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(54) **Title:** SYSTEM AND METHOD FOR NEUROENHANCEMENT TO ENHANCE EMOTIONAL RESPONSE

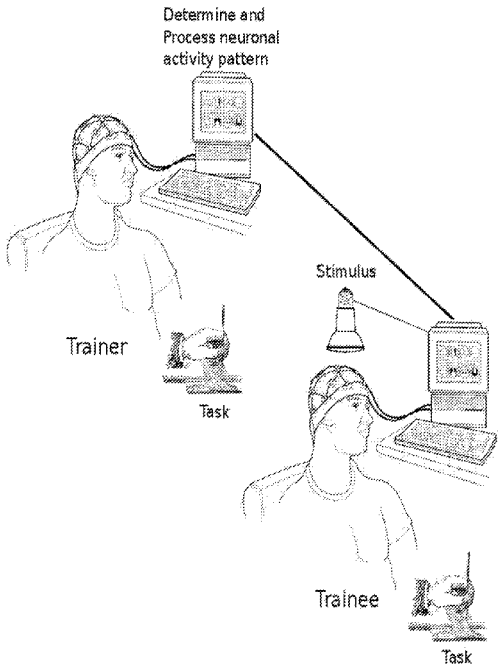

Fig. 14

(57) **Abstract:** A method of transplanting a desired emotional state from a donor to a recipient, comprising determining an emotional state of the donor; recording neural correlates of the emotional state of the donor who is in the desired emotional state; analyzing neural correlates of the emotional state of the donor to decode at least one of a temporal and a spatial pattern corresponding to the desirable emotional state; converting said at least one of a temporal and a spatial pattern corresponding to the desirable emotional state into a neurostimulation pattern; storing the neurostimulation pattern in the nonvolatile memory; retrieving the neurostimulation pattern from the nonvolatile memory; stimulating the recipient's brain with at least one stimulus modulated with the neurostimulation pattern to induce the desired emotional state in the recipient.

WO 2019/133997 A1

SYSTEM AND METHOD FOR NEUROENHANCEMENT TO ENHANCE EMOTIONAL RESPONSE

FIELD OF THE INVENTION

The present invention generally relates to the fields of neuroenhancement, neuromodulation, neurostimulation, and brain entrainment, and, more specifically, to devices, systems, and methods for selectively inducing brainwave activity patterns in humans or animals that correspond to, or enhance, an emotion or emotional response.

BACKGROUND OF THE INVENTION

People often substitute an authentic experience by a replica thereof. Those who cannot visit the Louvre Museum, can look at the Mona Lisa on a reproduction. Anybody who has seen the real Mona Lisa in the Louvre can testify that the emotional experience is completely different from just looking at a reproduction. Yet, people often substitute reproductions for authentic works of art, when the latter are not readily accessible. The emotional response to viewing a reproduction pales in comparison to the emotional response to viewing an authentic piece of art in a museum. Looking at a photograph of the Grand Canyon is incomparable with experiencing the real thing—visiting the Grand Canyon, which is a breathtaking experience. Yet, people unable to travel, often replace the authentic experience of traveling and visiting new places with watching videos on the Travel Chanel or on the Internet. Needless to say, watching TV or a video on the Internet is a poor substitute for the real experience of traveling and does not elicit the strong emotions, a person experiences when visiting new places.

Because of lack of excitement in their daily lives people seek excitement in the movies. Movies tend to be more immersive experiences and can produce strong emotional responses. Many movie-goers cry while watching movies. A sentimental, emotionally-charged movie is referred to as a tear-jerker due to its ability to elicit a strong emotional response, resulting in tears. However, the emotions experience of watching a movie cannot be compared with the broad range of emotions experienced in real life.

Recent advancements in 3D viewing technology and the emergence of Virtual Reality (VR) devices produce more realistic representation of reality they depict. However, even VR devices are incapable of producing emotional responses comparable to the emotions experienced in real life.

A viewer may benefit from enhanced emotional responses associated with viewing art reproductions, watching TV, movies, Internet videos, or Virtual Reality.

Some people lack certain emotions. For example, sociopathic personalities are incapable of experiencing emotions of empathy and compassion. A number of neurologic, psychiatric and psychological pathologies may affect the ability to experience certain emotions. Patients suffering from advanced stages of Parkinson and Alzheimer's diseases often exhibit subdued emotional response. Patients affected by paranoid schizophrenia, brain injury, or dementia sometimes experience Capgras delusion. They see a familiar face of a spouse or another family member but do not experience emotional response they expect to experience when seeing a face of a close family member,

which leads them to believe that they live with an imposter that only "looks like" their family member; they complaint about a doppelganger living with them. It may be beneficial to artificially enhance the emotional response of a patient, bringing it to the normal level expected of a healthy person.

It is well known that memory retention is affected by the emotional state of the person. Emotionally-charged experiences are etched in the memory, whereas experiences not associated with high emotions are easily forgotten. Artificially raising emotional levels during study may significantly increase the retention of the information and ease its subsequent recall.

It has been observed in neuroscience that various emotions correlate with different frequency and location of the brainwaves. Accordingly, inducing in a subject the brainwaves of particular frequency in a particular location may induce and/or enhance the desired emotional response.

Emotions are viewed as discrete and dimensional. The discrete framework classifies emotional states as physiological and behavioral manifestations of discrete emotions such as anger, happiness, etc. The dimensional perspective organizes emotional states by two factors, valence (positive/negative) and arousal (calm/exciting).

Emotions are thought to be associated with different parts of the brain:

Frontal Lobe (movement of the body; personality; concentration, planning, problem solving; meaning of words; emotional reactions; speech; smell); Parietal Lobe (touch and pressure; taste; body awareness); Temporal Lobe (hearing; recognizing faces; emotion; long-term memory); Occipital Lobe (sight); Cerebellum (Latin for little brain, fine motor (muscle) control; balance and coordination (avoid objects and keep from falling)); Limbic Lobe (controls emotions like happiness, sadness, and love).

Each reference and document cited herein is expressly incorporated herein by reference in its entirety, for all purposes.

Time in a biological matter Almost everything in biology is subject to change over time. These changes occur on many different time scales, which vary greatly. For example, there are evolutionary changes that affect entire populations over time rather than a single organism. Evolutionary changes are often slower than a human time scale that spans many years (usually, a human lifetime). Faster variations of the timing and duration of biological activity in living organisms occur, for example, in many essential biological processes in everyday life: in humans and animals, these variations occur, for example, in eating, sleeping, mating, hibernating, migration, cellular regeneration, etc. Other fast changes may include the transmission of a neural signal, for example, through a synapse, such as the Calyx of Held, a particularly large synapse in the auditory central nervous system of mammals that can reach transmission frequencies of up to 50 Hz. With recruitment modulation, the effective frequencies can be higher. A single nerve impulse can reach a speed as high as one hundred meters (0.06 mile) per second (Kraus, David. Concepts in Modern Biology. New York: Globe Book Company, 1969: 170.). Myelination of axons can increase the speed of transmission by segmenting the membrane depolarization process.

Many of these changes over time are repetitive or rhythmic and are described as some frequency or oscillation. The field of chronobiology, examines such periodic (cyclic) phenomena in living organisms and their adaptation, for example, to solar and lunar-related rhythms (DeCoursey, et al. (2003).) These cycles are also known as biological rhythms. The related terms “chronomics” and “chronome” have been used in some cases to describe either the molecular mechanisms involved in chronobiological phenomena or the more quantitative aspects of chronobiology, particularly where comparison of cycles between organisms is required. Chronobiological studies include, but are not limited to, comparative anatomy, physiology, genetics, molecular biology and behavior of organisms within biological rhythms’ mechanics (DeCoursey et al. (2003).). Other aspects include epigenetics, development, reproduction, ecology, and evolution.

The most important rhythms in chronobiology are the circadian rhythms, roughly 24-hour cycles shown by physiological processes in all organisms. They are regulated by circadian clocks. The circadian rhythms can be further broken down into routine cycles during the 24-hour day (Nelson RJ. 2005. An Introduction to Behavioral Endocrinology. Sinauer Associates, Inc.: Massachusetts. Pg. 587.) All animals can be classified according to their activity cycles: Diurnal, which describes organisms active during daytime; Nocturnal, which describes organisms active in the night; and Crepuscular, which describes animals primarily active during the dawn and dusk hours (e.g., white-tailed deer, some bats).

While circadian rhythms are defined as regulated by endogenous processes, other biological cycles may be regulated by exogenous signals. In some cases, multi-trophic systems may exhibit rhythms driven by the circadian clock of one of the members (which may also be influenced or reset by external factors).

Many other important cycles are also studied, including: Infradian rhythms, which are cycles longer than a day. Examples include circannual or annual cycles that govern migration or reproduction cycles in many plants and animals, or the human menstrual cycle; ultradian rhythms, which are cycles shorter than 24 hours, such as the 90-minute REM cycle, the 4-hour nasal cycle, or the 3-hour cycle of growth hormone production; tidal rhythms, commonly observed in marine life, which follow the roughly 12.4-hour transition from high to low tide and back; lunar rhythms, which follow the lunar month (29.5 days). They are relevant, for example, to marine life, as the level of the tides is modulated across the lunar cycle; and gene oscillations – some genes are expressed more during certain hours of the day than during other hours.

Within each cycle, the time period during which the process is more active is called the acrophase (Refinetti, Roberto (2006). Circadian Physiology. CRC Press/Taylor & Francis Group. ISBN 0-8493-2233-2. Lay summary). When the process is less active, the cycle is in its bathyphase, or trough phase. The particular moment of highest activity is the peak or maximum; the lowest point is the nadir. How high (or low) the process gets is measured by the amplitude.

Neural Correlates A neural correlate of an emotional or mental state is an electro-neuro-biological state or the state assumed by some biophysical subsystem of the brain, whose presence necessarily and regularly correlates with such specific emotional or mental states. All properties credited to the mind, including consciousness, emotion, and desires are thought to have direct neural correlates. For our purposes, neural correlates of an emotional or mental state can be defined as the minimal set of neuronal oscillations that correspond to the given emotional or mental state. Neuroscience uses empirical approaches to discover neural correlates of emotional or mental state.

Mental State A mental state is a state of mind that a subject is in. Some mental states are pure and unambiguous, while humans are capable of complex states that are a combination of mental representations, which may have in their pure state contradictory characteristics. There are several paradigmatic states of mind that a subject has: love, hate, pleasure, fear, and pain. Mental states can also include a waking state, a sleeping state, a flow (or being in the "zone"), a will (desire) for something, and a mood (a mental state). A mental state is a hypothetical state that corresponds to thinking and feeling, and consists of a conglomeration of mental representations. A mental state is related to an emotion, though it can also relate to cognitive processes. Because the mental state itself is complex and potentially possesses inconsistent attributes, clear interpretation of mental state through external analysis (other than self-reporting) is difficult or impossible. However, some studies report that certain attributes of mental state or thought processes may, in fact, be determined through passive monitoring, such as EEG, or fMRI with some degree of statistical reliability. In most studies, the characterization of mental state was an endpoint, and the raw signals, after statistical classification or semantic labeling, are superseded. The remaining signal energy treated as noise.

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Brain The brain is a key part of the central nervous system, enclosed in the skull. In humans, and mammals more generally, the brain controls both autonomic processes, as well as cognitive processes. The brain (and to a lesser extent, the spinal cord) controls all volitional functions of the body and interprets information from the outside world. Intelligence, memory, emotions, speech, thoughts, movements and creativity are controlled by the brain. The central nervous system also controls autonomic functions and many homeostatic and reflex actions, such as breathing, heart rate, etc. The human brain consists of the cerebrum, cerebellum, and brainstem. The brainstem includes the midbrain, the pons, and the medulla oblongata. Sometimes the diencephalon, the caudal part of the forebrain, is included.

The brain is composed of neurons, neuroglia (a.k.a., glia), and other cell types in connected networks that integrate sensory inputs, control movements, facilitate learning and memory, activate and express emotions, and control all other behavioral and cognitive functions. Neurons communicate primarily through electrochemical pulses

that transmit signals between connected cells within and between brain areas. Thus, the desire to noninvasively capture and replicate neural activity associated with cognitive states has been a subject of interest to behavioral and cognitive neuroscientists.

Technological advances now allow for non-invasive recording of large quantities of information from the brain at multiple spatial and temporal scales. Examples include electroencephalogram ("EEG") data using multi-channel electrode arrays placed on the scalp or inside the brain, magnetoencephalography ("MEG"), magnetic resonance imaging ("MRI"), functional data using functional magnetic resonance imaging ("fMRI"), positron emission tomography ("PET"), near-infrared spectroscopy ("NIRS"), single-photon emission computed tomography ("SPECT"), and others.

Noninvasive neuromodulation technologies have also been developed that can modulate the pattern of neural activity, and thereby cause altered behavior, cognitive states, perception, and motor output. Integration of noninvasive measurement and neuromodulation techniques for identifying and transplanting brain states from neural activity would be very valuable for clinical therapies, such as brain stimulation and related technologies often attempting to treat disorders of cognition.

The brainstem provides the main motor and sensory innervation to the face and neck via the cranial nerves. Of the twelve pairs of cranial nerves, ten pairs come from the brainstem. This is an extremely important part of the brain, as the nerve connections of the motor and sensory systems from the main part of the brain to the rest of the body pass through the brainstem. This includes the corticospinal tract (motor), the posterior column-medial lemniscus pathway (fine touch, vibration sensation, and proprioception), and the spinothalamic tract (pain, temperature, itch, and crude touch). The brainstem also plays an important role in the regulation of cardiac and respiratory function. It also regulates the central nervous system and is pivotal in maintaining consciousness and regulating the sleep cycle. The brainstem has many basic functions including controlling heart rate, breathing, sleeping, and eating.

The function of the skull is to protect delicate brain tissue from injury. The skull consists of eight fused bones: the frontal, two parietal, two temporal, sphenoid, occipital and ethmoid. The face is formed by 14 paired bones including the maxilla, zygoma, nasal, palatine, lacrimal, inferior nasal conchae, mandible, and vomer. The bony skull is separated from the brain by the dura, a membranous organ, which in turn contains cerebrospinal fluid. The cortical surface of the brain typically is not subject to localized pressure from the skull. The skull, therefore, imposes a barrier to electrical access to the brain functions, and in a healthy human, breaching the dura to access the brain is highly disfavored. The result is that electrical readings of brain activity are filtered by the dura, the cerebrospinal fluid, the skull, the scalp, hair, resulting in a loss of potential spatial resolution and amplitude of signals emanating from the brain. While magnetic fields resulting from brain electrical activity are accessible, the spatial resolution using feasible sensors is also limited.

