pichardo [44], Provencher and colleagues [61], and Ma and colleagues [62] investigated two or three neurostimulation methods within the umbrella of electric current and magnetic brain neurostimulation in one study. Research also showed other interesting results: a potential to treat epilepsy [70], smoking cessation using insula neurostimulation [71], and preliminary results in recovery from coma [72].

1.3.1 Techniques

- **Cranial electrotherapy stimulation** (CES) delivering low-intensity (50 µA to 4 mA) electrical current at 0.5-100 Hz via electrodes attached to the earlobes, maxilla-occipital junction, mastoid processes, or temples [73].
- **Electroconvulsive therapy** (ECT) apples 500–1000 mA. Most devices are already tuned with a default current of 800–900 mA. Some devices operate at lower currents (200-400 mA) [74]. There are at least three positions to place electrodes: Bitemporal (electrodes are placed in the left and right frontotemporal regions), Bifrontal (on frontal areas), Right (Left) unilateral (one electrode is placed 1 inch right to vertex and another on the right frontotemporal region) [74].
- **Transcranial Alternating Current Stimulation** (tACS) uses a current amplitude (Peak-To-Peak) of 0.65-4 mA, a frequency range between 4.5 and 120 Hz, and electrode location depending on the scope region of treatment [75].
- **Transcranial Direct Current Stimulation** (tDCS) generally applies a current intensity between 0.5 and 2 mA, although up to 4 mA has been tested in human studies [76, 77].
- **Transcranial random noise stimulation (tRNS)** uses an alternate current of 0.5 mA along with a random amplitude of up to 0.5 mA and frequency between 0.1 and 640 Hz [78].
- **Transcranial Magnetic Stimulation** (TMS): The stimulation coils produce a magnetic field of 0.5-7.5 T with a pulse frequency in the case of repetitive tMS ranging from 0.5 Hz to 250 Hz [79]. High-frequency rTMS with a stimulus frequency greater than 1 Hz is supposed to provoke cortical firing, while a stimulus frequency less than 1 Hz is believed to inhibit it [80].

1.3.2 Limitations and Side Effects

A recent review [81] highlighted several shortcomings in the research data of these techniques: (i) sample sizes were small, often case reports or case series; (ii) outcome measures and reported benefits varied; (iii) the optimal healthy irradiation dose (intensity and duration of the interventions) was not defined; most studies did not personalize the dose; (iv) protocols were different, including different electrode sizes, shapes, and locations; [81]. The last two constraints raise an essential challenge of the inability to localize the effect of these neurostimulation methods on specific tissues in the relevant neural zones [73]. These techniques target a large area of inadequately characterized tissue, which, together with an undefined dose, can destroy healthy cells during treatment [73].

1.4 Low-Frequency Sound Brain Stimulations

Because music can be defined as a derivative of vibration and an organized sequence of sounds generally within operating frequency [82], the current review observes Music Therapy (MT), Vibroacoustic therapy (VAT), and Rhythmic auditory stimulation (RAS) within the frame of the single neurostimulation domain of low-frequency sound brain stimulations. Although they are different therapeutic methods, from the perspective of brain stimulation, they implement a similar tool: acoustic wave. They demonstrate effectiveness in various areas:

- Depression. The literature shows significant reductions in anxiety, depression, and apathy that occurred after music therapy [83].
- Cognitive functions [84-88].
- Chronic pain. MT may provide a practical complementary approach to relieving pain [84, 87-89].
- Post-traumatic stress disorder. Empirical evidence shows that patients with post-traumatic stress disorder (PTSD) may benefit from MT [90].
- Insomnia. This therapy may improve sleep quality in adults with insomnia symptoms [91].

1.4.1 Techniques

According to the American Music Therapy Association, MT uses music interventions with a 1-1.5 Hz rhythm frequency for personalized treatment [92].

Vibroacoustic therapy (VAT) combines low-frequency sound vibration in a range of 20-300 Hz, music listening of the music rhythm in a range of 0.6-1.5 Hz, and therapeutic interaction, generally used in rehabilitation [93, 94].

Rhythmic auditory stimulation (RAS) uses the physiological effects of the rhythmic motor cueing in the tact of the rhythm in a range of 0.6-1.5 Hz [95, 96].

1.4.2 Limitations and Side Effects

Therapies within the frame of the sound brain stimulation show heterogeneous results. Most studies that tested VAT's effects on depression, pain, and cognitive functions have significant limitations because of research design and small sample sizes, which reduce the validity of other studies' positive results [94]. A systematic review highlighted controversial results reported on the effects of MT on improving the overall aspects of cognition (such as memory, orientation, and registration), agitation, daily functioning, and the quality of life of patients living with dementia [85].

1.5 Research Problem

Currently, from the literature on noninvasive brain stimulation, it is still being determined how long the effects of all four brain stimulation approaches last. What should the duration of one neurostimulation session be, and how many sessions should there be? Are the benefits of all therapies long-term? The author believes that if there were a generally accepted theoretical explanation for the therapeutic effect of noninvasive brain stimulation, it would be easier to answer the above questions. The research question of the current study is even more ambitious: whether or not a unique natural physicochemical set of actions underlies different brain stimulation approaches.

2. Materials and Methods

The narrative review tried to map promising hypotheses about processes at the cellular level underlying noninvasive brain stimulation mechanisms. Several articles are aimed at analyzing the theoretical foundations of neurostimulation. At the same time, many attempts have been made, but only a few propose an idea about the comprehensive architecture of neurostimulation from an agent (molecule or cell) to the physiological effect. The author believes that a review of the processes at the cellular level underlying various techniques from a wide range of noninvasive brain stimulation methods contributes to understanding the more predictable development of artificial neurostimulation techniques.

The topic of this narrative review is excessive; it encompasses four neurostimulation domains. Because of the broad topic, this review implemented the heuristic research approach that enabled the incorporation of essential neurostimulation elements that otherwise would be difficult to highlight. Therefore, the current study is not a systematic review. It only attempts to highlight the main hypotheses of the topic. The review does not provide a comprehensive discussion of current evidence regarding the effects of these techniques on brain functions, their contraindications, and side effects. It does not aim to provide a comprehensive view of the therapy's clinical relevance and safety profile.

The searched databases were Scopus and Web of Science. First, the study searched through key words "theory of brain stimulation", "theory of neuromodulation", "theory of light therapy", "theory of PBM", "theory of transcranial electrical stimulation", "theory of transcranial magnetic stimulation", "theory of Vibration, Acoustic and Music stimulation", etc. A further refined search included terms like “neurostimulation and adenosine”, “neurostimulation and Ca^{2+} and Na^{+} channels”, “neurostimulation and mitochondria”, “neurostimulation and mechanoreceptors”, etc.

The distinguishing of studies was motivated by an attempt to identify hypotheses about processes at the cellular level that contribute to synaptic activity during various artificial neurostimulations. The inclusion criteria used for selecting studies were as follows. Articles were selected based on (1) whether they proposed a hypothesis about the comprehensive architecture of neurostimulation from an agent (molecule or cell) to the physiological effect and (2) whether their theoretical definitions were based on empirical data.

To avoid explaining technical details when considering the hypotheses in the Results section, this section also clarifies reasons from physics (see below) that enable uniting hypotheses on the nature of transcranial electric current and magnetic field stimulations for their analysis in only one subsection, 3.3. Electricity and magnetism are two interconnected entities. In electrical circuits, a moving charge creates electric and magnetic fields. A magnetic field causes the movement of an electric charge, which creates an electric current. Human tissues have very different permittivities, which indicates their interaction with the electric field. In contrast, the magnetic permeability of tissues, except for tiny inclusions, is the same as that of air [97]. The electric and magnetic fields show the difference in interactions with biological tissue, which appears in the human body's reduced distribution of electric currents. In contrast, human tissues do not change the magnetic field propagation. Both fields induce electric fields and currents, producing similar effects on tissues [97]. Only in electrostatics does a stationary point charge induce solely an electric field without a magnetic field. From this perspective, it is not too controversial to say that, at the cellular level, current and magnetic brain stimulation may have a joint explanation.

The essential principle of the transcranial electric current and magnetic field brain stimulation approach is that neurons are both generators and recipients of electromagnetic fields; neuronal oscillations show a dual behavior in brain networks. Specifically, neuronal oscillations are influenced by spiking inputs and, in turn, affect the timing of spike outputs [98]. This fact means that neurons interact with other neurons' oscillations and, therefore, they may change their oscillations by interacting with other electromagnetic fields. Artificial (outside the brain) electric and magnetic stimulations may alter brain activity. Because transcranial electric current and magnetic field stimulations likely adhere to the same physics principles, only one theory may explain underlying processes, and they can be united for analysis in only one subsection.

3. Results

The section presents hypotheses about processes at the cellular level underlying different noninvasive brain stimulation techniques.

3.1 The Nature of LT

3.1.1 Brain Stimulation through the Image-Forming Vision Pathways

While the literature shows that LT is widely applied to treat various medical disorders associated with the brain, the mechanism behind the image-forming vision pathways (IFVP) remains largely unknown. Cones detect color and spatial detail at light levels relevant to the daytime, and rods only detect spatial detail at light levels in twilight and darker (suppressed at daytime light levels). The activation of the two groups of photoreceptors during light irradiation has no theoretical explanation yet of brain stimulation. The current review did not identify relevant hypotheses for treating brain disorders through the image-forming vision pathways in the literature.