The cerebrum is the largest part of the brain and is composed of right and left hemispheres. It performs higher functions, such as interpreting inputs from the senses, as well as speech, reasoning, emotions, learning, and fine

control of movement. The surface of the cerebrum has a folded appearance called the cortex. The human cortex contains about 70% of the nerve cells (neurons) and gives an appearance of gray color (grey matter). Beneath the cortex are long connecting fibers between neurons, called axons, which make up the white matter.

The cerebellum is located behind the cerebrum and brainstem. It coordinates muscle movements, helps to maintain balance and posture. The cerebellum may also be involved in some cognitive functions such as attention and language, as well as in regulating fear and pleasure responses. There is considerable evidence that the cerebellum plays an essential role in some types of motor learning. The tasks where the cerebellum most clearly comes into play are those in which it is necessary to make fine adjustments to the way an action is performed. There is a dispute about whether learning takes place within the cerebellum itself, or whether it merely serves to provide signals that promote learning in other brain structures. Cerebellum also plays an important role in sleep and long-term memory formation.

The brain communicates with the body through the spinal cord and twelve pairs of cranial nerves. Ten of the twelve pairs of cranial nerves that control hearing, eye movement, facial sensations, taste, swallowing and movement of the face, neck, shoulder and tongue muscles originate in the brainstem. The cranial nerves for smell and vision originate in the cerebrum.

The right and left hemispheres of the brain are joined by a structure consisting of fibers called the corpus callosum. Each hemisphere controls the opposite side of the body. The right eye sends visual signals to the left hemisphere and vice versa. However, the right ear sends signals to the right hemisphere, and the left ear sends signals to the left hemisphere. Not all functions of the hemispheres are shared. For example, speech is processed exclusively in the left hemisphere.

The cerebral hemispheres have distinct structures, which divide the brain into lobes. Each hemisphere has four lobes: frontal, temporal, parietal, and occipital. There are very complex relationships between the lobes of the brain and between the right and left hemispheres:

Frontal lobes control judgment, planning, problem-solving, behavior, emotions, personality, speech, self-awareness, concentration, intelligence, body movements.

Temporal lobes control understanding of language, memory, organization, and hearing.

Parietal lobes control the interpretation of language; input from vision, hearing, sensory, and motor; temperature, pain, tactile signals, memory, spatial and visual perception.

Occipital lobes interpret visual input (movement, light, color).

A neuron is a fundamental unit of the nervous system, which comprises the autonomic nervous system and the central nervous system.

Brain structures and particular areas within brain structures include but are not limited to hindbrain structures (e.g., myelencephalon structures (e.g., medulla oblongata, medullary pyramids, olivary body, inferior olivary nucleus,

respiratory center, cuneate nucleus, gracile nucleus, intercalated nucleus, medullary cranial nerve nuclei, inferior salivatory nucleus, nucleus ambiguous, dorsal nucleus of the vagus nerve, hypoglossal nucleus, solitary nucleus, etc.), metencephalon structures (e.g., pons, pontine cranial nerve nuclei, chief or pontine nucleus of the trigeminal nerve sensory nucleus (V), motor nucleus for the trigeminal nerve (V), abducens nucleus (VI), facial nerve nucleus (VII), vestibulocochlear nuclei (vestibular nuclei and cochlear nuclei) (VIII), superior salivatory nucleus, pontine tegmentum, respiratory centers, pneumotaxic center, apneustic center, pontine micturition center (Barrington's nucleus), locus coeruleus, pedunculopontine nucleus, laterodorsal tegmental nucleus, tegmental pontine reticular nucleus, superior olivary complex, paramedian pontine reticular formation, cerebellar peduncles, superior cerebellar peduncle, middle cerebellar peduncle, inferior cerebellar peduncle, fourth ventricle, cerebellum, cerebellar vermis, cerebellar hemispheres, anterior lobe, posterior lobe, flocculonodular lobe, cerebellar nuclei, fastigial nucleus, interposed nucleus, globose nucleus, emboliform nucleus, dentate nucleus, etc.)), midbrain structures (e.g., tectum, corpora quadrigemina, inferior colliculi, superior colliculi, pretectum, tegmentum, periaqueductal gray, parabrachial area, medial parabrachial nucleus, lateral parabrachial nucleus, subparabrachial nucleus (Kolliker-Fuse nucleus), rostral interstitial nucleus of medial longitudinal fasciculus, midbrain reticular formation, dorsal raphe nucleus, red nucleus, ventral tegmental area, substantia nigra, pars compacta, pars reticulata, interpeduncular nucleus, cerebral peduncle, cms cerebri, mesencephalic cranial nerve nuclei, oculomotor nucleus (III), trochlear nucleus (IV), mesencephalic duct (cerebral aqueduct, aqueduct of sylvius), etc.), forebrain structures (e.g., diencephalon, epithalamus structures (e.g., pineal body, habenular nuclei, stria medullares, taenia thalami, etc.), third ventricle, thalamus structures (e.g., anterior nuclear group, anteroventral nucleus (a.k.a. ventral anterior nucleus), anterodorsal nucleus, anteromedial nucleus, medial nuclear group, medial dorsal nucleus, midline nuclear group, paratenial nucleus, reuniens nucleus, rhomboidal nucleus, intralaminar nuclear group, centromedial nucleus, parafascicular nucleus, paracentral nucleus, central lateral nucleus, central medial nucleus, lateral nuclear group, lateral dorsal nucleus, lateral posterior nucleus, pulvinar, ventral nuclear group, ventral anterior nucleus, ventral lateral nucleus, ventral posterior nucleus, ventral posterior lateral nucleus, ventral posterior medial nucleus, metathalamus, medial geniculate body, lateral geniculate body, thalamic reticular nucleus, etc.), hypothalamus structures (e.g., anterior, medial area, parts of preoptic area, medial preoptic nucleus, suprachiasmatic nucleus, paraventricular nucleus, supraoptic nucleus (mainly), anterior hypothalamic nucleus, lateral area, parts of preoptic area, lateral preoptic nucleus, anterior part of lateral nucleus, part of supraoptic nucleus, other nuclei of preoptic area, median preoptic nucleus, periventricular preoptic nucleus, tuberal, medial area, dorsomedial hypothalamic nucleus, ventromedial nucleus, arcuate nucleus, lateral area, tuberal part of lateral nucleus, lateral tuberal nuclei, posterior, medial area, mammillary nuclei (part of mammillary bodies), posterior nucleus, lateral area, posterior part of lateral nucleus, optic chiasm, subfornical organ, periventricular nucleus, pituitary stalk, tuber cinereum, tuberal nucleus, tuberomammillary nucleus, tuberal region, mammillary bodies, mammillary nucleus, etc.), subthalamus structures (e.g., thalamic

nucleus, zona incerta, etc.), pituitary gland structures (e.g., neurohypophysis, pars intermedia (intermediate lobe), adenohypophysis, etc.), telencephalon structures, white matter structures (e.g., corona radiata, internal capsule, external capsule, extreme capsule, arcuate fasciculus, uncinate fasciculus, perforant path, etc.), subcortical structures (e.g., hippocampus (medial temporal lobe), dentate gyrus, cornu ammonis (CA fields), cornu ammonis area 1 , cornu ammonis area 2, cornu ammonis area 3, cornu ammonis area 4, amygdala (limbic system) (limbic lobe), central nucleus (autonomic nervous system), medial nucleus (accessory olfactory system), cortical and basomedial nuclei (main olfactory system), lateral) and basolateral nuclei (frontotemporal cortical system), claustrum, basal ganglia, striatum, dorsal striatum (a.k.a. neostriatum), putamen, caudate nucleus, ventral striatum, nucleus accumbens, olfactory tubercle, globus pallidus (forms nucleus lentiformis with putamen), subthalamic nucleus, basal forebrain, anterior perforated substance, substantia innominata, nucleus basalis, diagonal band of Broca, medial septal nuclei, etc.), rhinencephalon structures (e.g., olfactory bulb, piriform cortex, anterior olfactory nucleus, olfactory tract, anterior commissure, uncus, etc.), cerebral cortex structures (e.g., frontal lobe, cortex, primary motor cortex (precentral gyrus, M1), supplementary motor cortex, premotor cortex, prefrontal cortex, gyri, superior frontal gyrus, middle frontal gyrus, inferior frontal gyrus, Brodmann areas: 4, 6, 8, 9, 10, 11, 12, 24, 25, 32, 33, 44, 45, 46, 47, parietal lobe, cortex, primary somatosensory cortex (S1), secondary somatosensory cortex (S2), posterior parietal cortex, gyri, postcentral gyrus (primary somesthetic area), precuneus, Brodmann areas 1, 2, 3 (primary somesthetic area); 5, 7, 23, 26, 29, 31 , 39, 40, occipital lobe, cortex, primary visual cortex (V1), V2, V3, V4, V5/MT, lateral occipital gyrus, cuneus, Brodmann areas 17 (V1 , primary visual cortex); 18, 19, temporal lobe, primary auditory cortex (A1), secondary auditory cortex (A2), inferior temporal cortex, posterior inferior temporal cortex, superior temporal gyrus, middle temporal gyrus, inferior temporal gyrus, entorhinal cortex, perirhinal cortex, parahippocampal gyrus, fusiform gyrus, Brodmann areas: 9, 20, 21 , 22, 27, 34, 35, 36, 37, 38, 41 , 42, medial superior temporal area (MST), insular cortex, cingulate cortex, anterior cingulate, Posterior cingulate, Retrosplenial cortex, Indusium griseum, Subgenual area 25, Brodmann areas 23, 24; 26, 29, 30 (retrosplenial areas); 31 , 32, etc.).

The brain is the largest sex organ controlling the biological urge, mediating all thoughts, experiences and physiological responses to sex. The euphoric and pleasurable experience of sex stems primarily from the limbic system including the amygdala, hippocampus and limbic lobe (dentate and cingulate gyrus).

Neurons Neurons are electrically excitable cells that receive, process, and transmit information, and based on that information sends a signal to other neurons, muscles, or glands through electrical and chemical signals. These signals between neurons occur via specialized connections called synapses. Neurons can connect to each other to form neural networks. The basic purpose of a neuron is to receive incoming information and, based upon that information send a signal to other neurons, muscles, or glands. Neurons are designed to rapidly send signals across physiologically long distances. They do this using electrical signals called nerve impulses or action potentials. When a nerve impulse reaches the end of a neuron, it triggers the release of a chemical, or neurotransmitter. The

neurotransmitter travels rapidly across the short gap between cells (the synapse) and acts to signal the adjacent cell. See www.biologyreference.com/Mo-Nu/Neuron.html#ixzz5AVxCuM5a.

Neurons can receive thousands of inputs from other neurons through synapses. Synaptic integration is a mechanism whereby neurons integrate these inputs before the generation of a nerve impulse, or action potential. The ability of synaptic inputs to effect neuronal output is determined by a number of factors: Size, shape and relative timing of electrical potentials generated by synaptic inputs; the geometric structure of the target neuron; the physical location of synaptic inputs within that structure; and the expression of voltage-gated channels in different regions of the neuronal membrane.

Neurons within a neural network receive information from, and send information to, many other cells, at specialized junctions called synapses. Synaptic integration is the computational process by which an individual neuron processes its synaptic inputs and converts them into an output signal. Synaptic potentials occur when neurotransmitter binds to and opens ligand-operated channels in the dendritic membrane, allowing ions to move into or out of the cell according to their electrochemical gradient. Synaptic potentials can be either excitatory or inhibitory depending on the direction and charge of ion movement. Action potentials occur if the summed synaptic inputs to a neuron reach a threshold level of depolarization and trigger regenerative opening of voltage-gated ion channels. Synaptic potentials are often brief and of small amplitude, therefore summation of inputs in time (temporal summation) or from multiple synaptic inputs (spatial summation) is usually required to reach action potential firing threshold.

There are two types of synapses: electrical synapses and chemical synapses. Electrical synapses are a direct electrical coupling between two cells mediated by gap junctions, which are pores constructed of connexin proteins – essentially result in the passing of a gradient potential (may be depolarizing or hyperpolarizing) between two cells. Electrical synapses are very rapid (no synaptic delay). It is a passive process where signal can degrade with distance and may not produce a large enough depolarization to initiate an action potential in the postsynaptic cell. Electrical synapses are bidirectional, i.e., postsynaptic cell can actually send messages to the “presynaptic cell.

Chemical synapses are a coupling between two cells through neuro-transmitters, ligand or voltage gated channels, receptors. They are influenced by the concentration and types of ions on either side of the membrane. Among the neurotransmitters, Glutamate, sodium, potassium, and calcium are positively charged. GABA and chloride are negatively charged. Neurotransmitter junctions provide an opportunity for pharmacological intervention, and many different drugs, including illicit drugs, act at synapses.

An excitatory postsynaptic potential (EPSP) is a postsynaptic potential that makes the postsynaptic neuron more likely to fire an action potential. An electrical charge (hyperpolarization) in the membrane of a postsynaptic neuron is caused by the binding of an inhibitory neurotransmitter from a presynaptic cell to a postsynaptic receptor. It makes it more difficult for a postsynaptic neuron to generate an action potential. An electrical change (depolarization) in the

membrane of a postsynaptic neuron caused by the binding of an excitatory neurotransmitter from a presynaptic cell to a postsynaptic receptor. It makes it more likely for a postsynaptic neuron to generate an action potential. In a neuronal synapse that uses glutamate as receptor, for example, receptors open ion channels that are non-selectively permeable to cations. When these glutamate receptors are activated, both Na+ and K+ flow across the postsynaptic membrane. The reversal potential (Erev) for the post - synaptic current is approximately 0 mV. The resting potential of neurons is approximately -60 mV. The resulting EPSP will depolarize the post synaptic membrane potential, bringing it toward 0 mV.

An inhibitory postsynaptic potential (IPSP) is a kind of synaptic potential that makes a postsynaptic neuron less likely to generate an action potential. An example of inhibitory post synaptic action is a neuronal synapse that uses γ-Aminobutyric acid (GABA) as its transmitter. At such synapses, the GABA receptors typically open channels that are selectively permeable to Cl-. When these channels open, negatively charged chloride ions can flow across the membrane. The postsynaptic neuron has a resting potential of -60 mV and an action potential threshold of -40 mV. Transmitter release at this synapse will inhibit the postsynaptic cell. Since ECl is more negative than the action potential threshold, e.g., -70 mV, it reduces the probability that the postsynaptic cell will fire an action potential.

Some types of neurotransmitters, such as glutamate, consistently result in EPSPs. Others, such as GABA, consistently result in IPSPs. The action potential lasts about one millisecond (1 msec). In contrast, the EPSPs and IPSPs can last as long as 5 to 10 msec. This allows the effect of one postsynaptic potential to build upon the next and so on.

Membrane leakage, and to a lesser extent, potentials per se, can be influenced by external electrical and magnetic fields. These fields may be generated focally, such as through implanted electrodes, or less specifically, such as through transcranial stimulation. Transcranial stimulation may be subthreshold or superthreshold. In the former case, the external stimulation acts to modulate resting membrane potential, making nerves more or less excitable. Such stimulation may be direct current or alternating current. In the latter case, this will tend to synchronize neuron depolarization with the signals. Superthreshold stimulation can be painful (at least because the stimulus directly excites pain neurons) and must be pulsed. Since this has correspondence to electroconvulsive therapy, superthreshold transcranial stimulation is sparingly used.

A number of neurotransmitters are known, as are pharmaceutical interventions and therapies that influence these compounds. Typically, the major neurotransmitters are small monoamine molecules, such as dopamine, epinephrine, norepinephrine, serotonin, GABA, histamine, etc., as well as acetylcholine. In addition, neurotransmitters also include amino acids, gas molecules such as nitric oxide, carbon monoxide, carbon dioxide, and hydrogen sulfide, as well as peptides. The presence, metabolism, and modulation of these molecules may influence learning and memory. Supply of neurotransmitter precursors, control of oxidative and mental stress conditions, and other

influences on learning and memory-related brain chemistry, may be employed to facilitate memory, learning, and learning adaption transfer.

The neuropeptides, as well as their respective receptors, are widely distributed throughout the mammalian central nervous system. During learning and memory processes, besides structural synaptic remodeling, changes are observed at molecular and metabolic levels with the alterations in neurotransmitter and neuropeptide synthesis and release. While there is a consensus that brain cholinergic neurotransmission plays a critical role in the processes related to learning and memory, it is also well known that these functions are influenced by a tremendous number of neuropeptides and non-peptide molecules. Arginine vasopressin (AVP), oxytocin, angiotensin II, insulin, growth factors, serotonin (5-HT), melanin-concentrating hormone, histamine, bombesin and gastrin-releasing peptide (GRP), glucagon-like peptide-1 (GLP-1), cholecystokinin (CCK), dopamine, corticotropin-releasing factor (CRF) have modulatory effects on learning and memory. Among these peptides, CCK, 5-HT, and CRF play strategic roles in the modulation of memory processes under stressful conditions. CRF is accepted as the main neuropeptide involved in both physical and emotional stress, with a protective role during stress, possibly through the activation of the hypothalamo-pituitary (HPA) axis. The peptide CCK has been proposed to facilitate memory processing, and CCK-like immunoreactivity in the hypothalamus was observed upon stress exposure, suggesting that CCK may participate in the central control of stress response and stress-induced memory dysfunction. On the other hand, 5-HT appears to play a role in behaviors that involve a high cognitive demand and stress exposure activates serotonergic systems in a variety of brain regions.

Brainwaves At the root of all our thoughts, emotions and behaviors is the communication between neurons within our brains, a rhythmic or repetitive neural activity in the central nervous system. The oscillation can be produced by a single neuron or by synchronized electrical pulses from ensembles of neurons communicating with each other. The interaction between neurons can give rise to oscillations at a different frequency than the firing frequency of individual neurons. The synchronized activity of large numbers of neurons produces macroscopic oscillations, which can be observed in an electroencephalogram. They are divided into bandwidths to describe their purported functions or functional relationships. Oscillatory activity in the brain is widely observed at different levels of organization and is thought to play a key role in processing neural information. Numerous experimental studies support a functional role of neural oscillations. A unified interpretation, however, is still not determined. Neural oscillations and synchronization have been linked to many cognitive functions such as information transfer, perception, motor control and memory. Electroencephalographic (EEG) signals are relatively easy and safe to acquire, have a long history of analysis, and can have high dimensionality, e.g., up to 128 or 256 separate recording electrodes. While the information represented in each electrode is not independent of the others, and the noise in the signals high, there is much information available through such signals that has not been fully characterized to date.

Brainwaves have been widely studied in neural activity generated by large groups of neurons, mostly by EEG. In general, EEG signals reveal oscillatory activity (groups of neurons periodically firing in synchrony), in specific frequency bands: alpha (7.5–12.5 Hz) that can be detected from the occipital lobe during relaxed wakefulness and which increases when the eyes are closed; delta (1–4 Hz), theta (4–8 Hz), beta (13–30 Hz), low gamma (30–70 Hz), and high gamma (70–150 Hz) frequency bands, where faster rhythms such as gamma activity have been linked to cognitive processing. Higher frequencies imply multiple groups of neurons firing in coordination, either in parallel or in series, or both, since individual neurons do not fire at rates of 100 Hz. Neural oscillations of specific characteristics have been linked to cognitive states, such as awareness and consciousness and different sleep stages.

Nyquist Theorem states that the highest frequency that can be accurately represented is one-half of the sampling rate. Practically, the sampling rate should be ten times higher than the highest frequency of the signal. (See, www.slideshare.net/ertvk/eeg-examples). While EEG signals are largely band limited, the superimposed noise may not be. Further, the EEG signals themselves represent components from a large number of neurons, which fire independently. Therefore, large bandwidth signal acquisition may have utility.

It is a useful analogy to think of brainwaves as music. In orchestral music, where various instrument groups (string groups, such as violins, violas, cellos and double basses, brass, woodwind, and percussion instruments) produce particular sounds bases on their respective characteristic frequencies of vibrations that all come together in a musical composition. Similarly, in the brain, groups of neurons oscillate in unison producing specific frequencies that combine in brainwaves. Like in a symphony, the higher and lower frequencies link and cohere with each other through harmonics, especially when one considers that neurons may be coordinated not only based on transitions, but also on phase delay. Oscillatory activity is observed throughout the central nervous system at all levels of organization. Each respective mental state is associated with the dominant neuro oscillation frequency. Moreover, the nuances of each mental state may be associated with secondary and tertiary harmonics or, using musical analogy, the “overtones.” Some hypothesize that very slow brainwaves serve to synchronize various lobes and neuronal groups in the brain (similarly to law-frequency instruments, such as drums and double basses, serve to provide overall rhythm to the orchestra).

The functions of brainwaves are wide-ranging and vary for different types of oscillatory activity. Neural oscillations also play an important role in many neurological disorders.

Delta wave is the frequency range from 0.5 Hz to 4 Hz. It tends to be the highest in amplitude and the slowest waves (except for very-slow waves that have frequency less than 0.5 Hz). It is normally seen in adults in NREM (en.wikipedia.org/wiki/NREM). It is also seen normally in babies. It may occur focally with subcortical lesions and in general distribution with diffuse lesions, metabolic encephalopathy hydrocephalus or deep midline lesions. It is usually most prominent frontally in adults (e.g., FIRDA-frontal intermittent rhythmic delta) and posteriorly in children (e.g., OIRDA-occipital intermittent rhythmic delta).

Theta is the frequency range from 4 Hz to 7 Hz. Theta is normally seen in young children. It may be seen in drowsiness or arousal in older children and adults; it can also be seen in meditation. Excess theta for age represents abnormal activity. It can be seen as a focal disturbance in focal subcortical lesions; it can be seen in generalized distribution in diffuse disorder or metabolic encephalopathy or deep midline disorders or some instances of hydrocephalus. On the other hand, this range has been associated with reports of relaxed, meditative, and creative states.

Alpha is the frequency range from 7.5 Hz to 12.5 Hz. This is the "posterior basic rhythm" (also called the "posterior dominant rhythm," the "posterior alpha rhythm" or the Berger's wave), arising from the synchronous and coherent electrical activity in the thalamic pacemaker cells and seen in the posterior regions of the head on both sides, higher in amplitude on the dominant side. They predominantly originate from the occipital lobe during wakeful relaxation with closed eyes. Alpha wave emerges with the closing of the eyes and with relaxation and attenuates with eye opening or mental exertion. The posterior basic rhythm is actually slower than 8 Hz in young children (therefore technically in the theta range). In addition to the posterior basic rhythm, there are other normal alpha rhythms such as the sensorimotor, or mu rhythm (alpha activity in the contralateral sensory and motor cortical areas) that emerges when the hands and arms are idle; and the "third rhythm" (alpha activity in the temporal or frontal lobes). Alpha can be abnormal; for example, an EEG that has diffuse alpha occurring in coma and is not responsive to external stimuli is referred to as "alpha coma."

Beta is the frequency range from 15 Hz to about 30 Hz. It is usually seen on both sides in symmetrical distribution and is most evident frontally. Beta activity is closely linked to motor behavior and is generally attenuated during active movements. Low-amplitude beta with multiple and varying frequencies is often associated with active, busy or anxious thinking and active concentration. Rhythmic beta with a dominant set of frequencies is associated with various pathologies, such as Dup15q syndrome, and drug effects, especially benzodiazepines. It may be absent or reduced in areas of cortical damage. It is the dominant rhythm in patients who are alert or anxious or who have their eyes open.

Gamma is the frequency range approximately 250-100 Hz. Gamma rhythms are thought to represent binding of different populations of neurons together into a network to carry out a certain cognitive or motor function. Low gamma (25–70 Hz), and high gamma (70–150 Hz) frequency bands are also recognized with higher frequencies being associated with cognitive processing.

Mu range is 8-13 Hz and partly overlaps with other frequencies, but is generally considered one of the two types of alpha wave (the second type being the third rhythm). It reflects the synchronous firing of motor neurons in a rest state. Mu suppression is thought to reflect motor mirror neuron systems, because when an action is observed, the pattern extinguishes, possibly because of the normal neuronal system and the mirror neuron system "go out of sync" and interfere with each other.

TABLE 1

Comparison of EEG bands				
Band	Freq. (Hz)	Location	Normally	Pathologically
Delta	< 4	frontally in adults, posteriorly in children; high-amplitude waves	adult slow-wave sleep in babies Has been found during some continuous-attention tasks	subcortical lesions diffuse lesions metabolic encephalopathy hydrocephalus deep midline lesions
Theta	4-7	Found in locations not related to task at hand	higher in young children drowsiness in adults and teens idling Associated with inhibition of elicited responses (has been found to spike in situations where a person is actively trying to repress a response or action).	focal subcortical lesions metabolic encephalopathy deep midline disorders some instances of hydrocephalus
Alpha	7.5-12.5	posterior regions of head, both sides, higher in amplitude on dominant side. Central sites (c3-c4) at rest	relaxed/reflecting closing the eyes Also associated with inhibition control, seemingly with the purpose of timing inhibitory activity in different locations across the brain.	Coma
Beta	12.5-30	both sides, symmetrical distribution, most evident frontally; low-amplitude waves	range span: active calm → intense → stressed → mild obsessive active thinking, focus, high alert, anxious	Benzodiazepines (en.wikipedia.org/wiki/Benzodiazepines) Dup15q syndrome
Gamma	25-100	Somatosensory cortex	Displays during cross-modal sensory processing (perception that combines two different senses, such as sound and sight) Also is shown during short-term memory	A decrease in gamma-band activity may be associated with cognitive decline, especially when related to the theta band; however, this has not been proven for use as a clinical diagnostic measurement

			matching of recognized objects, sounds, or tactile sensations	
Mu	8-12	Sensorimotor cortex	Shows rest-state motor neurons.	Mu suppression could indicate that motor mirror neurons are working. Deficits in Mu suppression, and thus in mirror neurons, might play a role in autism.

EEG AND qEEG An EEG electrode will mainly detect the neuronal activity in the brain region just beneath it. However, the electrodes receive the activity from thousands of neurons. One square millimeter of cortex surface, for example, has more than 100,000 neurons. It is only when the input to a region is synchronized with electrical activity occurring at the same time that simple periodic waveforms in the EEG become distinguishable. The temporal pattern associated with specific brainwaves can be digitized and encoded a non-transient memory, and embodied in or referenced by, computer software.

EEG (electroencephalography) and MEG (magnetoencephalography) are available technologies to monitor brain electrical activity. Each generally has sufficient temporal resolution to follow dynamic changes in brain electrical activity. Electroencephalography (EEG) and quantitative electroencephalography (qEEG) are electrophysiological monitoring methods that analyze the electrical activity of the brain to measure and display patterns that correspond to cognitive states and/or diagnostic information. It is typically noninvasive, with the electrodes placed on the scalp, although invasive electrodes are also used in some cases. EEG signals may be captured and analyzed by a mobile device, often referred as “brain wearables”. There are a variety of “brain wearables” readily available on the market today. EEGs can be obtained with a non-invasive method where the aggregate oscillations of brain electric potentials are recorded with numerous electrodes attached to the scalp of a person. Most EEG signals originate in the brain’s outer layer (the cerebral cortex), believed largely responsible for our thoughts, emotions, and behavior. Cortical synaptic action generates electrical signals that change in the 10 to 100-millisecond range. Transcutaneous EEG signals are limited by the relatively insulating nature of the skull surrounding the brain, the conductivity of the cerebrospinal fluid and brain tissue, relatively low amplitude of individual cellular electrical activity, and distances between the cellular current flows and the electrodes. EEG is characterized by: (1) Voltage; (2) Frequency; (3) Spatial location; (4) Inter-hemispheric symmetries; (5) Reactivity (reaction to state change); (6) Character of waveform occurrence (random, serial, continuous); and (7) Morphology of transient events. EEGs can be separated into two main categories. Spontaneous EEG which occur in the absence of specific sensory stimuli and evoked potentials (EPs) which are associated with sensory stimuli like repeated light flashes, auditory tones, finger pressure or mild electric shocks. The latter is recorded for example by time averaging to remove effects of spontaneous EEG. Non-sensory triggered potentials are also known. EP’s typically are time synchronized with the trigger, and thus have an organization principle. Event-related potentials (ERPs) provide evidence of a direct link between cognitive events and brain electrical activity in a wide range of cognitive paradigms. It has generally been held that an ERP is the result of a

set of discrete stimulus-evoked brain events. Event-related potentials (ERPs) are recorded in the same way as EPs, but occur at longer latencies from the stimuli and are more associated with an endogenous brain state.