3.1.2 Brain Stimulation through the Photoreceptive Ganglion Cells Pathways

The literature review did not find a comprehensive theory of brain stimulation through the photoreceptive ganglion cell pathways (PGCP). However, a few hypotheses on this topic are included:

- A small fraction of secondary neurons (ganglion cells–the rudimentary visual brightness detectors) in the retina send light information to the brain through the retinohypothalamic tract, i.e., from intrinsically photosensitive retinal ganglion cells to the Suprachiasmatic nucleus. During the light part of the day, the Suprachiasmatic nucleus impacts the pineal gland to suppress the release of melatonin, reducing drowsiness. In contrast, the melatonin concentration increases due to the absence of light at night. Through this daily cycle, the Suprachiasmatic nucleus rhythmically acts on the pineal gland release of melatonin, ultimately affecting the human body’s rhythm [99]. To regulate seasonal affective disorder and other circadian rhythm-related disorders, light therapy can compensate for the seasonal daily lack of light perception, restoring a healthy balance of neural information of light perception necessary for healthy biochemical processes.
- Research has shown that photoreceptive ganglion cells transmit light information to the supraoptic and paraventricular nuclei [100]. This pathway may facilitate brain development. Light stimulation of this visual subset associated with photosensitive retinal ganglion cells

increases the release of oxytocin from the supraoptic nucleus and the paraventricular nucleus into the cerebrospinal fluid [84].

- Another pathway of photo-receptive ganglion cells underlies the modulatory effects of light on affecting memory. Research has shown that bright light facilitates spatial memory by activating the path to the ventral lateral geniculate nucleus and intergeniculate leaflet and nucleus reunions [1]. The latter pathway is also linked with the lateral habenula, part of the epithalamus. This pathway is associated with pain perception relief [1, 101]. Specific activation of the ventral lateral geniculate nucleus and intergeniculate leaflet not only induces inhibitory post-synaptic currents in gamma-aminobutyric acid-expressing neurons but also reduces the excitatory effects of pain-related stimuli on these neurons [1, 100].

3.1.3 Brain Stimulation through Skin Irradiation

Light, even when not perceived by the visual system, can trigger biochemical responses and, as a result, neuromodulation of the brain in neurological disorders, as well as disruption of the brain's stress response system and glucose homeostasis.

- Recent animal studies have demonstrated that trunk exposure to light can activate neurostimulation effects [102-104]. Red and near-infrared light (620-825 nm) is believed to induce molecules or cells in the body, such as immune cells, inflammatory mediators, and/or bone marrow-derived stem cells [105]. Skin irradiation by red and near-infrared light can even lead to brain neuromodulation by producing nerve growth factors or brain-derived neurotrophic factors [105], suggesting the potential of light to activate the body's natural healing mechanisms. When the skin is irradiated by red light near-infrared light, metal molecules in the cytochrome c oxidase (CCO) absorb photons. The light irradiation upgrades the CCO, passing it to the excited state [105, 106]. Nitric oxide (NO) photo dissociates from CCO during this activation, and NO inhibits electron transportation [105]. After NO dissociation, the mitochondrial membrane potential increases [89]. This state elevates oxygen consumption levels, establishing a proton gradient that boosts Adenosine triphosphate production [105, 107]. These processes cause the release of reactive oxygen species, Ca^{2+}, and cyclic adenosine monophosphate [105, 108] that can additionally activate a set of signaling pathways and transcription factors as second messengers [105].
- Another hypothesis for brain stimulation through skin irradiation is based on a unique signaling system between mitochondria across different organ systems [89, 105]. Mitochondria, when under stress, release a yet-to-be-identified signaling molecule called mitokine. Mitokine, encoded by both fibroblast growth factor 21 [FGF21] and mitochondrial DNA, is perspired in reaction to mitochondrial stress or the mitochondrial unfolded protein response, stimulating inter-tissue communication to manage cellular responses to mitochondrial distress [109]. This underscores the crucial role of mitochondria in the body's response to light stimulation. Cytokine release drives a mitochondrial stress response in other body parts [110]. Fibroblast growth factor 21 (FGF21) is upregulated in response to mitochondrial stress and during the mitochondrial unfolded protein response [109]. FGF21 is a hormone that significantly regulates metabolism, energy homeostasis, and mitochondrial function [109]. The overall metabolic and thermogenic effects of FGF21 may indirectly regulate mitochondrial function in various brain regions. For instance, the receptor-mediated

role of FGF21 affects the hypothalamus, a critical brain region that controls energy balance, food intake, and body weight [111]. Research has shown that FGF21 exerts neuroprotective effects in various neurological disorders, such as Alzheimer's and Parkinson's [112, 113]. FGF21 regulates the corticotropin-releasing factor, a vital component of the brain's stress response system [112]. FGF21 contributes to glucose homeostasis [114-116]. According to Liu and colleagues [105], the signaling system between mitochondria across different organ systems may contribute to modulating the brain activity that would appear in altering cognitive functions.

3.2 The Nature of Transcranial PBM

Two hypotheses rely upon enhancing mitochondrial metabolism, which is caused by, from one view, (1) an increase in mitochondrial oxygen consumption and cellular energy metabolism, and, from another, (2) modulates the production of reactive oxygen species (ROS) and causes transcriptional changes.

- According to the received view, at the cellular level, transcranial laser radiation causes adenosine triphosphate synthesis (ATP) in mitochondria [117, 118] and a release of mitochondrial reactive oxygen species and nitric oxide (NO) [23, 25, 26, 119]. In the brain in vivo, the laser beam can reach the aimed brain tissue with established parameters' treatment power. Research reported that the primary PBM impact is the photonic oxidation of mitochondrial cytochrome c oxidase (CCO), the fourth enzyme complex in the electron transport chain within mitochondria [25, 26, 120-122]. The absorption peaks of CCO are mainly distributed in the range of 620–760 nm (red) and 780–825 nm (near-infrared) [105]. The red and near-infrared light stimulates the activity of CCO, and its excessive binding with nitric oxide (NO) is dissociated by the photons, which causes an increase in mitochondrial oxygen consumption and cellular energy metabolism [117, 122]. Since it is already known that neurodegeneration and neurological dysfunction are associated with impaired mitochondrial oxidative metabolism, PBM improves the function of the brain by enhancing mitochondrial metabolism [122]. This neurostimulation secondarily leads to vasodilation (increasing oxygenation) [20-26] and intracellular signaling molecules [123].
- Another hypothesis of transcranial PBM is that light modulates the release of reactive oxygen species (ROS) and causes transcriptional changes [122]. Research reported that light (810 nm wavelength) regulates the generation of ROS in mitochondria, induces retrograde signaling pathways from mitochondria to the nucleus, and modulates the expression of transcription factors such as NF-κB in mouse embryonic cells [122, 124]. NF-κB regulates gene expression, including those with functions of antioxidant, anti-apoptotic, cell proliferation, and migration promotion [122]. According to Dong and colleagues [122], transcranial PBM can reduce NF-κB levels in activated inflammatory neuronal cells, thus exerting a neuroinflammatory suppressive effect [122].

3.3 The Nature of Transcranial Electric Current and Magnetic Stimulation

The nature of transcranial electric current and magnetic brain stimulation methods remains mysterious because the same stimulation, applied in different situations, can produce categorically different effects [125]. A systematic literature review emphasized the heterogeneity of these

methods and outcome measures [126]. The cause of these discrepancies is likely based on the limitations of the studies mentioned in subsection 1.3.2 in the Introduction. Another reason may rely upon a poor understanding of underlying processes. This subsection aims to observe the state-of-the-art in our knowledge about them. Altering brain activity due to electrical and magnetic stimulation may have one explanation. The current review explains why it is so in section 2, Materials and Methods. In short, both electric current and magnetic fields exert similar effects on brain tissues [97]. Neuronal oscillations have a dual function in brain networks: neuronal oscillations are influenced by spiking inputs, and, in turn, they affect the timing of spike outputs [98]. These facts imply that interactions with both electric current and magnetic fields can alter neuronal activity. Therefore, this subsection observes hypotheses of the nature of all these brain stimulation techniques from the above-noted perspective. The review has found two hypotheses:

- A first approximation, analyses of the literature give the insight that transcranial current stimulation methods (and also magnetic ones) alter the spiking activity of neurons [123]. Due to the bidirectional property of neurons in relationship with oscillations (as noted above), the phase of a slow oscillation modulates the amplitude of a faster rhythm, the so-called nested oscillation. Nested oscillations mean that the amplitude of higher frequency oscillations depends on the phase of slower oscillations [127]. Growing evidence shows that delta-nested gamma oscillations play an essential role in the temporal coordination of central and peripheral neural subsystems associated with cognitive functions [128-130]. In transcranial neurostimulation, the artificial currents [123], as well as external magnetic fields shift neurons' spikes towards certain phases of the sinusoid's waveform. But how does transcranial current stimulation or magnetic field stimulation affect the spiking activity of neurons? Given the above physics arguments, all these methods may exploit the same intrinsic qualities of physicochemical interactions, regardless of whether electric currents or magnetic fields accomplish transcranial brain stimulation. Magnetic fields may perturb Ca^{2+} and Na^{+} channel activity, considering the diamagnetic anisotropic characteristics of membrane phospholipids [131-135]. The voltage-gated Ca^{2+} channels are the primary conduits for the Ca^{2+} ions that cause a confluence of neurotransmitter-containing vesicles with the presynaptic membrane [135]. The timing and strength of synaptic output can be profoundly changed by alterations in the intrinsic function of these channels and their positioning within the active area [135]. The altered Ca^{2+} and Na^{+} channel activity contributes to neuronal excitability. Thus, coordinated neuronal activity may appear due to cellular properties that react in magnetic fields [131-135].
- Another hypothesis argues that electromagnetic fields can cause an increase in adenosine receptors for neuronal communication [136]. According to Varani and colleagues [136], pulsed electromagnetic fields can mediate a transient and significant increase in A(2A) adenosine receptor density in cortex cell membranes. Adenosine modifies cell functioning by operating G-protein-coupled receptors (GPCR; A(1), A(2A), A(2B), A(3)). G-protein–coupled receptors set into motion chemical signaling events within the cell and enhance neuronal communication [137]. This altering appears because A(2A) regulates the production of other neurotransmitters, such as glutamate and dopamine. Interchanges between adenosine receptors and other G-protein-coupled receptors, receptors for neurotrophins, and ionotropic receptors also contribute to the adjustment of neuronal functions [136].

3.4 The Nature of Low-Frequency Sound Brain Stimulation

The hypotheses in this topic rely upon two different mechanisms of low-frequency vibrations to specific body parts: (1) vibrations alter the release of essential neurotransmitters and (2) transmitting vibrations to mechanoreceptors and pain receptors to send neurological non-pain messages to the brain:

- The first insight, a prerequisite of a further convincing hypothesis into the nature of this brain stimulation technique, states that neurostimulation is induced by vibrations that alter the release of essential neurotransmitters, such as dopamine, serotonin, and corticosterone [138, 139].
- Another idea, a potential prerequisite of a further convincing hypothesis, proposes the transmission of vibrations to mechanoreceptors and pain receptors, such as the Pacinian Corpuscle, that can reduce chronic pain in patients and regenerate those cells [140, 141]. These large mechanoreceptors in the subcutaneous and connective tissues surrounding visceral organs and joints are sensitive to pressure and can react to vibration from 60 Hz upward [140, 141]. When Pacinian corpuscles are stimulated, they send neurological non-pain messages to the brain that appear to inhibit the pain impulse. A-b nerve fibers transmit information from vibration receptors Pacinian corpuscles and Meissner corpuscles. They touch receptors in the skin and stimulate inhibitory interneurons in the spinal cord that, in turn, act to reduce the number of pain signals (for further reading [140, 141]).

4. Discussion

Since the narrative review aims to determine whether or not a unique natural physicochemical set of actions underlies different brain stimulation approaches, several hypotheses are acknowledged in the results section. Insofar as these hypotheses seem plausible and are based on empirical evidence, this section attempts to show that mitochondria are likely a central player in cellular processes underlying all brain stimulation techniques. The further reflections in this section based on the empirical data of other research explore whether mitochondrial metabolism pretends to become an agent of the universal endogenous neurostimulation mechanism, unique for the different brain stimulation approaches. Following this assumption, the section revises the existing hypotheses of neurostimulation to add their explanation with insight into the role of mitochondria.

The current review also highlights that:

- All noted techniques are used in the treatment of a similar set of diagnoses related to the brain, such as depression, chronic pain, post-traumatic stress disorders, insomnia, and cognitive function disorders.
- According to comprehensive analyses, all techniques are needed to refine the dose and develop personalized therapeutics.

These insights and findings in psychology and neuroscience allow the article in section 4.7 to propose a hypothesis of the natural brain stimulation derived from our ongoing research.

4.1 The Agent of the Universal Neuromodulation

To our knowledge, adenosine-5’-triphosphate (ATP protein) stores and transports energy in organisms. Mitochondria are the cellular "powerhouse," the energy factories of cells, which are

highly proteome efficient in generating ATP. Mitochondria provide energy for normal functioning [103]. Mitochondrial ATP generation is even more proteome-efficient than glycolysis [142]. These organelles produce energy in oxidative phosphorylation: the electron transport chain and the enzyme ATP synthase convert oxygen and nutrients into ATP. Research shows three mechanisms of ATP production in animals. The mitochondria synthesize the vast majority of ATP through respiration, the so-called catabolic process [143]. The second mechanism benefits from light-harvesting chlorophyll pigments; mitochondria synthesize ATP when mixed with a light-capturing metabolite of chlorophyll [143]. Even more, research shows that red light (650-800 nm) impacts mitochondrial complex IV or cytochrome oxidase that raises ATP protein release [144, 145]. Large numbers of mitochondria exist in the inner cells of the retina.

At the same time, mitochondrial output signals regulate other organelles' functions and systemically tune physiology by integrating information through dynamic, network-based physical interactions and diffusion mechanisms. [146]. According to Picard and Shirihai [146], mitochondria (being the processor of the cells) constitute the mitochondrial information processing system (MIPS), providing signal processing and integration [146].

Mitochondria, commonly found in synaptic terminals, play a crucial role in maintaining neurotransmission by producing ATP and buffering Ca^{2+}. This underscores their importance in neurological function [147].

Insofar as the above arguments are correct (i.e., mitochondria produce energy for cells by oxygen and light transduction, maintain neurotransmission, and provide interactive networks MIPS), these cells may contribute to a unique physicochemical set of actions underlies different brain stimulation approaches. In the following sections, this assumption is developed with support from empirical data.

4.2 Mitochondria for Brain Stimulation through the IFVP and PGCP

The physicochemical sequence of actions behind the brain stimulation through the image-forming vision pathways remains (IFVP) largely unknown (see the 3.1 section). The current work proposes a hypothesis of brain stimulation by light through these pathways. Insofar as the above arguments from the 4.1 section are correct: (i) The retina's inner cells, rich in mitochondria, serve as the powerhouse for energy transduction through the optic nerve, a crucial process in vision and brain function. (ii) Mitochondria are interactive networks of signal processing and integration (MIPS), and finally. (iii) Mitochondria play a crucial role in maintaining neurotransmission in synaptic terminals. Consequently, light can directly modulate synaptic activity in the brain through the image-forming vision pathways and the photoreceptive ganglion cell pathways by exerting its functions by stimulating ATP production of mitochondria in the retina. Indeed, there is a consensus in cognitive sciences that color lights of different wavelengths stimulate the neuronal activity of various frequency bands in multiple networks [148-150]. Red color elicits higher brain activity in the frontal and parietal areas [148]. In contrast, violet only evokes a response in the prefrontal cortex [150].

4.3 Mitochondria for Brain Stimulation through Skin Irradiation

This section shows that skin irradiation, by light for brain stimulation and a therapeutic effect, relies on mitochondrial activity. When the skin is irradiated by light, mitochondria release a yet-to-

be-identified signaling molecule called mitokine (also see 3.3 section). Mitokine is encoded by fibroblast growth factor 21 [FGF21]. The release of mitokine triggers a mitochondrial stress response in other areas of the body [108]. Fibroblast growth factor 21 (FGF21) is up-regulated in response to mitochondrial stress and during the mitochondrial unfolded protein response [107]. FGF21 is a hormone that significantly regulates metabolism, energy homeostasis, and mitochondrial function [107]. The overall metabolic and thermogenic effects of FGF21 may indirectly regulate mitochondrial function in various brain regions. Based on the signaling system MIPS between mitochondria across different organ systems [103], FGF21 regulates their corticotropin-releasing factor, a vital component of the brain's stress response system, altering neurological functions.

4.4 Mitochondria for Transcranial PBM

The hypothesis of a therapeutic effect of transcranial laser radiation on tissues from the 3.4 section can be complemented with the experimental data that reveal the mitochondrial role in laser-to-ATP (adenosine triphosphate) synthesis. Specifically, laser radiation causes ATP production in mitochondria [115, 116] and a release of mitochondrial reactive oxygen species (ROS) and nitric oxide (NO) [23, 25, 26, 117, 151]. This provides an increase in mitochondrial oxygen consumption and cellular energy metabolism. Mitochondria impact synoptic activity by producing ATP, and due to MIPS, altering neurological functions.

4.5 Mitochondria for Brain Stimulation in Electric Currents and Magnetic Fields

As noted above, electromagnetic fields can increase A(2A) adenosine receptor density in cortex cell membranes [122] (for more information, see 3.3 section above). Adenosine A(2A) receptor stimulation enhances mitochondrial metabolism [152]. Research has reported that adenosine is endogenously generated and exogenously applied [152]. Because electromagnetic fields enhance mitochondrial bioenergetics [153], mitochondria energy metabolism increases ATP release. These data can complement the hypothesis from the 3.5 section on how external electrical currents and magnetic fields affect synoptic activity, highlighting the mitochondria' role in this brain therapeutic method.

4.6 Mitochondria for Brain Stimulation by Sounds

As noted in section 3.4, empirical data have shown that sounds may exert brain stimulation due to the dopamine, serotonin, and corticosterone release, which is altered when a body receives vibrations [138, 139]. However, the link between vibrations and neurotransmitters would become more apparent when considering two empirical facts: (1) sound vibrations modulate the mitochondrial functions [154], and, as already noted, (2) mitochondria activity exerts neurostimulation by altering the production of neurotransmitters such as dopamine, serotonin, and corticosterone. Interestingly, investigating changes in synaptic plasticity under different vibration protocols, research has found that only lower frequency oscillations (<30 Hz) positively modulate hippocampal synaptic plasticity, increasing cognitive functions such as memory [155].