In standard EEG recording practice, 19 recording electrodes are placed uniformly on the scalp (the International 10-20 System). In addition, one or two reference electrodes (often placed on earlobes) and a ground electrode (often placed on the nose to provide amplifiers with reference voltages) are required. However, additional electrodes may add minimal useful information unless supplemented by computer algorithms to reduce raw EEG data to a manageable form. When large numbers of electrodes are employed, the potential at each location may be measured with respect to the average of all potentials (the common average reference), which often provides a good estimate of potential at infinity. The common average reference is not appropriate when electrode coverage is sparse (perhaps less than 64 electrodes). (See, Paul L. Nunez and Ramesh Srinivasan (2007) Electroencephalogram. Scholarpedia, 2(2):1348, scholarpedia.org/article/Electroencephalogram.Dipole localization algorithms may be useful to determine spatial emission patterns in EEG.)

Scalp potential may be expressed as a volume integral of dipole moment per unit volume over the entire brain provided P(r,t) defined generally rather than in columnar terms. For the important case of dominant cortical sources, scalp potential may be approximated by the following integral over the cortical volume Θ, $VS(r,t)=\iiint_{\Theta} G(r,r')\cdot P(r',t)d\Theta(r')$. If the volume element $d\Theta(r')$ is defined in terms of cortical columns, the volume integral may be reduced to an integral over the folded cortical surface. The time-dependence of scalp potential is the weighted sum of all dipole time variations in the brain, although deep dipole volumes typically make negligible contributions. The vector Green's function G(r,r') contains all geometric and conductive information about the head volume conductor and weights the integral accordingly. Thus, each scalar component of the Green's function is essentially an inverse electrical distance between each source component and scalp location. For the idealized case of sources in an infinite medium of constant conductivity, the electrical distance equals the geometric distance. The Green's function accounts for the tissue's finite spatial extent and its inhomogeneity and anisotropy. The forward problem in EEG consists of choosing a head model to provide G(r,r') and carrying out the integral for some assumed source distribution. The inverse problem consists of using the recorded scalp potential distribution VS(r,t) plus some constraints (usual assumptions) on P(r,t) to find the best fit source distribution P(r,t). Since the inverse problem has no unique solution, any inverse solution depends critically on the chosen constraints, for example, only one or two isolated sources, distributed sources confined to the cortex, or spatial and temporal smoothness criteria. High-resolution EEG uses the experimental scalp potential VS(r,t) to predict the potential on the dura surface (the unfolded membrane surrounding the cerebral cortex) VD(r,t). This may be accomplished using a head model Green's function G(r,r') or by estimating the surface Laplacian with either spherical or 3D splines. These two approaches typically provide very similar dura potentials VD(r,t); the estimates of dura potential distribution are unique subject to head model, electrode density, and noise issues.

In an EEG recording system, each electrode is connected to one input of a differential amplifier (one amplifier per pair of electrodes); a common system reference electrode (or synthesized reference) is connected to the other input of each differential amplifier. These amplifiers amplify the voltage between the active electrode and the reference (typically 1,000-100,000 times, or 60-100 dB of voltage gain). The amplified signal is digitized via an analog-to-digital converter, after being passed through an anti-aliasing filter. Analog-to-digital sampling typically occurs at 256-512 Hz in clinical scalp EEG; sampling rates of up to 20 kHz are used in some research applications. The EEG signals can be captured with open source hardware such as OpenBCI, and the signal can be processed by freely available EEG software such as EEGLAB or the Neurophysiological Biomarker Toolbox. A typical adult human EEG signal is about 10 µV to 100 µV in amplitude when measured from the scalp and is about 10-20 mV when measured from subdural electrodes.

Typically, a magnetic sensor with sufficient sensitivity to individual cell depolarization or small groups is a superconducting quantum interference device (SQIUD), which requires cryogenic temperature operation, either at liquid nitrogen temperatures (high temperature superconductors, HTS) or at liquid helium temperatures (low temperature superconductors, LTS). However, current research shows possible feasibility of room temperature superconductors (20C). Magnetic sensing has an advantage, due to the dipole nature of sources, of having better potential volumetric localization; however, due to this added information, complexity of signal analysis is increased.

In general, the electromagnetic signals detected represent action potentials, an automatic response of a nerve cell to depolarization beyond a threshold, which briefly opens conduction channels. The cells have ion pumps which seek to maintain a depolarized state. Once triggered, the action potential propagates along the membrane in two-dimensions, causing a brief high level of depolarizing ion flow. There is a quiescent period after depolarization that generally prevents oscillation within a single cell. Since the exon extends from the body of the neuron, the action potential will typically proceed along the length of the axon, which terminates in a synapse with another cell. While direct electrical connections between cells occur, often the axon releases a neurotransmitter compound into the synapse, which causes a depolarization or hyperpolarization of the target cell. Indeed, the result may also be release of a hormone or peptide, which may have a local or more distant effect.

The electrical fields detectable externally tend to not include signals which low frequency signals, such as static levels of polarization, or cumulative depolarizing or hyperpolarizing effects between action potentials. In myelinated tracts, the current flows at the segments tend to be small, and therefore the signals from individual cells are small. Therefore, the largest signal components are from the synapses and cell bodies. In the cerebrum and cerebellum, these structures are mainly in the cortex, which is largely near the skull, making electroencephalography useful, since it provides spatial discrimination based on electrode location. However, deep signals are attenuated, and poorly localized. Magnetoencephalography detects dipoles, which derive from current flow, rather than voltage changes. In the case of a radially or spherically symmetric current flow within a short distance, the dipoles will tend to cancel, while

net current flows long axons will reinforce. Therefore, an electroencephalogram reads a different signal than a magnetoencephalogram.

EEG-based studies of emotional specificity at the single-electrode level demonstrated that asymmetric activity at the frontal site, especially in the alpha (8–12 Hz) band, is associated with emotion. Voluntary facial expressions of smiles of enjoyment produce higher left frontal activation. Decreased left frontal activity is observed during the voluntary facial expressions of fear. In addition to alpha band activity, theta band power at the frontal midline (Fm) has also been found to relate to emotional states. Pleasant (as opposed to unpleasant) emotions are associated with an increase in frontal midline theta power. Many studies have sought to utilize pattern classification, such as neural networks, statistical classifiers, clustering algorithms, etc., to differentiate between various emotional states reflected in EEG.

EEG-based studies of emotional specificity at the single-electrode level demonstrated that asymmetric activity at the frontal site, especially in the alpha (8–12 Hz) band, is associated with emotion. Ekman and Davidson found that voluntary facial expressions of smiles of enjoyment produced higher left frontal activation (Ekman P, Davidson RJ (1993) Voluntary Smiling Changes Regional Brain Activity. Psychol Sci 4: 342–345). Another study by Coan et al. found decreased left frontal activity during the voluntary facial expressions of fear (Coan JA, Allen JJ, Harmon-Jones E (2001) Voluntary facial expression and hemispheric asymmetry over the frontal cortex. Psychophysiology 38: 912–925). In addition to alpha band activity, theta band power at the frontal midline (Fm) has also been found to relate to emotional states. Sammler and colleagues, for example, showed that pleasant (as opposed to unpleasant) emotion is associated with an increase in frontal midline theta power (Sammler D, Grigutsch M, Fritz T, Koelsch S (2007) Music and emotion: Electrophysiological correlates of the processing of pleasant and unpleasant music. Psychophysiology 44: 293–304). To further demonstrate whether these emotion-specific EEG characteristics are strong enough to differentiate between various emotional states, some studies have utilized a pattern classification analysis approach.

Detecting different emotional states by EEG may be more appropriate using EEG-based functional connectivity. There are various ways to estimate EEG-based functional brain connectivity: correlation, coherence and phase synchronization indices between each pair of EEG electrodes had been used. The assumption is that a higher correlation map indicates a stronger relationship between two signals. (Brazier MA, Casby JU (1952) Cross-correlation and autocorrelation studies of electroencephalographic potentials. Electroen clin neuro 4: 201–211). Coherence gives information similar to correlation, but also includes the covariation between two signals as a function of frequency. (Cantero JL, Atienza M, Salas RM, Gomez CM (1999) Alpha EEG coherence in different brain states: an electrophysiological index of the arousal level in human subjects. Neurosci lett 271: 167–70.) The assumption is that higher coherence indicates a stronger relationship between two signals. (Guevara MA, Corsi-Cabrera M (1996) EEG coherence or EEG correlation? Int J Psychophysiology 23: 145–153; Cantero JL, Atienza M, Salas RM, Gomez CM (1999) Alpha EEG coherence in different brain states: an electrophysiological index of the arousal level in human

subjects. Neurosci lett 271: 167–70; Adler G, Brassen S, Jajcevic A (2003) EEG coherence in Alzheimer's dementia. J Neural Transm 110: 1051–1058; Deeny SP, Hillman CH, Janelle CM, Hatfield BD (2003) Cortico-cortical communication and superior performance in skilled marksmen: An EEG coherence analysis. J Sport Exercise Psy 25: 188–204.) Phase synchronization among the neuronal groups estimated based on the phase difference between two signals is another way to estimate the EEG-based functional connectivity among brain areas. It is. (Franaszczuk PJ, Bergey GK (1999) An autoregressive method for the measurement of synchronization of interictal and ictal EEG signals. Biol Cybern 81: 3–9.)

A number of groups have examined emotional specificity using EEG-based functional brain connectivity. For example, Shin and Park showed that, when emotional states become more negative at high room temperatures, correlation coefficients between the channels in temporal and occipital sites increase (Shin J-H, Park D-H. (2011) Analysis for Characteristics of Electroencephalogram (EEG) and Influence of Environmental Factors According to Emotional Changes. In Lee G, Howard D, Ślęzak D, editors. Convergence and Hybrid Information Technology. Springer Berlin Heidelberg, 488–500.) Hinrichs and Machleidt demonstrated that coherence decreases in the alpha band during sadness, compared to happiness (Hinrichs H, Machleidt W (1992) Basic emotions reflected in EEG-coherences. Int J Psychophysiol 13: 225–232). Miskovic and Schmidt found that EEG coherence between the prefrontal cortex and the posterior cortex increased while viewing highly emotionally arousing (i.e., threatening) images, compared to viewing neutral images (Miskovic V, Schmidt LA (2010) Cross-regional cortical synchronization during affective image viewing. Brain Res 1362: 102–111). Costa and colleagues applied the synchronization index to detect interaction in different brain sites under different emotional states (Costa T, Rognoni E, Galati D (2006) EEG phase synchronization during emotional response to positive and negative film stimuli. Neurosci Lett 406: 159–164). Costa's results showed an overall increase in the synchronization index among frontal channels during emotional stimulation, particularly during negative emotion (i.e., sadness). Furthermore, phase synchronization patterns were found to differ between positive and negative emotions. Costa also found that sadness was more synchronized than happiness at each frequency band and was associated with a wider synchronization both between the right and left frontal sites and within the left hemisphere. In contrast, happiness was associated with a wider synchronization between the frontal and occipital sites.

Different connectivity indices are sensitive to different characteristics of EEG signals. Correlation is sensitive to phase and polarity, but is independent of amplitudes. Changes in both amplitude and phase lead to a change in coherence. A number of studies have tried to classify emotional states by means of recording and statistically analyzing EEG signals from the central nervous systems.

EEG-based functional connectivity change was found to be significantly different among emotional states of neutral, positive, or negative. A connectivity pattern may be detected by pattern classification analysis using Quadratic Discriminant Analysis. The results indicated that the classification rate was better than chance. The authors found the

following correlations:

Theta band. Compared to neutral emotions, a significantly lower correlation at the frontal site and higher correlations at the temporal and occipital sites were found when watching negative films. No differences between a negative state and a positive state were found in the theta band. A significantly lower correlation was found in a positive state than in a neutral state at the frontal and parietal sites. A positive state showed higher correlations than a neutral state mainly at the temporal, parietal and occipital sites.

Alpha band. A significantly higher correlation was found in a neutral state only in the case of F7-P7 activity. A negative state showed a significantly higher correlation than a positive state, especially at the parietal and occipital sites. A neutral state showed a lower correlation than a positive state mainly at the right temporal site.

Beta band. No significant difference in correlation was observed among emotional states in the beta band.

Gamma band. No significant difference in correlation was observed among emotional states in the gamma band.

They concluded that estimating EEG-based functional connectivity provides a useful tool for studying the relationship between brain activity and emotional states.

Emotions affect learning. Intelligent Tutoring Systems (ITS) learner model initially composed of a cognitive module was extended to include a psychological module and an emotional module. Alicia Heraz et al. introduced an emomental agent. It interacts with an ITS to communicate the emotional state of the learner based upon his mental state. The mental state was obtained from the learner's brainwaves. The agent learns to predict the learner's emotions by using machine learning techniques.

Using EEG to assess the emotional state has numerous practical applications. One of the first such applications was the development of a travel guide based on emotions by measuring brainwaves by the Singapore tourism group. “By studying the brainwaves of a family on vacation, the researchers drew up the Singapore Emotion Travel Guide, which advises future visitors of the emotions they can expect to experience at different attractions.” (www.lonelyplanet.com/news/2017/04/12/singapore-emotion-travel-guide) Joel Pearson at University of New South Wales and his group developed the protocol of measuring brainwaves of travelers using EEG and decoding specific emotional states.

Another recently released application pertains to virtual reality (VR) technology. On September 18, 2017 Looxid Labs launched a technology that harnesses EEG from a subject waring a VR headset. Looxid Labs intention is to factor in brainwaves into VR applications in order to accurately infer emotions. Other products such as MindMaze and even Samsung have tried creating similar applications through facial muscles recognition. (scottamyx.com/2017/10/13/looxid-labs-vr-brain-waves-human-emotions/). According to its website (looxidlabs.com/device-2/), the Looxid Labs Development Kit provides a VR headset embedded with miniaturized eye and brain sensors. It uses 6 EEG channels: Fp1, Fp2, AF7, AF8, AF3, AF4 in international 10-20 system.