The idea of transmitting sound vibrations to mechanoreceptors and pain receptors, such as the Pacinian Corpuscle, that can reduce chronic pain in patients and regenerate those cells [140, 141], also seems plausible (see more in the 3.4 section). However, this explanation needs to be completed

at the cellular level. Significantly, even during brain stimulation due to vibrations, mitochondrial activity can comprehensively explain how sounds can provide a therapeutic neurostimulation effect. Because the transduction within the Pacinian corpuscle (PC) mechanoreceptors occurs at or near the filopodia with a high concentration of mitochondria, the PC activity depends on mitochondria activity. Since it is already known that neurological dysfunction and neurodegeneration are closely related to impaired mitochondrial oxidative metabolism [120], enhancing mitochondrial metabolism enables PC to send neurological non-pain messages to a brain that appears to inhibit the pain impulse [141]. Moreover, research shows low-frequency sounds of 1-1.5 Hz (e.g., different classic music) enhance ATP [156]. These experimental data also support the insight into mitochondria' contribution to the brain stimulation of low-frequency sounds.

4.7 Mitochondria in Universal Natural Neuromodulation

The literature analysis reveals that mitochondria participate in physicochemical interactions of different brain stimulation approaches. Since one agent plays a central role in various techniques and all techniques are used to treat the same brain-related diseases, one can ponder that these neurostimulation methods are just exceptional cases of a universal natural sequence of actions, a part of a natural flow of physicochemical interactions in nervous system development during pregnancy. However, this hypothesis is only based on known facts and has yet to be proven. Even though it relies upon empirical data from our research and other researchers, this is the only hypothesis that needs to be verified in further study. It requires more empirical evidence to be considered a robust theory. This conclusion enables further research on a natural "architect" of brain development. This section attempts to provide the first insight into the natural nervous system stimulation that appears in pregnancy and can become a prototype of the predictive therapeutic method to treat disorders related to the brain.

4.7.1 The Mother-Fetus Neurocognitive Model

Research on the first step of a child's cognitive development reveals insights into beginning cognition during pregnancy [157-166] through mother-fetus interactions [128, 130, 167]. According to the received view in cognitive sciences, the mother-child interplay is essential for the first step in cognition, which is associated with psychophysiological processes of shared intentionality [168]. Any inborn capacity manifests itself during lifespan. Growing empirical evidence supports emerging cognition due to interpersonal interactions through shared intentionality in young children and adults [169-174]. The comprehensive analysis of research data on child development during gestation and after birth [128, 130, 167] and recent findings about neurophysiological processes underlying interpersonal dynamics in neuroscience [166, 175-180] allows the neurophysiological hypothesis of shared intentionality to argue about the emergence of cognitive functions as perception through heart-brain interplay during gestation [128, 130, 167]. Beginning from the basic pattern of stimulus-response coordination, the human capacity to appropriately detect changes within themselves and in their environments depends on the specific nervous system architecture, which evolves in a particular way during gestation [128, 130, 167]. The proper jumpy system development makes us humans [128, 130, 167]. The physicochemical properties of the mother-fetus bio-system, primarily the electromagnetic and acoustic oscillations of the mother's heart, consolidate the neuronal activity of both organisms in a choir, shaping harmony from a cacophony

of distinct oscillations [128, 130, 167]. During the mother's intentional act, the interactions within this bio-system of acoustic fluctuations, electromagnetic waves, and chemical interactions synchronize brain oscillations, affecting neuroplasticity in the fetus [128, 130, 167]. At the same time, interactions with the external environment during the mother's intentional acts provide a clue to the fetus's nervous system, binding synoptic activity with appropriate stimuli [128, 130, 167]. The mother-fetus interaction enables the child's nervous system to evolve with adequate biological sentience. This so-called mother-fetus neurocognitive (MFN) model forms the specific architecture of the child's nervous system and contributes to the beginning of cognition [128, 130, 167].

4.7.2 The MFN Model Components and Experimental Validation

Recent empirical studies implemented the MFN model in psychophysiological design to verify the modulation of shared intentionality [170-177]. The research design emulated this bio-system in children and adults by applying relevant parameters with their magnitude proportional to the scale of the model. The case studies [181, 182] reported the central characteristics of the model implemented to cause mitochondrial and cognitive stress in subjects: a display with color lights, an acoustic transducer, and an intellectual task. The display radiated an electromagnetic field with a frequency of 50-60 Hz and a magnetic flux density of 0.13-0.3 μT at a distance of 0.2-0.4 m, which delivered 400 lux of light. It emitted impulses of alternately flashing color lights with wavelengths of 400 nm and 700 nm (lights of violet and red, respectively) with a frequency of 1.3 Hz of alternate flashing. The sound transducer emulated the MFN model in the patient to simulate the impact of the mother's heartbeats on the fetus's nervous system. Specifically, headphones emitted a complex acoustic wave with a flux density of 0.08 T formed within the operating frequency of 1.3 Hz by the first sinusoid, the second sinusoid, and the third sinusoid. Each first, second, and third sinusoid had a period equal to the operating frequency. At the same time, the phase of the second sinusoid is shifted by a value equal to one-third of the operating frequency and the second sinusoid by two-thirds of the operating frequency. The first sine wave had an amplitude of 85 dB, and the second sine wave and the third sine wave had an amplitude of 25 dB.

As noted above, a theory argues that cognition emerges due to psychophysiological processes of shared intentionality; research shows modulation of shared intentionality in adult subjects by emulating the above-noted components of the MFN model [170-174]. Insofar as shared intentionality modulation is already observed experimentally and as we know that the mother-fetus interaction, specifically shared intentionality, enables evolving the child's nervous system with adequate biological sentience, it is not too controversial to suppose that environmental conditions tested in shared intentionality modulation, can also treat the injured nervous system. This natural stimulation of the fetal nervous system, the impact of the mother's heart during pregnancy, can become a prototype for "gentle" neuromodulation.

4.7.3 Establishment of Acoustic Photonic Intellectual Neurostimulation

By drawing on evidence from cognitive sciences (esp. psychology and neuroscience) and evidence from research on modulation of shared intentionality, the nature-based brain stimulation technique called Acoustic Photonic Intellectual Neurostimulation (APIN) has been developed [181, 182]. The APIN technique implements three therapeutic agents derived from studying natural neurostimulation during gestation. They cooperatively stimulate specific neuronal networks of the

brain, emulating the mother-fetus neurocognitive model in a patient (see above). Because mother-fetus interactions enable the evolution of the child's nervous system with adequate biological sentience, the APIN can treat the injured nervous system in patients by scaling characteristics of this bio-system [181, 182]. The therapy exerts its functions by affecting neuronal plasticity and vasodilation, which increases microvascular blood flow velocity and tissue oxygenation. The APIN technique has already shown significant results in testing three cases: dysmenorrhea [181], neurodegenerative disorder [182], and phantom pain sensation (in press). The author believes this significant outcome was achieved due to fine-tuning the nervous system by modulating neural plasticity. This research has the potential to influence future studies in the field of neuromodulation research significantly.

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References

1. Huang X, Tao Q, Ren C. A comprehensive overview of the neural mechanisms of light therapy. Neurosci Bull. 2024; 40: 350-362.
2. Hirakawa H, Terao T, Muronaga M, Ishii N. Adjunctive bright light therapy for treating bipolar depression: A systematic review and meta-analysis of randomized controlled trials. Brain Behav. 2020; 10: e01876.
3. Wang S, Zhang Z, Yao L, Ding N, Jiang L, Wu Y. Bright light therapy in the treatment of patients with bipolar disorder: A systematic review and meta-analysis. PLoS One. 2020; 15: e0232798.
4. Dong C, Shi H, Liu P, Si G, Yan Z. A critical overview of systematic reviews and meta-analyses of light therapy for non-seasonal depression. Psychiatry Res. 2022; 314: 114686.
5. Millot F, Endomba FT, Forestier N. Light therapy in post-traumatic stress disorder: A systematic review of interventional studies. J Clin Med. 2024; 13: 3926.
6. Chambe J, Reynaud E, Maruani J, Fraih E, Geoffroy PA, Bourgin P. Light therapy in insomnia disorder: A systematic review and meta-analysis. J Sleep Res. 2023; 32: e13895.
7. Burns A, Allen H, Tomenson B, Duignan D, Byrne J. Bright light therapy for agitation in dementia: A randomized controlled trial. Int Psychogeriatr. 2009; 21: 711-721.
8. Onega LL, Pierce TW, Epperly L. Effect of bright light exposure on depression and agitation in older adults with dementia. Issues Ment Health Nurs. 2016; 37: 660-667.
9. Sanassi LA. Seasonal affective disorder: Is there light at the end of the tunnel? JAAPA. 2014; 27: 18-22.