To assess a user’s state of mind, a computer may be used to analyze the EEG signals produced by the brain of

the user. However, the emotional states of a brain are complex, and the brainwaves associated with specific emotions seem to change over time. Wei-Long Zheng at Shanghai Jiao Tong University used machine learning to identify the emotional brain states and to repeat it reliably. The machine learning algorithm found a set of patterns that clearly distinguished positive, negative, and neutral emotions that worked for different subjects and for the same subjects over time with an accuracy of about 80 percent. (See Wei-Long Zheng, Jia-Yi Zhu, Bao-Liang Lu, Identifying Stable Patterns over Time for Emotion Recognition from EEG, arxiv.org/abs/1601.02197; see also How One Intelligent Machine Learned to Recognize Human Emotions, MIT Technology Review, January 23, 2016.)

MEG Magnetoencephalography (MEG) is a functional neuroimaging technique for mapping brain activity by recording magnetic fields produced by electrical currents occurring naturally in the brain, using very sensitive magnetometers. Arrays of SQUIDs (superconducting quantum interference devices) are currently the most common magnetometer, while the SERF (spin exchange relaxation-free) magnetometer is being investigated, It is known that "neuronal activity causes local changes in cerebral blood flow, blood volume, and blood oxygenation"

In some cases, magnetic fields cancel, and thus the detectable electrical activity may fundamentally differ from the detectable electrical activity obtained via EEG. However, the main types of brain rhythms are detectable by both methods.

MEGs seek to detect the magnetic dipole emission from an electrical discharge in cells, e.g., neural action potentials. Typical sensors for MEGs are superconducting quantum interference devices (SQUIDs). These currently require cooling to liquid nitrogen or liquid helium temperatures. However, the development of room temperature, or near room temperature superconductors, and miniature cryocoolers, may permit field deployments and portable or mobile detectors. Because MEGs are less influenced by medium conductivity and dielectric properties, and because they inherently detect the magnetic field vector, MEG technology permits volumetric mapping of brain activity and distinction of complementary activity that might suppress detectable EEG signals. MEG technology also supports vector mapping of fields, since magnetic emitters are inherently dipoles, and therefore a larger amount of information is inherently available.

EEGs and MEGs can monitor the state of consciousness. For example, states of deep sleep are associated with slower EEG oscillations of larger amplitude. Various signal analysis methods allow for robust identifications of distinct sleep stages, depth of anesthesia, epileptic seizures and connections to detailed cognitive events.

Positron Emission Tomography (PET) Scan A PET scan is an imaging test that helps reveal how tissues and organs are functioning (Bailey, D.L; D.W. Townsend; P.E. Valk; M.N. Maisey (2005). Positron Emission Tomography: Basic Sciences. Secaucus, NJ: Springer-Verlag. ISBN 1-85233-798-2.). A PET scan uses a radioactive drug (positron-emitting tracer) to show this activity. It uses this radiation to produce 3-D, images colored for the different activity of the brain.

fMRI Functional magnetic resonance imaging or functional MRI (fMRI) is a functional neuroimaging procedure

using MRI technology that measures brain activity by detecting changes associated with blood flow.

Yukiyasu Kamitani et al., Neuron (DOI: 10.1016/j.neuron.2008.11.004) used an image of brain activity taken in a functional MRI scanner to recreate a black-and-white image from scratch.

Functional Near Infrared Spectroscopy (fNIRS) fNIR is a non-invasive imaging method involving the quantification of chromophore concentration resolved from the measurement of near infrared (NIR) light attenuation or temporal or phasic changes. NIR spectrum light takes advantage of the optical window in which skin, tissue, and bone are mostly transparent to NIR light in the spectrum of 700–900 nm, while hemoglobin (Hb) and deoxygenated-hemoglobin (deoxy-Hb) are stronger absorbers of light. Differences in the absorption spectra of deoxy-Hb and oxy-Hb allow the measurement of relative changes in hemoglobin concentration through the use of light attenuation at multiple wavelengths. Two or more wavelengths are selected, with one wavelength above and one below the isosbestic point of 810 nm at which deoxy-Hb and oxy-Hb have identical absorption coefficients. Using the modified Beer-Lambert law (mBLL), relative concentration can be calculated as a function of total photon path length. Typically, the light emitter and detector are placed ipsilaterally on the subject's skull so recorded measurements are due to back-scattered (reflected) light following elliptical pathways. The use of fNIR as a functional imaging method relies on the principle of neuro-vascular coupling also known as the hemodynamic response or blood-oxygen-level dependent (BOLD) response. This principle also forms the core of fMRI techniques. Through neuro-vascular coupling, neuronal activity is linked to related changes in localized cerebral blood flow. fNIR and fMRI are sensitive to similar physiologic changes and are often comparative methods. Studies relating fMRI and fNIR show highly correlated results in cognitive tasks. fNIR has several advantages in cost and portability over fMRI, but cannot be used to measure cortical activity more than 4 cm deep due to limitations in light emitter power and has more limited spatial resolution. fNIR includes the use of diffuse optical tomography (DOT/NIRDOT) for functional purposes. Multiplexing fNIRS channels can allow 2D topographic functional maps of brain activity (e.g. with Hitachi ETG-4000 or Artinis Oxymon) while using multiple emitter spacings may be used to build 3D tomographic maps.

Beste Yuksel and Robert Jacob, Brain Automated Chorales (BACh), ACM CHI 2016, DOI: 10.1145/2858036.2858388, provides a system that helps beginners learn to play Bach chorales on piano by measuring how hard their brains are working. This is accomplished by estimating the brain's workload using functional Near-Infrared Spectroscopy (fNIRS), a technique that measures oxygen levels in the brain - in this case in the prefrontal cortex. A brain that's working hard pulls in more oxygen. Sensors strapped to the player's forehead talk to a computer, which delivers the new music, one line at a time. See also "Mind-reading tech helps beginners quickly learn to play Bach." By Anna Nowogrodzki, New Scientist, 9 February 2016 available online at www.newscientist.com/article/2076899-mind-reading-tech-helps-beginners-quickly-learn-to-play-bach/.

LORETA Low-resolution brain electromagnetic tomography often referred as LORETA is a functional imaging technology usually using a linearly constrained minimum variance vector beamformer in the time-frequency domain

as described in Gross et al., "Dynamic imaging of coherent sources: Studying neural interactions in the human brain," PNAS 98, 694-699, 2001. It allows to the image (mostly 3D) evoked and induced oscillatory activity in a variable time-frequency range, where time is taken relative to a triggered event. There are three categories of imaging related to the technique used for LORETA. See,

wiki.besa.de/index.php?title=Source_Analysis_3D_Imaging#Multiple_Source_Beamformer_.28MSBF.29. The Multiple Source Beamformer (MSBF) is a tool for imaging brain activity. It is applied in the time-frequency domain and based on single-trial data. Therefore, it can image not only evoked, but also induced activity, which is not visible in time-domain averages of the data. Dynamic Imaging of Coherent Sources (DICS) can find coherence between any two pairs of voxels in the brain or between an external source and brain voxels. DICS requires time-frequency-transformed data and can find coherence for evoked and induced activity. The following imaging methods provides an image of brain activity based on a distributed multiple source model: CLARA is an iterative application of LORETA images, focusing the obtained 3D image in each iteration step. LAURA uses a spatial weighting function that has the form of a local autoregressive function. LORETA has the 3D Laplacian operator implemented as spatial weighting prior. sLORETA is an unweighted minimum norm that is standardized by the resolution matrix. swLORETA is equivalent to sLORETA, except for an additional depth weighting. SSLOFO is an iterative application of standardized minimum norm images with consecutive shrinkage of the source space. A User-defined volume image allows experimenting with the different imaging techniques. It is possible to specify user-defined parameters for the family of distributed source images to create a new imaging technique. If no individual MRI is available, the minimum norm image is displayed on a standard brain surface and computed for standard source locations. If available, an individual brain surface is used to construct the distributed source model and to image the brain activity. Unlike classical LORETA, cortical LORETA is not computed in a 3D volume, but on the cortical surface. Unlike classical CLARA, cortical CLARA is not computed in a 3D volume, but on the cortical surface. The Multiple Source Probe Scan (MSPS) is a tool for the validation of a discrete multiple source model. The Source Sensitivity image displays the sensitivity of a selected source in the current discrete source model and is, therefore, data independent.

Neurofeedback Neurofeedback (NFB), also called neurotherapy or neurobiofeedback, is a type of biofeedback that uses real-time displays of brain activity-most commonly electroencephalography (EEG), to teach self-regulation of brain function. Typically, sensors are placed on the scalp to measure activity, with measurements displayed using video displays or sound. The feedback may be in various other forms as well. Typically, the feedback is sought to be presented through primary sensory inputs, but this is not a limitation on the technique.

The applications of neurofeedback to enhance performance extend to the arts in fields such as music, dance, and acting. A study with conservatoire musicians found that alpha-theta training benefitted the three music domains of musicality, communication, and technique. Historically, alpha-theta training, a form of neurofeedback, was created to assist creativity by inducing hypnagogia, a "borderline waking state associated with creative insights", through

facilitation of neural connectivity. Alpha-theta training has also been shown to improve novice singing in children. Alpha-theta neurofeedback, in conjunction with heart rate variability training, a form of biofeedback, has also produced benefits in dance by enhancing performance in competitive ballroom dancing and increasing cognitive creativity in contemporary dancers. Additionally, neurofeedback has also been shown to instill a superior flow state in actors, possibly due to greater immersion while performing.

Several studies of brain wave activity in experts while performing a task related to their respective area of expertise revealed certain characteristic telltale signs of so-called “flow” associated with top-flight performance. Mihaly Csikszentmihalyi (University of Chicago) found that the most skilled chess players showed less EEG activity in the prefrontal cortex, which is typically associated with higher cognitive processes such as working memory and verbalization, during a game.

Chris Berka et al., Advanced Brain Monitoring, Carlsbad, California, The International J. Sport and Society, vol 1, p 87, looked at the brainwaves of Olympic archers and professional golfers. A few seconds before the archers fired off an arrow or the golfers hit the ball, the team spotted a small increase in alpha band patterns. This may correspond to the contingent negative variation observed in evoked potential studies, and the Bereitschaftspotential or BP (from German, “readiness potential”), also called the pre-motor potential or readiness potential (RP), a measure of activity in the motor cortex and supplementary motor area of the brain leading up to voluntary muscle movement. Berka also trained novice marksmen using neurofeedback. Each person was hooked up to electrodes that tease out and display specific brainwaves, along with a monitor that measured their heartbeat. By controlling their breathing and learning to deliberately manipulate the waveforms on the screen in front of them, the novices managed to produce the alpha waves characteristic of the flow state. This, in turn, helped them improve their accuracy at hitting the targets.

Low Energy Neurofeedback System (LENS) The LENS, or Low Energy Neurofeedback System, uses a very low power electromagnetic field, to carry feedback to the person receiving it. The feedback travels down the same wires carrying the brainwaves to the amplifier and computer. Although the feedback signal is weak, it produces a measurable change in the brainwaves without conscious effort from the individual receiving the feedback. The system is software controlled, to receive input from EEG electrodes, to control the stimulation. Through the scalp. Neurofeedback uses a feedback frequency that is different from, but correlates with, the dominant brainwave frequency. When exposed to this feedback frequency, the EEG amplitude distribution changes in power. Most of the time the brainwaves reduce in power; but at times they also increase in power. In either case the result is a changed brainwave state, and much greater ability for the brain to regulate itself.

Content-Based Brainwave Analysis Memories are not unique. Janice Chen, Nature Neuroscience, DOI: 10.1038/nn.4450, showed that when people describe the episode from Sherlock Holmes drama, their brain activity patterns were almost exactly the same as each other's, for each scene. Moreover, there's also evidence that, when a person tells someone else about it, they implant that same activity into their brain as well. Moreover, research in which

people who have not seen a movie listen to someone else's description of it, Chen et al. have found that the listener's brain activity looks much like that of the person who has seen it. See also “Our brains record and remember things in exactly the same way” by Andy Coghlan, New Scientist, December 5, 2016 (www.newscientist.com/article/2115093-our-brains-record-and-remember-things-in-exactly-the-same-way/)

Brian Pasley, Frontiers in Neuroengineering, doi.org/whb, developed a technique for reading thoughts. The team hypothesized that hearing speech and thinking to oneself might spark some of the same neural signatures in the brain. They supposed that an algorithm trained to identify speech heard out loud might also be able to identify words that are thought. In the experiment, the decoder trained on speech was able to reconstruct which words several of the volunteers were thinking, using neural activity alone. See also “Hearing our inner voice” by Helen Thomson. New Scientist, October 29, 2014 (www.newscientist.com/article/mg22429934-000-brain-decoder-can-eavesdrop-on-your-inner-voice/)

Jack Gallant et al. were able to detect which of a set of images someone was looking at from a brain scan, using software that compared the subject's brain activity while looking at an image with that captured while they were looking at “training” photographs. The program then picked the most likely match from a set of previously unseen pictures.

Ann Graybiel and Mark Howe used electrodes to analyze brainwaves in the ventromedial striatum of rats while they were taught to navigate a maze. As rats were learning the task, their brain activity showed bursts of fast gamma waves. Once the rats mastered the task, their brainwaves slowed to almost a quarter of their initial frequency, becoming beta waves. Graybiel's team posited that this transition reflects when learning becomes a habit.

Bernard Balleine, Proceedings of the National Academy of Sciences, DOI: 10.1073/pnas.1113158108. See also “Habits form when brainwaves slow down” by Wendy Zukerman. New Scientist, September 26, 2011 (www.newscientist.com/article/dn20964-habits-form-when-brainwaves-slow-down/) posits that the slower brainwaves may be the brain weeding out excess activity to refine behavior. He suggests it might be possible to boost the rate at which they learn a skill by enhancing such beta-wave activity.

US 9,763,592 provides a system for instructing a user behavior change comprising: collecting and analyzing bioelectrical signal datasets; and providing a behavior change suggestion based upon the analysis. A stimulus may be provided to prompt an action by the user, which may be visual, auditory, or haptic.

The chess game is a good example of a cognitive task which needs a lot of training and experience. A number of EEG studies have been done on chess players. Pawel Stepien, Wlodzimierz Klonowski and Nikolay Suvorov, Nonlinear analysis of EEG in chess players, EPJ Nonlinear Biomedical Physics 20153:1, showed better applicability of Higuchi Fractal Dimension method for analysis of EEG signals related to chess tasks than that of Sliding Window Empirical Mode Decomposition. The paper shows that the EEG signal during the game is more complex, non-linear, and non-stationary even when there are no significant differences between the game and relaxed state in the

contribution of different EEG bands to total power of the signal. There is the need of gathering more data from more chess experts and of comparing them with data from novice chess players. See also Junior, L.R.S., Cesar, F.H.G., Rocha, F.T., and Thomaz, C.E. EEG and Eye Movement Maps of Chess Players. Proceedings of the Sixth International Conference on Pattern Recognition Applications and Methods. (ICPRAM 2017) pp. 343-441. (fei.edu.br/~cet/icpram17_LaercioJunior.pdf).