10. Benedetti F, Colombo C, Pontiggia A, Bernasconi A, Florita M, Smeraldi E. Morning light treatment hastens the antidepressant effect of citalopram: A placebo-controlled trial. J Clin Psychiatry. 2003; 64: 648-653.
11. Zaidi FH, Hull JT, Peirson SN, Wulff K, Aeschbach D, Gooley JJ, et al. Short-wavelength light sensitivity of circadian, pupillary, and visual awareness in humans lacking an outer retina. Curr Biol. 2007; 17: 2122-2128.
12. Fu Y, Liao HW, Do MT, Yau KW. Non-image-formingocular photoreception in vertebrates. Curr Opin Neurobiol. 2005; 15: 415-422.
13. Coelho MM, Apetato M. The dark side of the light: Phototherapy adverse effects. Clin Dermatol. 2016; 34: 556-562.
14. Fernandes F, Oliveira S, Monteiro F, Gasik M, Silva FS, Sousa N, et al. Devices used for photobiomodulation of the brain—A comprehensive and systematic review. J NeuroEng Rehabil. 2024; 21: 53.
15. Martin PI, Chao L, Krengel MH, Ho MD, Yee M, Lew R, et al. Transcranial photobiomodulation to improve cognition in Gulf War illness. Front Neurol. 2021; 11: 574386.
16. Hipskind SG, Grover FL, Fort TR, Helffenstein D, Burke TJ, Quint SA, et al. Pulsed transcranial red/near-infrared light therapy using light-emitting diodes improves cerebral blood ow and cognitive function in veterans with chronic traumatic brain injury: A case series. Photomed Laser Surg. 2018. doi: 10.1089/pho. 2018.4489.
17. Carneiro AM, Barros AP, de Oliveira RP, de Paula BL, Silva AM, de Melo Alencar C, et al. The effect of photobiomodulation using low-level laser therapy on tooth sensitivity after dental bleaching: A systematic review. Lasers Med Sci. 2022; 37: 2791-2804.
18. Naeser MA, Saltmarche A, Krengel MH, Hamblin MR, Knight JA. Improved cognitive function after transcranial, light-emitting diode treatments in chronic, traumatic brain injury: Two case reports. Photomed Laser Surg. 2011; 29: 351-358.
19. Naeser MA, Zafonte R, Krengel MH, Martin PI, Frazier J, Hamblin MR, et al. Significant improvements in cognitive performance post-transcranial, red/near-infrared light-emitting diode treatments in chronic, mild traumatic brain injury: Open-protocol study. J Neurotrauma. 2014; 31: 1008-1017.
20. Tian F, Hase SN, Gonzalez-Lima F, Liu H. Transcranial laser stimulation improves human cerebral oxygenation. Lasers Surg Med. 2016; 48: 343-349.
21. Holmes E, Barrett DW, Saucedo CL, O'Connor P, Liu H, Gonzalez-Lima F. Cognitive enhancement by transcranial photobiomodulation is associated with cerebrovascular oxygenation of the prefrontal cortex. Front Neurosci. 2019; 13: 1129.
22. Pastore D, Greco M, Petragallo VA, Passarella S. Increase in H^+/e^- ratio of the cytochrome c oxidase reaction in mitochondria irradiated with helium-neon laser. Biochem Mol Biol Int. 1994; 34: 817-826.
23. Karu TI, Pyatibrat LV, Afanasyeva NI. Cellular effects of low power laser therapy can be mediated by nitric oxide. Lasers Surg Med. 2005; 36: 307-314.
24. Plass CA, Loew HG, Podesser BK, Prusa AM. Light-induced vasodilation of coronary arteries and its possible clinical implication. Ann Thorac Surg. 2012; 93: 1181-1186.
25. dos Santos Cardoso F, Mansur FC, Araújo BH, Gonzalez-Lima F, Gomes da Silva S. Photobiomodulation improves the inflammatory response and intracellular signaling proteins

linked to vascular function and cell survival in the brain of aged rats. Mol Neurobiol. 2022; 59: 420-428.
26. Cardoso FD, Salehpour F, Coimbra NC, Gonzalez-Lima F, Gomes da Silva S. Photobiomodulation for the treatment of neuroinflammation: A systematic review of controlled laboratory animal studies. Front Neurosci. 2022; 16: 1006031.
27. Liebert A, Bicknell B, Laakso EL, Heller G, Jalilitabaei P, Tilley S, et al. Improvements in clinical signs of Parkinson's disease using photobiomodulation: A prospective proof-of-concept study. BMC Neurol. 2021; 21: 256.
28. Qi X, Nizamutdinov D, Berman MH, Dougal G, Chazot PL, Wu E, et al. Gender differences of dementia in response to intensive self-administered transcranial and intraocular near-infrared stimulation. Cureus. 2021; 13: e16188.
29. Salehpour F, Hamblin MR, Diduro JO. Rapid reversal of cognitive decline, olfactory dysfunction, and quality of life using multi-modality photobiomodulation therapy: Case report. Photobiomodulation Photomed Laser Surg. 2019; 37: 159-167.
30. Saltmarche AE, Naeser MA, Ho KF, Hamblin MR, Lim L. Significant improvement in cognition in mild to moderately severe dementia cases treated with transcranial plus intranasal photobiomodulation: Case series report. Photomed Laser Surg. 2017; 35: 432-441.
31. Santos L, del Olmo-Aguado S, Valenzuela PL, Winge K, Iglesias-Soler E, Argüelles-Luis J, et al. Photobiomodulation in Parkinson's disease: A randomized controlled trial. Brain Stimul. 2019; 12: 810-812.
32. Cassano P, Petrie SR, Mischoulon D, Cusin C, Katnani H, Yeung A, et al. Transcranial photobiomodulation for the treatment of major depressive disorder. The ELATED-2 pilot trial. Photomed Laser Surg. 2018; 36: 634-646.
33. Disner SG, Beevers CG, Gonzalez-Lima F. Transcranial laser stimulation as neuroenhancement for attention bias modification in adults with elevated depression symptoms. Brain Stimul. 2016; 9: 780-787.
34. Iosifescu DV, Norton RJ, Tural U, Mischoulon D, Collins K, McDonald E, et al. Very low-level transcranial photobiomodulation for major depressive disorder: The ELATED-3 multicenter, randomized, sham-controlled trial. J Clin Psychiatry. 2022; 83: 42180.
35. Cassano P, Cusin C, Mischoulon D, Hamblin MR, De Taboada L, Pisoni A, et al. Near-infrared transcranial radiation for major depressive disorder: Proof of concept study. Psychiatry J. 2015; 2015: 352979.
36. González-Muñoz A, Cuevas-Cervera M, Pérez-Montilla JJ, Aguilar-Núñez D, Hamed-Hamed D, Aguilar-García M, et al. Efficacy of photobiomodulation therapy in the treatment of pain and inflammation: A literature review. Healthcare. 2023; 11: 938.
37. Cheng K, Martin LF, Slepian MJ, Patwardhan AM, Ibrahim MM. Mechanisms and pathways of pain photobiomodulation: A narrative review. J Pain. 2021; 22: 763-777.
38. Caldieraro MA, Cassano P. Transcranial photobiomodulation for major depressive and anxiety disorders and for posttraumatic stress disorder. In: Photobiomodulation in the Brain. London, UK: Academic Press; 2019. pp. 479-487.
39. Lin YP, Ding RS, Yin CH, Chen YS, Chen JS, Chang ST. Effects of intravascular photobiomodulation on insomnia, muscle soreness, and biochemistry profiles: An eight-year retrospective cohort. Medicina. 2023; 59: 1006.

40. Cios A, Cieplak M, Szymański Ł, Lewicka A, Cierniak S, Stankiewicz W, et al. Effect of different wavelengths of laser irradiation on the skin cells. Int J Mol Sci. 2021; 22: 2437.
41. Heiskanen V, Hamblin MR. Photobiomodulation: Lasers vs. light emitting diodes? Photochem Photobiol Sci. 2018; 17: 1003-1017. Erratum in: Photochem Photobiol Sci. 2018; 18: 259.
42. Cassano P, Caldieraro MA, Norton R, Mischoulon D, Trinh NH, Nyer M, et al. Reported side effects, weight and blood pressure, after repeated sessions of transcranial photobiomodulation. Photobiomodulation Photomed Laser Surg. 2019; 37: 651-656.
43. Smith KC. Laser (and LED) therapy is phototherapy. Photomed Laser Surg. 2005; 23: 78-80.
44. Moo-Estrella JA, Pérez-Pichardo MF. Cranial electrical stimulation for the treatment of insomnia, anxiety, and depression symptoms in adults. Rev Mex Neurocienc. 2020; 21: 104-110.
45. Trifu S, Sevcenco A, Stănescu M, Drăgoi AM, Cristea MB. Efficacy of electroconvulsive therapy as a potential first-choice treatment in treatment-resistant depression. Exp Ther Med. 2021; 22. doi: 10.1089/photob.2019.4678.
46. Wang H, Wang K, Xue Q, Peng M, Yin L, Gu X, et al. Transcranial alternating current stimulation for treating depression: A randomized controlled trial. Brain. 2022; 145: 83-91.
47. Jog MA, Anderson C, Kubicki A, Boucher M, Leaver A, Hellemann G, et al. Transcranial direct current stimulation (tDCS) in depression induces structural plasticity. Sci Rep. 2023; 13: 2841.
48. Price L, Briley J, Haltiwanger S, Hitching R. A meta-analysis of cranial electrotherapy stimulation in the treatment of depression. J Psychiatr Res. 2021; 135: 119-134.
49. Mollica A, Ng E, Burke MJ, Nestor SM, Lee H, Rabin JS, et al. Treatment expectations and clinical outcomes following repetitive transcranial magnetic stimulation for treatment-resistant depression. Brain Stimul. 2024; 17: 752-759.
50. Tan G, Rintala DH, Thornby JI, Yang J, Wade W, Vasilev C. Using cranial electrotherapy stimulation to treat pain associated with spinal cord injury. J Rehabil Res Dev. 2006; 43: 461-474.
51. Rasmussen KG, Rummans TA. Electroconvulsive therapy in the management of chronic pain. Curr Pain Headache Rep. 2002; 6: 17-22.
52. Chang MC, Briand MM, Boudier-Revéret M, Yang S. Effectiveness of transcranial alternating current stimulation for controlling chronic pain: A systematic review. Front Neurol. 2023; 14: 1323520.
53. Moshfeghinia R, Shekouh D, Mostafavi S, Hosseinzadeh M, Bahadori AR, Abdollahifard S, et al. The effects of transcranial direct-current stimulation (tDCS) on pain intensity of patients with fibromyalgia: A systematic review and meta-analysis. BMC Neurol. 2023; 23: 395.
54. Wu Q, Li X, Zhang Y, Chen S, Jin R, Peng W. Analgesia of noninvasive electrical stimulation of the dorsolateral prefrontal cortex: A systematic review and meta-analysis. J Psychosom Res. 2024; 185: 111868.
55. Conde-Antón Á, Hernando-Garijo I, Jiménez-Del-Barrio S, Mingo-Gómez MT, Medrano-de-la-Fuente R, Ceballos-Laita L. Effects of transcranial direct current stimulation and transcranial magnetic stimulation in patients with fibromyalgia. A systematic review. Neurología. 2023; 38: 427-439.
56. Zhong M, Liu Q, Li L, Tang VM, Wong AH, Liu Y. Evaluating the effect of electroconvulsive therapy (ECT) on post-traumatic stress disorder (PTSD): A systematic review and meta-analysis of five studies. J Psychiatr Res. 2023; 164: 37-45.

57. Saccenti D, Lodi L, Moro AS, Scaini S, Forresi B, Lamanna J, et al. Novel approaches for the treatment of post-traumatic stress disorder: A systematic review of non-invasive brain stimulation interventions and insights from clinical trials. Brain Sci. 2024; 14: 210.
58. Xu G, Li G, Yang Q, Li C, Liu C. Explore the durability of repetitive transcranial magnetic stimulation in treating post-traumatic stress disorder: An updated systematic review and meta-analysis. Stress Health. 2024; 40: e3292.
59. Zhang AD, Pola A, Lin Y. Consider early ECT treatment for chronic insomnia-induced suicidal ideation. Eur Psychiatry. 2023; 66: S1100.
60. Motamedi GK, Jeliazkov PG, Oyegbile-Chidi TO, Song SS, Sharma VD, Mete M, et al. Transcranial alternating current stimulation (tACS) as a treatment for insomnia. Can J Neurol Sci. 2023; 50: 446-449.
61. Provencher T, Charest J, Bastien C. Non-invasive brain stimulation for insomnia-a review of current data and future implications. OBM Integr Complement Med. 2020; 5: 001.
62. Ma H, Lin J, He J, Lo DH, Tsang HW. Effectiveness of TES and rTMS for the treatment of insomnia: Meta-analysis and meta-regression of randomized sham-controlled trials. Front Psychiatry. 2021; 12: 744475.
63. Brunyé TT, Giles GE, Eddy MD, Navarro E. Cranial electrotherapy stimulation (CES) does not reliably influence emotional, physiological, biochemical, or behavioral responses to acute stress. J Cogn Enhanc. 2022; 6: 417-433.
64. Sigström R, Nordenskjöld A, Juréus A, Clements C, Joas E, Pålsson E, et al. Long-term subjective memory after electroconvulsive therapy. BJPsych Open. 2020; 6: e26.
65. Booth SJ, Taylor JR, Brown LJ, Pobric G. The effects of transcranial alternating current stimulation on memory performance in healthy adults: A systematic review. Cortex. 2022; 147: 112-139.
66. Cavaleiro C, Martins J, Goncalves J, Castelo-Branco M. Memory and cognition-related neuroplasticity enhancement by transcranial direct current stimulation in rodents: A systematic review. Neural Plast. 2020; 1: 4795267.
67. Liu Y, Gu N, Cao X, Zhu Y, Wang J, Smith RC, et al. Effects of transcranial electrical stimulation on working memory in patients with schizophrenia: A systematic review and meta-analysis. Psychiatry Res. 2021; 296: 113656.
68. Heath AM, Brewer M, Yesavage J, McNerney MW. Improved object recognition memory using post-encoding repetitive transcranial magnetic stimulation. Brain Stimul. 2022; 15: 78-86.
69. Michals ML, Crismon ML, Misko JS, Childs A. A double-blind, sham-controlled evaluation of cranial electrotherapy stimulation in posttraumatic memory impairment. Head Trauma Rehabil. 1993; 8: 77-86.
70. Jin G, Chen J, Du J, H e L, Qi L, Wu D, et al. Repetitive transcranial magnetic stimulation to treat benign epilepsy with centrotemporal spikes. Brain Stimul. 2022; 15: 601-604.
71. Ibrahim C, Tang VM, Blumberger DM, Malik S, Tyndale RF, Trevizol AP, et al. Efficacy of insula deep repetitive transcranial magnetic stimulation combined with varenicline for smoking cessation: A randomized, double-blind, sham controlled trial. Brain Stimul. 2023; 16: 1501-1509.
72. Pape TLB, Rosenow J, Lewis G, Ahmed G, Walker M, Guernon A, et al. Repetitive transcranial magnetic stimulation-associated neurobehavioral gains during coma recovery. Brain Stimul. 2009; 2: 22-35.

73. Kirsch DL, Nichols F. Cranial electrotherapy stimulation for treatment of anxiety, depression, and insomnia. Psychiatr Clin N Am. 2013; 36: 169-176.
74. Thirthalli J, Sinha P, Sreeraj VS. Clinical practice guidelines for the use of electroconvulsive therapy. Indian J Psychiatry. 2023; 65: 258-269.
75. Elyamany O, Leicht G, Herrmann CS, Mulert C. Transcranial alternating current stimulation (tACS): From basic mechanisms towards first applications in psychiatry. Eur Arch Psychiatry Clin Neurosci. 2021; 271: 135-156.
76. Bikson M, Datta A, Elwassif M. Establishing safety limits for transcranial direct current stimulation. Clin Neurophysiol. 2009; 120: 1033-1034.
77. Reed T, Cohen Kadosh R. Transcranial electrical stimulation (tES) mechanisms and its effects on cortical excitability and connectivity. J Inherit Metab Dis. 2018; 41: 1123-1130.
78. Ambrus GG, Paulus W, Antal A. Cutaneous perception thresholds of electrical stimulation methods: Comparison of tDCS and tRNS. Clin Neurophysiol. 2010; 121: 1908-1914.
79. Gutiérrez-Muto AM, Bestmann S, Sánchez de la Torre R, Pons JL, Oliviero A, Tornero J. The complex landscape of TMS devices: A brief overview. PloS One. 2023; 18: e0292733.
80. Cusin C, Dougherty DD. Somatic therapies for treatment-resistant depression: ECT, TMS, VNS, DBS. Biol Mood Anxiety Disord. 2012; 2: 14.
81. Benussi A, Pascual-Leone A, Borroni B. Non-invasive cerebellar stimulation in neurodegenerative ataxia: A literature review. Int J Mol Sci. 2020; 21: 1948.
82. Exbrayat JM, Brun C. Some effects of sound and music on organisms and cells: A review. Annu Res Rev Biol. 2019; 32: 1-12.
83. Wang X, Xie Z, Du G. Research on the intervention effect of vibroacoustic therapy in the treatment of patients with depression. Int J Ment Health Promot. 2024; 26: 149-160.
84. Lam HL, Li WT, Laher I, Wong RY. Effects of music therapy on patients with dementia—A systematic review. Geriatrics. 2020; 5: 62.
85. Koger SM, Chapin K, Brotons M. Is music therapy an effective intervention for dementia? A meta-analytic review of literature. J Music Ther. 1999; 36: 2-15.
86. Ward EV, Isac A, Donnelly M, Van Puyvelde M, Franco F. Memory improvement in aging as a function of exposure to mood-matching music. Acta Psychol. 2021; 212: 103206.
87. Pongan E, Tillmann B, Leveque Y, Trombert B, Getenet JC, Auguste N, et al. Can musical or painting interventions improve chronic pain, mood, quality of life, and cognition in patients with mild Alzheimer's disease? Evidence from a randomized controlled trial. J Alzheimers Dis. 2017; 60: 663-677.
88. Lee JH. The effects of music on pain: A meta-analysis. J Music Ther. 2016; 53: 430-477. Erratum in: J Music Ther. 2021; 58: 372.
89. Kühlmann AY, De Rooij A, Kroese LF, Van Dijk M, Hunink MG, Jeekel J. Meta-analysis evaluating music interventions for anxiety and pain in surgery. Br J Surg. 2018; 105: 773-783.
90. Landis-Shack N, Heinz AJ, Bonn-Miller MO. Music therapy for posttraumatic stress in adults: A theoretical review. Psychomusicology. 2017; 27: 334-342.
91. Jespersen KV, Pando-Naude V, Koenig J, Jennum P, Vuust P. Listening to music for insomnia in adults. Cochrane Database Syst Rev. 2022; 8: CD010459.
92. American Music Therapy Association. About Music Therapy & AMTA [Internet]. Silver Spring, MD: American Music Therapy Association; [cited date 2024 September 8]. Available from: https://www.musictherapy.org/about/.