Estimating EEG-based functional connectivity provides a useful tool for studying the relationship between brain activity and emotional states. See You-Yun Lee, Shulan Hsieh. Classifying Different Emotional States by Means of EEG-Based Functional Connectivity Patterns. 4/17/2014, (doi.org/10.1371/journal.pone.0095415), which aimed to classify different emotional states by means of EEG-based functional connectivity patterns, and showed that the EEG-based functional connectivity change was significantly different among emotional states. Furthermore, the connectivity pattern was detected by pattern classification analysis using Quadratic Discriminant Analysis. The results indicated that the classification rate was better than chance. Estimating EEG-based functional connectivity provides a useful tool for studying the relationship between brain activity and emotional states.

Neuromodulation/Neuroenhancement Neuromodulation is the alteration of nerve activity through targeted delivery of a stimulus, such as electrical stimulation or chemical agents, to specific neurological sites in the body. It is carried out to normalize—or modulate—nervous tissue function. Neuromodulation is an evolving therapy that can involve a range of electromagnetic stimuli such as a magnetic field (TMS, rTMS), an electric current (TES, e.g., tDCS, HD-tDCS, tACS, osc-tDCS, electrosleep), or a drug instilled directly in the subdural space (intrathecal drug delivery). Emerging applications involve targeted introduction of genes or gene regulators and light (optogenetics). The most clinical experience has been with electrical stimulation. Neuromodulation, whether electrical or magnetic, employs the body's natural biological response by stimulating nerve cell activity that can influence populations of nerves by releasing transmitters, such as dopamine, or other chemical messengers such as the peptide Substance P, that can modulate the excitability and firing patterns of neural circuits. There may also be more direct electrophysiological effects on neural membranes. According to some applications, the end effect is a “normalization” of a neural network function from its perturbed state. Presumed mechanisms of action for neurostimulation include depolarizing blockade, stochastic normalization of neural firing, axonal blockade, reduction of neural firing keratosis, and suppression of neural network oscillations. Although the exact mechanisms of neurostimulation are not entirely clear, the empirical effectiveness has led to considerable application clinically.

Neuroenhancement refers to the targeted enhancement and extension of cognitive, affective, and motor abilities based on an understanding of their underlying neurobiology in healthy persons who do not have any mental illness. As such, it can be thought of as an umbrella term that encompasses pharmacological and non-pharmacological methods of improving cognitive, affective, and motor functionality. Critically, for any agent to qualify as a neuroenhancer, it must reliably engender substantial cognitive, affective, or motor benefits beyond normal functioning

in healthy individuals (or in select groups of individuals having pathology), while causing few side effects: at most at the level of commonly used comparable legal substances or activities, such as caffeine, alcohol, and sleep-deprivation. Pharmacological neuroenhancement agents include the well-validated nootropics, such as racetam, vinpocetine, and phosphatidylserine, as well as other drugs used for treating patients suffering from neurological disorders. Non-pharmacological measures include non-invasive brain stimulation, which has been employed to improve various cognitive and affective functions, and brain-machine interfaces, which hold much potential to extend the repertoire of motor and cognitive actions available to humans.

Brain Stimulation The entrainment hypothesis, suggests the possibility of inducing a particular oscillation frequency in the brain using an external oscillatory force (e.g., rTMS, tDCS, tACS, binaural beats, isochronic tones, light stimulation). The physiological basis of oscillatory cortical activity lies in the timing of the interacting neurons; when groups of neurons synchronize their firing activities, brain rhythms emerge, network oscillations are generated, and the basis for interactions between brain areas may develop. Synchronization of spatially separated lobes of the brain may also play a role. Because of the variety of experimental protocols for brain stimulation, limits on descriptions of the actual protocols employed, and limited controls, consistency of reported studies is lacking, and extrapolability is limited. Thus, while there is some consensus in various aspects of the effects of extra cranial brain stimulation, the results achieved have a degree of uncertainty dependent on details of implementation. On the other hand, within a specific experimental protocol, it is possible to obtain statistically significant and repeatable results. This implies that feedback control might be effective to control implementation of the stimulation for a given purpose; however, prior studies that employ feedback control are lacking.

Changes in the neuronal threshold result from changes in membrane permeability (Liebetanz et al., 2002), which influence the response of the task-related network. The same mechanism of action may be responsible for both TES methods and TMS, i.e., the induction of noise in the system. However, the neural activity induced by TES will be highly influenced by the state of the system because it is a neuromodulatory method (Paulus, 2011), and its effect will depend on the activity of the stimulated area. Therefore, the final result will depend strongly on the task characteristics, the system state and the way in which TES will interact with such a state.

In TMS, the magnetic pulse causes a rapid increase in current flow, which can in some cases cause and above-threshold depolarization of cell membranes affected by the current, triggering an action potential, and leading to the trans-synaptic depolarization or hyperpolarization of connected cortical neurons, depending on their natural response to the firing of the stimulated neuron(s). Therefore, TMS activates a neural population that, depending on several factors, can be congruent (facilitate) or incongruent (inhibit) with task execution. TES induces a polarization of cortical neurons at a subthreshold level that is too weak to evoke an action potential. However, by inducing a polarity shift in the intrinsic neuronal excitability, TES can alter the spontaneous firing rate of neurons and modulate the response to afferent signals. In this sense, TES-induced effects are even more bound to the state of the stimulated area that is

determined by the conditions. In short, NIBS leads to a stimulation-induced modulation of the state that can be substantially defined as noise induction. Induced noise will not be just random activity, but will depend on the interaction of many parameters, from the characteristics of the stimulation to the state.

The noise induced by NIBS will be influenced by the state of the neural population of the stimulated area. Although the types and number of neurons "triggered" by NIBS are theoretically random, the induced change in neuronal activity is likely to be correlated with ongoing activity, yet even if we are referring to a non-deterministic process, the noise introduced will not be a totally random element. Because it will be partially determined by the experimental variables, the level of noise that will be introduced by the stimulation and by the context can be estimated, as well as the interaction between the two levels of noise (stimulation and context). Although, HD-tDCS made a significantly more focused spatial application of TES possible, generally, known transcranial stimulation does not permit stimulation with a focused and highly targeted signal to a clearly defined area of the brain to establish a unique brain-behavior relationship; therefore, the known introduced stimulus activity in the brain stimulation is 'noise.'

Cosmetic neuroscience has emerged as a new field of research. Roy Hamilton, Samuel Messing, and Anjan Chatterjee, "Rethinking the thinking cap - Ethics of neural enhancement using noninvasive brain stimulation." Neurology, January 11, 2011, vol. 76 no. 2 187-193. (www.neurology.org/content/76/2/187.) discuss the use noninvasive brain stimulation techniques such as transcranial magnetic stimulation and transcranial direct current stimulation to enhance neurologic function: cognitive skills, mood, and social cognition.

Electrical brain stimulation (EBS), also known as, focal brain stimulation (FBS), is a form of clinical neurobiology electrotherapy used to stimulate a neuron or neural network in the brain through the direct or indirect excitation of cell membranes using an electric current. Motor skills can be affected by CNS stimulation.

Michael A. Nitsche, and Armin Kibele. "Noninvasive brain stimulation and neural entrainment enhance athletic performance-a review." J. Cognitive Enhancement 1.1 (2017): 73-79, discusses that non-invasive brain stimulation (NIBS) bypasses the correlative approaches of other imaging techniques, making it possible to establish a causal relationship between cognitive processes and the functioning of specific brain areas. NIBS can provide information about where a particular process occurs. NIBS offers the opportunity to study brain mechanisms beyond process localization, providing information about when activity in a given brain region is involved in a cognitive process, and even how it is involved. When using NIBS to explore cognitive processes, it is important to understand not only how NIBS functions but also the functioning of the neural structures themselves. Non-invasive brain stimulation (NIBS) methods, which include transcranial magnetic stimulation (TMS) and transcranial electric stimulation (tES), are used in cognitive neuroscience to induce transient changes in brain activity and thereby alter the behavior of the subject. The application of NIBS aims at establishing the role of a given cortical area in an ongoing specific motor, perceptual or cognitive process (Hallett, 2000; Walsh and Cowey, 2000). Physically, NIBS techniques affect neuronal states through different mechanisms. In TMS, a solenoid (coil) is used to deliver a strong and transient magnetic field, or

"pulse," to induce a transitory electric current at the cortical surface beneath the coil. (US 2004078056) The pulse causes the rapid and above-threshold depolarization of cell membranes affected by the current (Barker et al., 1985, 1987), followed by the transsynaptic depolarization or hyperpolarization of interconnected neurons. Therefore, TMS induces a current that elicits action potentials in neurons. A complex set of coils can deliver a complex 3D excitation field. By contrast, in tES techniques, the stimulation involves the application of weak electrical currents directly to the scalp through a pair of electrodes (Nitsche and Paulus, 2000; Priori et al., 1998). As a result, tES induces a subthreshold polarization of cortical neurons that is too weak to generate an action potential. However, by changing the intrinsic neuronal excitability, tES can induce changes in the resting membrane potential and the postsynaptic activity of cortical neurons. This, in turn, can alter the spontaneous firing rate of neurons and modulate their response to afferent signals (Bindman et al., 1962, 1964, 1979; Creutzfeldt et al., 1962), leading to changes in synaptic efficacy. The typical application of NIBS involves different types of protocols: TMS can be delivered as a single pulse (spTMS) at a precise time, as pairs of pulses separated by a variable interval, or as a series of stimuli in conventional or patterned protocols of repetitive TMS (rTMS) (for a complete classification see Rossi et al., 2009). In tES, different protocols are established by the electrical current used and by its polarity, which can be direct (anodal or cathodal transcranial direct current stimulation: tDCS), high-definition transcranial direct current stimulation (HD-tDCS), oscillating transcranial direct current stimulation (osc-tDCS), alternating at a fix frequency (transcranial alternating current stimulation: tACS) transcranial pulsed current stimulation (tPCS) (electrosleep), or at random frequencies (transcranial random noise stimulation: tRNS) (Nitsche et al., 2008; Paulus, 2011).

NIBS also includes brain entrainment using light stimulation and sound stimulation. The latter can be binaural beats (BB) or isochronic tones.

In general, the final effects of NIBS on the central nervous system depend on a lengthy list of parameters (e.g., frequency, temporal characteristics, intensity, geometric configuration of the coil/electrode, i.e., "montage," current direction), when it is delivered before (off-line) or during (on-line) the task as part of the experimental procedure (e.g., Jacobson et al., 2011; Nitsche and Paulus, 2011; Sandrini et al., 2011). In addition, these factors interact with several variables related to the brain anatomy and morphology (e.g., brain size, properties of the brain tissue and its location, Radman et al., 2007), as well as physiological (e.g., gender and age, Landi and Rossini, 2010; Lang et al., 2011; Ridding and Ziemann, 2010) and cognitive (e.g., Miniussi et al., 2010; Silvanto et al., 2008; Walsh et al., 1998) states of the stimulated area/subject.

Transcranial Direct Current Stimulation (tDCS) Cranial electrotherapy stimulation (CES) is a form of non-invasive brain stimulation that applies a small, pulsed electric current across a person's head to treat a variety of conditions such as anxiety, depression and insomnia. See, en.wikipedia.org/wiki/Cranial_electrotherapy_stimulation. Transcranial direct current stimulation (tDCS, HD-tDCS, osc-tDCS, tPCS) is a form of neurostimulation that uses constant, low current delivered to the brain area of interest via electrodes on the scalp. It was originally developed to

help patients with brain injuries or psychiatric conditions like major depressive disorder. tDCS appears to have some potential for treating depression. See, en.wikipedia.org/wiki/Transcranial_direct-current_stimulation.

The hypotheses concerning the application of tDCS in cognition are very similar to those of TMS, with the exception that tDCS was never considered a virtual lesion method. tDCS can increase or decrease cortical excitability in the stimulated brain regions and facilitate or inhibit behavior accordingly. TES does not induce action potentials but instead modulates the neuronal response threshold so that it can be defined as subthreshold stimulation.

tDCS is being studied for acceleration of learning. The mild electrical shock (usually, a 2-milliamp current) is used to depolarize the neuronal membranes, making the cells more excitable and responsive to inputs. Weisend, Experimental Brain Research, vol 213, p 9 (DARPA) showed that tDCS accelerates the formation of new neural pathways during the time that someone practices a skill. tDCS appears to bring about the flow state. The movements of the subjects become more automatic; they report calm, focused concentration, and their performance improves immediately. (See Adee, Sally, "Zap your brain into the zone: Fast track to pure focus", New Scientist, No. 2850, Feb. 1, 2012, www.newscientist.com/article/mg21328501-600-zap-your-brain-into-the-zone-fast-track-to-pure-focus/).

Reinhart, Robert MG. "Disruption and rescue of interareal theta phase coupling and adaptive behavior." Proceedings of the National Academy of Sciences (2017): provide evidence for a causal relation between interareal theta phase synchronization in frontal cortex and multiple components of adaptive human behavior. Reinhart's results support the idea that the precise timing of rhythmic population activity spatially distributed in frontal cortex conveys information to direct behavior. Given prior work showing that phase synchronization can change spike time-dependent plasticity, together with Reihart's findings showing stimulation effects on neural activity and behavior can outlast a 20-min period of electrical stimulation, it is reasonable to suppose that the externally modulated interareal coupling changed behavior by causing neuroplastic modifications in functional connectivity. Reinhart suggests that we may be able to noninvasively intervene in the temporal coupling of distant rhythmic activity in the human brain to optimize (or impede) the postsynaptic effect of spikes from one area on the other, improving (or impairing) the cross-area communication necessary for cognitive action control and learning. Moreover, these neuroplastic alterations in functional connectivity were induced with a 0° phase, suggesting that inducing synchronization does not require a meticulous accounting of the communication delay between regions such as medial frontal cortex (MFC) and lateral prefrontal cortex (lPFC) to effectively modify behavior and learning. This conforms to work showing that despite long axonal conduction delays between distant brain areas, theta phase synchronizations at 0° phase lag can occur between these regions and underlie meaningful functions of cognition and action. It is also possible that a third subcortical or posterior region with a nonzero time lag interacted with these two frontal areas to drive changes in goal-directed behavior.

High-Definition-tDCS High-Definition transcranial Direct Current Stimulation (HD-tDCS) was invented by Dr. Marom Bikson's group at The City College of New York with the introduction of the 4x1 HD-tDCS montage. The 4x1

HD-tDCS montage allows precise targeting of cortical structures. The region of current flow is circumscribed by the area of the 4x ring, such that decreasing ring radius increases focality. 4x1 HD-tDCS allows for unifocal stimulation, meaning the polarity of the center 1x electrode will determine the direction of neuromodulation under the ring. This is in contrast to conventional tDCS where the need for one anode and one cathode always produces bidirectional modulation (even when an extra-cephalic electrode is used). 4x1 HD-tDCS thus provides the ability not only to select a cortical brain region to target, but to modulate the excitability of that brain region with a designed polarity without having to consider return counter-electrode flow.

Osc-tDCS Oscillating transcranial direct current stimulation (osc-tDCS) is a tDCS wherein the amplitude of the current is modulated with a sinusoid waveform of a certain frequency. Osc-tDCS modulates the spontaneous brain activity in a frequency-specific manner. Osc-tDCS mainly affects brain oscillatory activity. Anodal oscillatory stimulation at 0.75 Hz (slow osc-tDCS) in frontal areas during sleep stage 2 of a diurnal nap or during nocturnal sleep can induce a frequency-specific enhancement of Slow-Wave Activity (SWA, 0.5–4 Hz) during sleep. The enhancement in normal subjects of SWA induced by osc-tDCS at 0.75 Hz during sleep significantly improves performance in a memory task after sleep.

Transcranial Alternative Current Stimulation (tACS) Transcranial alternating current stimulation (tACS) is a noninvasive means by which alternating electrical current applied through the skin and skull entrains in a frequency-specific fashion the neural oscillations of the underlying brain. See, en.wikipedia.org/wiki/Transcranial_alternating_current_stimulation

Transcranial Random Noise Stimulation (tRNS) Transcranial random noise stimulation (tRNS) is a non-invasive brain stimulation technique and a form of transcranial electrical stimulation (tES). See, en.wikipedia.org/wiki/Transcranial_random_noise_stimulation,

Transcranial pulsed current stimulation (tPCS) The stimulus may comprise transcranial pulsed current stimulation (tPCS).

Transcranial Magnetic Stimulation Transcranial magnetic stimulation (TMS) is a method in which a changing magnetic field is used to cause electric current to flow in a small region of the brain via electromagnetic induction. During a TMS procedure, a magnetic field generator, or “coil”, is placed near the head of the person receiving the treatment. The coil is connected to a pulse generator, or stimulator, that delivers a changing electric current to the coil. TMS is used diagnostically to measure the connection between the central nervous system and skeletal muscle to evaluate damage in a wide variety of disease states, including stroke, multiple sclerosis, amyotrophic lateral sclerosis, movement disorders, and motor neuron diseases. Evidence is available suggesting that TMS is useful in treating neuropathic pain, major depressive disorder, and other conditions. See, en.wikipedia.org/wiki/Transcranial_magnetic_stimulation.

Pulsed electromagnetic field (PEMF) Pulsed electromagnetic field (PEMF) when applied to the brain is

referred to as Transcranial magnetic stimulation, and has been FDA approved since 2008 for use in people who failed to respond to antidepressants. Weak magnetic stimulation of the brain is often called transcranial pulsed electromagnetic field (tPEMF) therapy. See, en.wikipedia.org/wiki/Pulsed_electromagnetic_field_therapy.

Deep Brain Stimulation (DBS) Deep brain stimulation (DBS) is a neurosurgical procedure involving the implantation of a medical device called a neurostimulator (sometimes referred to as a 'brain pacemaker'), which sends electrical impulses, through implanted electrodes, to specific targets in the brain (brain nuclei) for the treatment of movement and neuropsychiatric disorders. See, en.wikipedia.org/wiki/Deep_brain_stimulation.

Transcranial Pulse Ultrasound (TPU) Transcranial pulsed ultrasound (TPU) uses low intensity, low frequency ultrasound (LILFU) as a method to stimulate the brain. See, en.wikipedia.org/wiki/Transcranial_pulsed_ultrasound.

Sensory Stimulation Light, sound or electromagnetic fields may be used to remotely convey a temporal pattern of brainwaves.

Light Stimulation The functional relevance of brain oscillations in the alpha frequency range (7.5–12 Hz) has been repeatedly investigated through the use of rhythmic visual stimulation. There are two hypotheses on the origin of steady-state visual evoked potential (SSVEP) measured in EEG during rhythmic stimulation: entrainment of brain oscillations and superposition of event-related responses (ERPs). The entrainment but not the superposition hypothesis justifies rhythmic visual stimulation as a means to manipulate brain oscillations, because superposition assumes a linear summation of single responses, independent from ongoing brain oscillations. Participants stimulated with rhythmic flickering light of different frequencies and intensities, and entrainment was measured by comparing the phase coupling of brain oscillations stimulated by rhythmic visual flicker with the oscillations induced by arrhythmic jittered stimulation, varying the time, stimulation frequency, and intensity conditions. Phase coupling was found to be more pronounced with increasing stimulation intensity as well as at stimulation frequencies closer to each participant's intrinsic frequency. Even in a single sequence of an SSVEP, non-linear features (intermittency of phase locking) was found that contradict the linear summation of single responses, as assumed by the superposition hypothesis. Thus, evidence suggests that visual rhythmic stimulation entrains brain oscillations, validating the approach of rhythmic stimulation as a manipulation of brain oscillations. See, Notbohm A, Kurths J, Herrmann CS, Modification of Brain Oscillations via Rhythmic Light Stimulation Provides Evidence for Entrainment but Not for Superposition of Event-Related Responses, Front Hum Neurosci. 2016 Feb 3;10:10. doi: 10.3389/fnhum.2016.00010. eCollection 2016.

It is also known that periodic visual stimulation can trigger epileptic seizures.

Cochlear Implant A cochlear implant is a surgically implanted electronic device that provides a sense of sound to a person who is profoundly deaf or severely hard of hearing in both ears. See, en.wikipedia.org/wiki/Cochlear_implant.

Vagus Nerve Stimulation Vagus nerve stimulation (VNS) is a medical treatment that involves delivering

electrical impulses to the vagus nerve. It is used as an adjunctive treatment for certain types of intractable epilepsy and treatment-resistant depression. See, en.wikipedia.org/wiki/Vagus_nerve_stimulation.

Brain-To-Brain Interface A brain–brain interface is a direct communication pathway between the brain of one animal and the brain of another animal. Brain to brain interfaces have been used to help rats collaborate with each other. When a second rat was unable to choose the correct lever, the first rat noticed (not getting a second reward), and produced a round of task-related neuron firing that made the second rat more likely to choose the correct lever. Human studies have also been conducted.

In 2013, researcher from the University of Washington were able to use electrical brain recordings and a form of magnetic stimulation to send a brain signal to a recipient, which caused the recipient to hit the fire button on a computer game. In 2015, researchers linked up multiple brains, of both monkeys and rats, to form an “organic computer.” It is hypothesized that by using brain-to-brain interfaces (BTBIs) a biological computer, or brain-net, could be constructed using animal brains as its computational units. Initial exploratory work demonstrated collaboration between rats in distant cages linked by signals from cortical microelectrode arrays implanted in their brains. The rats were rewarded when actions were performed by the “decoding rat” which conformed to incoming signals and when signals were transmitted by the “encoding rat” which resulted in the desired action. In the initial experiment the rewarded action was pushing a lever in the remote location corresponding to the position of a lever near a lighted LED at the home location. About a month was required for the rats to acclimate themselves to incoming "brainwaves." When a decoding rat was unable to choose the correct lever, the encoding rat noticed (not getting an expected reward), and produced a round of task-related neuron firing that made the second rat more likely to choose the correct lever.

In another study, electrical brain readings were used to trigger a form of magnetic stimulation, to send a brain signal based on brain activity on a subject to a recipient, which caused the recipient to hit the fire button on a computer game.

Brain-To-Computer Interface A brain–computer interface (BCI), sometimes called a neural-control interface (NCI), mind-machine interface (MMI), direct neural interface (DNI), or brain–machine interface (BMI), is a direct communication pathway between an enhanced or wired brain and an external device. BCI differs from neuromodulation in that it allows for bidirectional information flow. BCIs are often directed at researching, mapping, assisting, augmenting, or repairing human cognitive or sensory-motor functions.

Synthetic telepathy, also known as techlepathy or psychotronics (geeldon.wordpress.com/2010/ 09/06/synthetic-telepathy-also-known-as-techlepathy-or-psychotronics/), describes the process of use of brain-computer interfaces by which human thought (as electromagnetic radiation) is intercepted, processed by computer and a return signal generated that is perceptible by the human brain. Dewan, E.M., “Occipital Alpha Rhythm Eye Position and Lens Accommodation.” Nature 214, 975 - 977 (03 June 1967), demonstrates the mental control of Alpha waves, turning

them on and off, to produce Morse code representations of words and phrases by thought alone. U.S. 3,951,134 proposes remotely monitoring and altering brainwaves using radio, and references demodulating the waveform, displaying it to an operator for viewing and passing this to a computer for further analysis. In 1988, Farwell, L. A., & Donchin, E. (1988). Talking off the top of your head: toward a mental prosthesis utilizing event-related brain potentials. Electroencephalography and Clinical Neurophysiology, 70(6), 510-523 describes a method of transmitting linguistic information using the P300 response system, which combines matching observed information to what the subject was thinking of. In this case, being able to select a letter of the alphabet that the subject was thinking of. In theory, any input could be used and a lexicon constructed. U.S. Patent No. 6,011,991 describes a method of monitoring an individual's brainwaves remotely, for the purposes of communication, and outlines a system that monitors an individual's brainwaves via a sensor, then transmits this information, specifically by satellite, to a computer for analysis. This analysis would determine if the individual was attempting to communicate a "word, phrase, or thought corresponding to the matched stored normalized signal."

Approaches to synthetic telepathy can be categorized into two major groups, passive and active. Like sonar, the receiver can take part or passively listen. Passive reception is the ability to "read" a signal without first broadcasting a signal. This can be roughly equated to tuning into a radio station—the brain generates electromagnetic radiation which can be received at a distance. That distance is determined by the sensitivity of the receiver, the filters used and the bandwidth required. Most universities would have limited budgets, and receivers, such as EEG (and similar devices), would be used. A related military technology is the surveillance system TEMPEST. Robert G. Malech's approach requires a modulated signal to be broadcast at the target. The method uses an active signal, which is interfered with by the brain's modulation. Thus, the return signal can be used to infer the original brainwave.

Computer mediation falls into two basic categories, interpretative and interactive. Interpretative mediation is the passive analysis of signals coming from the human brain. A computer "reads" the signal then compares that signal against a database of signals and their meanings. Using statistical analysis and repetition, false-positives are reduced over time. Interactive mediation can be in a passive-active mode or active-active mode. In this case, passive and active denote the method of reading and writing to the brain and whether or not they make use of a broadcast signal. Interactive mediation can also be performed manually or via artificial intelligence. Manual interactive mediation involves a human operator producing return signals such as speech or images. A.I. mediation leverages the cognitive system of the subject to identify images, pre-speech, objects, sounds and other artifacts, rather than developing A.I. routines to perform such activities. A.I. based systems may incorporate natural language processing interfaces that produce sensations, mental impressions, humor and conversation to provide a mental picture of a computerized personality. Statistical analysis and machine learning techniques, such as neural networks can be used.

ITV News Service, in March 1991, produced a report of ultrasound piggybacked on a commercial radio broadcast (100 MHz) aimed at entraining the brains of Iraqi troops and creating feelings of despair. U.S. 5,159,703

that refers to a “silent communications system in which nonaural carriers, in the very low or very high audio frequency range or in the adjacent ultrasonic frequency spectrum, are amplitude or frequency modulated with the desired intelligence and propagated acoustically or vibrationally, for inducement into the brain, typically through the use of loudspeakers, earphones or piezoelectric transducers.”

It is known to analyze EEG patterns to extract an indication of certain volitional activity (U.S. Patent No. 6,011,991). This technique describes that an EEG recording can be matched against a stored normalized signal using a computer. This matched signal is then translated into the corresponding reference. The patent application describes a method “a system capable of identifying particular nodes in an individual’s brain, the firings of which affect characteristics such as appetite, hunger, thirst, communication skills” and “devices mounted to the person (e.g. underneath the scalp) may be energized in a predetermined manner or sequence to remotely cause particular identified brain node(s) to be fired in order to cause a predetermined feeling or reaction in the individual” without technical description of implementation. This patent also describes, that “brain activity (is monitored) by way of electroencephalograph (EEG) methods, magnetoencephalograph (MEG) methods, and the like.

Brain entrainment Brain entrainment, also referred to as brainwave synchronization and neural entrainment, refers to the capacity of the brain to naturally synchronize its brainwave frequencies with the rhythm of periodic external stimuli, most commonly auditory, visual, or tactile. Brainwave entrainment technologies are used to induce various brain states, such as relaxation or sleep, by creating stimuli that occur at regular, periodic intervals to mimic electrical cycles of the brain during the desired states, thereby "training" the brain to consciously alter states. Recurrent acoustic frequencies, flickering lights, or tactile vibrations are the most common examples of stimuli applied to generate different sensory responses. It is hypothesized that listening to these beats of certain frequencies one can induce a desired state of consciousness that corresponds with specific neural activity. Patterns of neural firing, measured in Hz, correspond with alertness states such as focused attention, deep sleep, etc.

The term “entrainment” has been used to describe a shared tendency of many physical and biological systems to synchronize their periodicity and rhythm through interaction. This tendency has been identified as specifically pertinent to the study of sound and music generally, and acoustic rhythms specifically. The most ubiquitous and familiar examples of neuromotor entrainment to acoustic stimuli is observable in spontaneous foot or finger tapping to the rhythmic beat of a song. Exogenous rhythmic entrainment, which occurs outside the body, has been identified and documented for a variety of human activities, which include the way people adjust the rhythm of their speech patterns to those of the subject with whom they communicate, and the rhythmic unison of an audience clapping. Even among groups of strangers, the rate of breathing, locomotive and subtle expressive motor movements, and rhythmic speech patterns have been observed to synchronize and entrain, in response to an auditory stimulus, such as a piece of music with a consistent rhythm. Furthermore, motor synchronization to repetitive tactile stimuli occurs in animals, including cats and monkeys as well as humans, with accompanying shifts in electroencephalogram (EEG) readings.