93. Zabrecky G, Shahrampour S, Whitely C, Alizadeh M, Conklin C, Wintering N, et al. An fMRI study of the effects of vibroacoustic stimulation on functional connectivity in patients with insomnia. Sleep Disord. 2020; 2020: 7846914.
94. Kantor J, Campbell EA, Kantorová L, Marečková J, Regec V, Karasová K, et al. Exploring vibroacoustic therapy in adults experiencing pain: A scoping review. BMJ Open. 2022; 12: e046591.
95. Thaut MH. Rhythm, music, and the brain. Scientific foundations and clinical applications. New York, NY: Taylor and Francis Group; 2008. pp. 39-164.
96. Gonzalez-Hoelling S, Bertran-Noguer C, Reig-Garcia G, Suñer-Soler R. Effects of a music-based rhythmic auditory stimulation on gait and balance in subacute stroke. Int J Environ Res Public Health. 2021; 18: 2032.
97. Stuchly MA, Dawson TW. Interaction of low-frequency electric and magnetic fields with the human body. Proc IEEE. 2000; 88: 643-664.
98. Buzsáki G, Vöröslakos M. Brain rhythms have come of age. Neuron. 2023; 111: 922-926.
99. Stein RM, Kang HJ, McCorvy JD, Glatfelter GC, Jones AJ, Che T, et al. Virtual discovery of melatonin receptor ligands to modulate circadian rhythms. Nature. 2020; 579: 609-614.
100. Hu J, Shi Y, Zhang J, Huang X, Wang Q, Zhao H, et al. Melanopsin retinal ganglion cells mediate light-promoted brain development. Cell. 2022; 185: 3124-3137.e15.
101. Huang LU, Xi Y, Peng Y, Yang Y, Huang X, Fu Y, et al. A visual circuit related to habenula underlies the antidepressive effects of light therapy. Neuron. 2019; 102: 128-142.e8.
102. Johnstone DM, El Massri N, Moro C, Spana S, Wang XS, Torres N, et al. Indirect application of near infrared light induces neuroprotection in a mouse model of parkinsonism–An abscopal neuroprotective effect. Neuroscience. 2014; 274: 93-101.
103. Kim B, Mitrofanis J, Stone J, Johnstone DM. Remote tissue conditioning is neuroprotective against MPTP insult in mice. IBRO Rep. 2018; 4: 14-17.
104. Ganeshan V, Skladnev NV, Kim JY, Mitrofanis J, Stone J, Johnstone DM. Pre-conditioning with remote photobiomodulation modulates the brain transcriptome and protects against MPTP insult in mice. Neuroscience. 2019; 400: 85-97.
105. Liu H, Liu H, Prokosch V. The relationship between mitochondria and neurodegeration in the eye: A review. Appl Sci. 2021; 11: 7385.
106. Santana-Blank L, Rodríguez-Santana E, Santana-Rodríguez K. Theoretic, experimental, clinical bases of the water oscillator hypothesis in near-infrared photobiomodulation. Photomed Laser Surg. 2010; 28: S41-S52.
107. Chung H, Dai T, Sharma SK, Huang YY, Carroll JD, Hamblin MR. The nuts and bolts of low-level laser (light) therapy. Ann Biomed Eng. 2012; 40: 516-533.
108. Wu S, Zhou F, Wei Y, Chen WR, Chen Q, Xing D. Cancer phototherapy via selective photoinactivation of respiratory chain oxidase to trigger a fatal superoxide anion burst. Antioxid Redox Signal. 2014; 20: 733-746.
109. Zhang B, Chang JY, Lee MH, Ju SH, Yi HS, Shong M. Mitochondrial stress and mitokines: Therapeutic perspectives for the treatment of metabolic diseases. Diabetes Metab J. 2024; 48: 1-18.
110. Taylor RC, Berendzen KM, Dillin A. Systemic stress signalling: Understanding the cell non-autonomous control of proteostasis. Nat Rev Mol Cell Biol. 2014; 15: 211-217.

111. Kharitonenkov A, Di Marchi R. FGF21 revolutions: Recent advances illuminating FGF21 biology and medicinal properties. Trends Endocrinol Metab. 2015; 26: 608-617.
112. Rühlmann C, Dannehl D, Brodtrück M, Adams AC, Stenzel J, Lindner T, et al. Neuroprotective effects of the FGF21 analogue LY2405319. J Alzheimers Dis. 2021; 80: 357-369.
113. Fang X, Ma J, Mu D, Li B, Lian B, Sun C. FGF21 protects dopaminergic neurons in Parkinson's disease models via repression of neuroinflammation. Neurotox Res. 2020; 37: 616-627.
114. Liang Q, Zhong L, Zhang J, Wang Y, Bornstein SR, Triggle CR, et al. FGF21 maintains glucose homeostasis by mediating the cross talk between liver and brain during prolonged fasting. Diabetes. 2014; 63: 4064-4075.
115. Maratos-Flier E. Fatty liver and FGF21 physiology. Exp Cell Res. 2017; 360: 2-5.
116. Potthoff MJ. FGF21 and metabolic disease in 2016: A new frontier in FGF21 biology. Nat Rev Endocrinol. 2017; 13: 74-76.
117. Passarella S, Ostuni A, Atlante A, Quagliariello E. Increase in the ADP/ATP exchange in rat liver mitochondria irradiated in vitro by helium-neon laser. Biochem Biophys Res Commun. 1988; 156: 978-986.
118. Karu TI. Interactions of monochromatic visible light and near-IR radiation with cells: Currently discussed mechanisms. Laser Tissue Interact VI. 1995; 2391: 576-586.
119. Glass GE. Photobiomodulation: A systematic review of the oncologic safety of low-level light therapy for aesthetic skin rejuvenation. Aesthet Surg J. 2023; 43: NP357-NP371.
120. Wang X, Tian F, Reddy DD, Nalawade SS, Barrett DW, Gonzalez-Lima F, et al. Up-regulation of cerebral cytochrome-c-oxidase and hemodynamics by transcranial infrared laser stimulation: A broadband near-infrared spectroscopy study. J Cereb Blood Flow Metab. 2017; 37: 3789-3802.
121. Saucedo CL, Courtois EC, Wade ZS, Kelley MN, Kheradbin N, Barrett DW, et al. Transcranial laser stimulation: Mitochondrial and cerebrovascular effects in younger and older healthy adults. Brain Stimul. 2021; 14: 440-449.
122. Dong S, Ren H, Zhang R, Wei X. Recent advances in photobiomodulation therapy for brain diseases. Interdiscip Med. 2024; 2: e20230027.
123. Cardoso FD, Mansur FC, Lopes-Martins RÁ, Gonzalez-Lima F, Gomes da Silva S. Transcranial laser photobiomodulation improves intracellular signaling linked to cell survival, memory and glucose metabolism in the aged brain: A preliminary study. Front Cell Neurosci. 2021; 15: 683127.
124. Chen AC, Arany PR, Huang YY, Tomkinson EM, Sharma SK, Kharkwal GB, et al. Low-level laser therapy activates NF-κB via generation of reactive oxygen species in mouse embryonic fibroblasts. PloS One. 2011; 6: e22453.
125. Krause MR, Vieira PG, Pack CC. Transcranial electrical stimulation: How can a simple conductor orchestrate complex brain activity? PLoS Biol. 2023; 21: e3001973.
126. Ekhtiari H, Tavakoli H, Addolorato G, Baeken C, Bonci A, Campanella S, et al. Transcranial electrical and magnetic stimulation (tES and TMS) for addiction medicine: A consensus paper on the present state of the science and the road ahead. Neurosci Biobehav Rev. 2019; 104: 118-140.
127. Penny WD, Duzel E, Miller KJ, Ojemann JG. Testing for nested oscillation. J Neurosci Methods. 2008; 174: 50-61.
128. Val Danilov I. Low-Frequency oscillations for nonlocal neuronal coupling in shared intentionality before and after birth: Toward the origin of perception. OBM Neurobiol. 2023; 7: 192.

129. Val Danilov I. Shared intentionality modulation at the cell level: Low-frequency oscillations for temporal coordination in bioengineering systems. OBM Neurobiol. 2023; 7: 185.
130. Val Danilov I. Shared intentionality before birth: Emulating a model of mother-fetus communication for developing human-machine systems. In: Intelligent Systems Conference. Cham: Springer; 2023. pp. 56-69.
131. Rosen AD. Mechanism of action of moderate-intensity static magnetic fields on biological systems. Cell Biochem Biophys. 2003; 39: 163-173.
132. Ye SR, Yang JW, Chen CM. Effect of static magnetic fields on the amplitude of action potential in the lateral giant neuron of crayfish. Int J Radiat Biol. 2004; 80: 699-708.
133. Lu XW, Du L, Kou L, Song N, Zhang YJ, Wu MK, et al. Effects of moderate static magnetic fields on the voltage-gated sodium and calcium channel currents in trigeminal ganglion neurons. Electromagn Biol Med. 2015; 34: 285-292.
134. Premi E, Benussi A, La Gatta A, Visconti S, Costa A, Gilberti N, et al. Modulation of long-term potentiation-like cortical plasticity in the healthy brain with low frequency-pulsed electromagnetic fields. BMC Neurosci. 2018; 19: 34.
135. Dolphin AC, Lee A. Presynaptic calcium channels: Specialized control of synaptic neurotransmitter release. Nat Rev Neurosci. 2020; 21: 213-229.
136. Varani K, Vincenzi F, Targa M, Corciulo C, Fini M, Setti S, et al. Effect of pulsed electromagnetic field exposure on adenosine receptors in rat brain. Bioelectromagnetics. 2012; 33: 279-287.
137. Lovinger DM. Communication networks in the brain: Neurons, receptors, neurotransmitters, and alcohol. Alcohol Res Health. 2008; 31: 196-214.
138. Nakamura H, Moroji T, Nohara S, Nakamura H, Okada A. Activation of cerebral dopaminergic systems by noise and whole-body vibration. Environ Res. 1992; 57: 10-18.
139. Wei QS, Huang L, Chen XH, Wang HB, Sun WS, Huo SC, et al. Effect of whole body vibration therapy on circulating serotonin levels in an ovariectomized rat model of osteoporosis. Iran J Basic Med Sci. 2014; 17: 62-68.
140. Chesky KS, Michel DE. The music vibration. Table (MVT): Developing a technology and conceptual model for pain relief. Music Ther Perspect. 2013; 1991: 32-37.
141. Punkanen M, Ala-Ruona E. Contemporary vibroacoustic therapy: Perspectives on clinical practice, research, and training. Music Med. 2012; 4: 128-135.
142. Shen Y, Dinh HV, Cruz ER, Chen Z, Bartman CR, Xiao T, et al. Mitochondrial ATP generation is more proteome efficient than glycolysis. Nat Chem Biol. 2024; 20: 1123-1132.
143. Xu C, Zhang J, Mihai DM, Washington I. Light-harvesting chlorophyll pigments enable mammalian mitochondria to capture photonic energy and produce ATP. J Cell Sci. 2014; 127: 388-399.
144. Powner MB, Jeffery G. Light stimulation of mitochondria reduces blood glucose levels. J Biophotonics. 2024; 17: e202300521.
145. Osborne NN, Núñez-Álvarez C, Del Olmo-Aguado S, Merrayo-Lloves J. Visual light effects on mitochondria: The potential implications in relation to glaucoma. Mitochondrion. 2017; 36: 29-35.
146. Picard M, Shirihai OS. Mitochondrial signal transduction. Cell Metab. 2022; 34: 1620-1653.
147. Sheng ZH, Cai Q. Mitochondrial transport in neurons: Impact on synaptic homeostasis and neurodegeneration. Nat Rev Neurosci. 2012; 13: 77-93.

148. Yoto A, Katsuura T, Iwanaga K, Shimomura Y. Effects of object color stimuli on human brain activities in perception and attention referred to EEG alpha band response. J Physiol Anthropol. 2007; 26: 373-379.
149. Metz AJ, Klein SD, Scholkmann F, Wolf U. Continuous coloured light altered human brain haemodynamics and oxygenation assessed by systemic physiology augmented functional near-infrared spectroscopy. Sci Rep. 2017; 7: 10027.
150. Scholkmann F, Hafner T, Metz AJ, Wolf M, Wolf U. Effect of short-term colored-light exposure on cerebral hemodynamics and oxygenation, and systemic physiological activity. Neurophotonics. 2017; 4: 045005.
151. Huang YY, Chen AC, Carroll JD, Hamblin MR. Biphasic dose response in low level light therapy. Dose-response. 2009; 7: 09-027.
152. Castro CM, Corciulo C, Solesio ME, Liang F, Pavlov EV, Cronstein BN. Adenosine A2A receptor (A2AR) stimulation enhances mitochondrial metabolism and mitigates reactive oxygen species-mediated mitochondrial injury. FASEB J. 2020; 34: 5027-5045.
153. Stephenson MC, Krishna L, Pannir Selvan RM, Tai YK, Kit Wong CJ, Yin JN, et al. Magnetic field therapy enhances muscle mitochondrial bioenergetics and attenuates systemic ceramide levels following ACL reconstruction: Southeast Asian randomized-controlled pilot trial. J Orthop Transl. 2022; 35: 99-112.
154. Valenti D, Atlante A. Sound matrix shaping of living matter: From macrosystems to cell microenvironment, where mitochondria act as energy portals in detecting and processing sound vibrations. Int J Mol Sci. 2024; 25: 6841.
155. Cariati I, Bonanni R, Pallone G, Annino G, Tancredi V, D'Arcangelo G. Modulation of synaptic plasticity by vibratory training in young and old mice. Brain Sci. 2021; 11: 82.
156. Feng Q, Wang L, Chen Y, Teng J, Li M, Cai Z, et al. Effects of different music on HEK293T cell growth and mitochondrial functions. Explore. 2022; 18: 670-675.
157. Zoia S, Blason L, D'Ottavio G, Bulgheroni M, Pezzetta E, Scabar A, et al. Evidence of early development of action planning in the human foetus: A kinematic study. Exp Brain Res. 2007; 176: 217-226.
158. Castiello U, Becchio C, Zoia S, Nelini C, Sartori L, Blason L, et al. Wired to be social: The ontogeny of human interaction. PloS One. 2010; 5: e13199.
159. Sasaki M, Yanagihara T, Naitoh N, Hata T. Four-dimensional sonographic assessment of inter-twin contact late in the first trimester. Int J Gynecol Obstet. 2010; 108: 104-107.
160. Kisilevsky BC. Fetal auditory processing: Implications for language development? In: Fetal development. Cham: Springer; 2016. pp. 133-152.
161. Hepper PG, Scott D, Shahidullah S. Newborn and fetal response to maternal voice. J Reprod Infant Psychol. 1993; 11: 147-153.
162. Lee GY, Kisilevsky BS. Fetuses respond to father's voice but prefer mother's voice after birth. Dev Psychobiol. 2014; 56: 1-11.
163. Krueger CA, Cave EC, Garvan C. Fetal response to live and recorded maternal speech. Biol Res Nurs. 2015; 17: 112-120.
164. Lecanuet JP, Granier-Deferre C, Jacquet AY, Capponi I, Ledru L. Prenatal discrimination of a male and a female voice uttering the same sentence. Early Dev Parent. 1993; 2: 217-228.
165. Hepper P. Behavior during the prenatal period: Adaptive for development and survival. Child Dev Perspect. 2015; 9: 38-43.

166. Jardri R, Houfflin-Debarge V, Delion P, Pruvo JP, Thomas P, Pins D. Assessing fetal response to maternal speech using a noninvasive functional brain imaging technique. Int J Dev Neurosci. 2012; 30: 159-161.
167. Danilov IV. Child cognitive development with the maternal heartbeat: A mother-fetus neurocognitive model and architecture for bioengineering systems. In: Information Systems and Technological Advances for Sustainable Development. Cham: Springer; 2024.
168. Tomasello M. Becoming human: A theory of ontogeny. London: Harvard University Press; 2019.
169. Danilov IV, Mihailova S. Empirical evidence of shared intentionality: Towards bioengineering systems development. OBM Neurobiol. 2023; 7: 167.
170. Danilov IV, Svajyan A, Mihailova S. A new computer-aided method for assessing children's cognition in bioengineering systems for diagnosing developmental delay. OBM Neurobiol. 2023; 7: 189.
171. Danilov IV. A bioengineering system for assessing children's cognitive development by computerized evaluation of shared intentionality. Proceedings of the 2022 International Conference on Computational Science and Computational Intelligence; 2022 December 14-16; Las Vegas, Nevada, USA. Piscataway Township: IEEE.
172. Danilov IV, Mihailova S, Svajyan A. Computerized assessment of cognitive development in neurotypical and neurodivergent children. OBM Neurobiol. 2022; 6: 18.
173. Val Danilov I, Mihailova S. The origin of social skills: Manipulating shared intentionality in bioengineering systems for empathy training. OBM Neurobiol. 2024; 8: 243.
174. Val Danilov I, Mihailova S. An algorithm for the computer-aided method of empathy training by modulating shared intentionality. In: Innovations and advances in cognitive systems. Cham: Springer; 2024. pp. 31-38.
175. Fishburn FA, Murty VP, Hlutkowsky CO, MacGillivray CE, Bemis LM, Murphy ME, et al. Putting our heads together: Interpersonal neural synchronization as a biological mechanism for shared intentionality. Soc Cogn Affect Neurosci. 2018; 13: 841-849.
176. Liu J, Zhang R, Xie E, Lin Y, Chen D, Liu Y, et al. Shared intentionality modulates interpersonal neural synchronization at the establishment of communication system. Commun Biol. 2023; 6: 832.
177. Painter DR, Kim JJ, Renton AI, Mattingley JB. Joint control of visually guided actions involves concordant increases in behavioural and neural coupling. Commun Biol. 2021; 4: 816.
178. Hu Y, Pan Y, Shi X, Cai Q, Li X, Cheng X. Inter-brain synchrony and cooperation context in interactive decision making. Biol Psychol. 2018; 133: 54-62.
179. Szymanski C, Pesquita A, Brennan AA, Perdikis D, Enns JT, Brick TR, et al. Teams on the same wavelength perform better: Inter-brain phase synchronization constitutes a neural substrate for social facilitation. Neuroimage. 2017; 15: 425-436.
180. Astolfi L, Toppi J, De Vico Fallani F, Vecchiato G, Salinari S, Mattia D, et al. Neuroelectrical hyperscanning measures simultaneous brain activity in humans. Brain Topogr. 2010; 23: 243-256.
181. Mihailova S, Medne D, Val Danilov I. Acoustic photonic intellectual neurostimulation (APIN) in dysmenorrhea management: A case study on an adolescent. Brain Stimul J. Forthcoming 2024.
182. Val Danilov I, Medne D, Mihailova S. Modulating neuroplasticity with acoustic photonic intellectual neurostimulation (APIN): A case study on neurodegenerative disorder. Brain Stimul J. Forthcoming 2024.