Examples of endogenous entrainment, which occurs within the body, include the synchronizing of human circadian sleep-wake cycles to the 24-hour cycle of light and dark, and the frequency following response of humans to sounds and music.

Neural oscillations Neural oscillations are rhythmic or repetitive electrochemical activity in the brain and central nervous system. Such oscillations can be characterized by their frequency, amplitude and phase. Neural tissue can generate oscillatory activity driven by mechanisms within individual neurons, as well as by interactions between them. They may also adjust frequency to synchronize with the periodic vibration of external acoustic or visual stimuli. The functional role of neural oscillations is still not fully understood; however, they have been shown to correlate with emotional responses, motor control, and a number of cognitive functions including information transfer, perception, and memory. Specifically, neural oscillations, in particular theta activity, are extensively linked to memory function, and coupling between theta and gamma activity is considered to be vital for memory functions, including episodic memory. Electroencephalography (EEG) has been most widely used in the study of neural activity generated by large groups of neurons, known as neural ensembles, including investigations of the changes that occur in electroencephalographic profiles during cycles of sleep and wakefulness. EEG signals change dramatically during sleep and show a transition from faster frequencies to increasingly slower frequencies, indicating a relationship between the frequency of neural oscillations and cognitive states including awareness and consciousness.

Brainwaves, or neural oscillations, share the fundamental constituents with acoustic and optical waves, including frequency, amplitude and periodicity. The synchronous electrical activity of cortical neural ensembles can synchronize in response to external acoustic or optical stimuli and also entrain or synchronize their frequency and phase to that of a specific stimulus. Brainwave entrainment is a colloquialism for such 'neural entrainment', which is a term used to denote the way in which the aggregate frequency of oscillations produced by the synchronous electrical activity in ensembles of cortical neurons can adjust to synchronize with the periodic vibration of an external stimuli, such as a sustained acoustic frequency perceived as pitch, a regularly repeating pattern of intermittent sounds, perceived as rhythm, or of a regularly rhythmically intermittent flashing light.

Changes in neural oscillations, demonstrable through electroencephalogram (EEG) measurements, are precipitated by listening to music, which can modulate autonomic arousal ergotropically and trophotropically, increasing and decreasing arousal respectively. Musical auditory stimulation has also been demonstrated to improve immune function, facilitate relaxation, improve mood, and contribute to the alleviation of stress.

The Frequency following response (FFR), also referred to as Frequency Following Potential (FFP), is a specific response to hearing sound and music, by which neural oscillations adjust their frequency to match the rhythm of auditory stimuli. The use of sound with intent to influence cortical brainwave frequency is called auditory driving, by which frequency of neural oscillation is 'driven' to entrain with that of the rhythm of a sound source. See, en.wikipedia.org/wiki/Brainwave_entrainment.

A baseline correction of event-related time-frequency measure may be made to take pre-event baseline activity into consideration. In general, a baseline period is defined by the average of the values within a time window preceding the time-locking event. There are at least four common methods for baseline correction in time-frequency analysis. The methods include various baseline value normalizations.

Electroencephalograms (EEG) and functional Magnetic Resonance Imaging, fMRI have been used to study specific brain activity associated with different emotional states. Mauss and Robinson, in their review paper, have indicated that "emotional state is likely to involve circuits rather than any brain region considered in isolation" (Mauss IB, Robinson MD (2009) Measures of emotion: A review. Cogn Emot 23: 209–237.)

The amplitude, latency from the stimulus, and covariance (in the case of multiple electrode sites) of each component can be examined in connection with a cognitive task (ERP) or with no task (EP). Steady-state visually evoked potentials (SSVEPs) use a continuous sinusoidally-modulated flickering light, typically superimposed in front of a TV monitor displaying a cognitive task. The brain response in a narrow frequency band containing the stimulus frequency is measured. Magnitude, phase, and coherence (in the case of multiple electrode sites) may be related to different parts of the cognitive task. Brain entrainment may be detected through EEG or MEG activity. Brain entrainment may be detected through EEG or MEG activity.

The entrainment hypothesis (Thut and Miniussi, 2009; Thut et al., 2011a, 2012), suggests the possibility of inducing a particular oscillation frequency in the brain using an external oscillatory force (e.g., rTMS, but also tACS). The physiological basis of oscillatory cortical activity lies in the timing of the interacting neurons; when groups of neurons synchronize their firing activities, brain rhythms emerge, network oscillations are generated, and the basis for interactions between brain areas may develop (Buzsàki, 2006). Because of the variety of experimental protocols for brain stimulation, limits on descriptions of the actual protocols employed, and limited controls, consistency of reported studies is lacking, and extrapolability is limited. Thus, while there is various consensus in various aspects of the effects of extra cranial brain stimulation, the results achieved have a degree of uncertainty dependent on details of implementation. On the other hand, within a specific experimental protocol, it is possible to obtain statistically significant and repeatable results. This implies that feedback control might be effective to control implementation of the stimulation for a given purpose; however, studies that employ feedback control are lacking.

Different cognitive states are associated with different oscillatory patterns in the brain (Buzsàki, 2006; Canolty and Knight, 2010; Varela et al., 2001). Thut et al. (2011b) directly tested the entrainment hypothesis by means of a concurrent EEG-TMS experiment. They first determined the individual source of the parietal-occipital alpha modulation and the individual alpha frequency (magnetoencephalography study). They then applied rTMS at the individual alpha power while recording the EEG activity at rest. The results confirmed the three predictions of the entrainment hypothesis: the induction of a specific frequency after TMS, the enhancement of oscillation during TMS stimulation due to synchronization, and a phase alignment of the induced frequency and the ongoing activity (Thut et

al., 2011b).

If associative stimulation is a general principle for human neural plasticity in which the timing and strength of activation are critical factors, it is possible that synchronization within or between areas using an external force to phase/align oscillations can also favor efficient communication and associative plasticity (or alter communication). In this respect associative, cortico-cortical stimulation has been shown to enhance coherence of oscillatory activity between the stimulated areas (Plewnia et al., 2008).

In coherence resonance (Longtin, 1997), the addition of a certain amount of noise in an excitable system results in the most coherent and proficient oscillatory responses. The brain's response to external timing-embedded stimulation can result in a decrease in phase variance and an enhanced alignment (clustering) of the phase components of the ongoing EEG activity (entraining, phase resetting) that can change the signal-to-noise ratio and increase (or decrease) signal efficacy.

If one considers neuron activity within the brain as a set of loosely coupled oscillators, then the various parameters that might be controlled include the size of the region of neurons, frequency of oscillation, resonant frequency or time-constant, oscillator damping, noise, amplitude, coupling to other oscillators, and of course, external influences that may include stimulation and/or power loss. In a human brain, pharmacological intervention may be significant. For example, drugs that alter excitability, such as caffeine, neurotransmitter release and reuptake, nerve conductance, etc. can all influence operation of the neural oscillators. Likewise, sub-threshold external stimulation effects, including DC, AC and magnetic electromagnetic effects, can also influence operation of the neural oscillators.

Phase resetting or shifting can synchronize inputs and favor communication and, eventually, Hebbian plasticity (Hebb, 1949). Thus, rhythmic stimulation may induce a statistically higher degree of coherence in spiking neurons, which facilitates the induction of a specific cognitive process (or hinders that process). Here, the perspective is slightly different (coherence resonance), but the underlining mechanisms are similar to the ones described so far (stochastic resonance), and the additional key factor is the repetition at a specific rhythm of the stimulation.

In the 1970's, the British biophysicist and psychobiologist, C. Maxwell Cade, monitored the brainwave patterns of advanced meditators and 300 of his students. Here he found that the most advanced meditators have a specific brainwave pattern that was different from the rest of his students. He noted that these meditators showed high activity of alpha brainwaves accompanied by beta, theta and even delta waves that were about half the amplitude of the alpha waves. See, Cade "The Awakened Mind: Biofeedback and the Development of Higher States of Awareness" (Dell, 1979). Anna Wise extended Cade's studies, and found that extraordinary achievers which included composers, inventors, artists, athletes, dancers, scientists, mathematicians, CEO's and presidents of large corporations have brainwave patterns differ from average performers, with a specific balance between Beta, Alpha, Theta and Delta brainwaves where Alpha had the strongest amplitude. See, Anna Wise, "The High-Performance Mind: Mastering Brainwaves for Insight, Healing, and Creativity".

Entrainment is plausible because of the characteristics of the demonstrated EEG responses to a single TMS pulse, which have a spectral composition which resemble the spontaneous oscillations of the stimulated cortex. For example, TMS of the "resting" visual (Rosanova et al., 2009) or motor cortices (Veniero et al., 2011) triggers alpha-waves, the natural frequency at the resting state of both types of cortices. With the entrainment hypothesis, the noise generation framework moves to a more complex and extended level in which noise is synchronized with on-going activity. Nevertheless, the model to explain the outcome will not change, stimulation will interact with the system, and the final result will depend on introducing or modifying the noise level. The entrainment hypothesis makes clear predictions with respect to online repetitive TMS paradigms' frequency engagement as well as the possibility of inducing phase alignment, i.e., a reset of ongoing brain oscillations via external spTMS (Thut et al., 2011a, 2012; Veniero et al., 2011). The entrainment hypothesis is superior to the localization approach in gaining knowledge about how the brain works, rather than where or when a single process occurs. TMS pulses may phase-align the natural, ongoing oscillation of the target cortex. When additional TMS pulses are delivered in synchrony with the phase-aligned oscillation (i.e., at the same frequency), further synchronized phase-alignment will occur, which will bring the oscillation of the target area in resonance with the TMS train. Thus, entrainment may be expected when TMS is frequency-tuned to the underlying brain oscillations (Veniero et al., 2011).

Binaural Beats Binaural beats are auditory brainstem responses which originate in the superior olivary nucleus of each hemisphere. They result from the interaction of two different auditory impulses, originating in opposite ears, below 1000 Hz and which differ in frequency between one and 30 Hz. For example, if a pure tone of 400 Hz is presented to the right ear and a pure tone of 410 Hz is presented simultaneously to the left ear, an amplitude modulated standing wave of 10 Hz, the difference between the two tones, is experienced as the two wave forms mesh in and out of phase within the superior olivary nuclei. This binaural beat is not heard in the ordinary sense of the word (the human range of hearing is from 20-20,000 Hz). It is perceived as an auditory beat and theoretically can be used to entrain specific neural rhythms through the frequency-following response (FFR)--the tendency for cortical potentials to entrain to or resonate at the frequency of an external stimulus. Thus, it is theoretically possible to utilize a specific binaural-beat frequency as a consciousness management technique to entrain a specific cortical rhythm. The binaural-beat appears to be associated with an electroencephalographic (EEG) frequency-following response in the brain.

Uses of audio with embedded binaural beats that are mixed with music or various pink or background sound are diverse. They range from relaxation, meditation, stress reduction, pain management, improved sleep quality, decrease in sleep requirements, super learning, enhanced creativity and intuition, remote viewing, telepathy, and out-of-body experience and lucid dreaming. Audio embedded with binaural beats is often combined with various meditation techniques, as well as positive affirmations and visualization.

When signals of two different frequencies are presented, one to each ear, the brain detects phase differences

between these signals. “Under natural circumstances a detected phase difference would provide directional information. The brain processes this anomalous information differently when these phase differences are heard with stereo headphones or speakers. A perceptual integration of the two signals takes place, producing the sensation of a third “beat” frequency. The difference between the signals waxes and wanes as the two different input frequencies mesh in and out of phase. As a result of these constantly increasing and decreasing differences, an amplitude-modulated standing wave -the binaural beat- is heard. The binaural beat is perceived as a fluctuating rhythm at the frequency of the difference between the two auditory inputs. Evidence suggests that the binaural beats are generated in the brainstem’s superior olivary nucleus, the first site of contralateral integration in the auditory system. Studies also suggest that the frequency-following response originates from the inferior colliculus. This activity is conducted to the cortex where it can be recorded by scalp electrodes. Binaural beats can easily be heard at the low frequencies (< 30 Hz) that are characteristic of the EEG spectrum.

Synchronized brainwaves have long been associated with meditative and hypnogogic states, and audio with embedded binaural beats has the ability to induce and improve such states of consciousness. The reason for this is physiological. Each ear is “hardwired” (so to speak) to both hemispheres of the brain. Each hemisphere has its own olivary nucleus (sound-processing center) which receives signals from each ear. In keeping with this physiological structure, when a binaural beat is perceived there are actually two standing waves of equal amplitude and frequency present, one in each hemisphere. So, there are two separate standing waves entraining portions of each hemisphere to the same frequency. The binaural beats appear to contribute to the hemispheric synchronization evidenced in meditative and hypnogogic states of consciousness. Brain function is also enhanced through the increase of cross-collosal communication between the left and right hemispheres of the brain. en.wikipedia.org/wiki/Beat_(acoustics)#Binaural_beats.

Isochronic Tones Isochronic tones are regular beats of a single tone that are used alongside monaural beats and binaural beats in the process called brainwave entrainment. At its simplest level, an isochronic tone is a tone that is being turned on and off rapidly. They create sharp, distinctive pulses of sound.

Time-Frequency Analysis Brian J. Roach and Daniel H. Mathalon, “Event-related EEG time-frequency analysis: an overview of measures and analysis of early gamma band phase locking in schizophrenia. Schizophrenia Bull. USA. 2008; 34:5:907-926., describes a mechanism for EEG time-frequency analysis. Fourier and wavelet transforms (and their inverse) may be performed on EEG signals.

There are many approaches to time-frequency decomposition of EEG data, including the short-term Fourier transform (STFT), (Gabor D. Theory of Communication. J. Inst. Electr. Engrs. 1946; 93:429-457) continuous (Daubechies I. Ten Lectures on Wavelets. Philadelphia, Pa: Society for Industrial and Applied Mathematics; 1992:357. 21. Combes JM, Grossmann A, Tchamitchian P. Wavelets: Time-Frequency Methods and Phase Space-Proceedings of the International Conference; December 14-18, 1987; Marseille, France) or discrete (Mallat SG. A

theory for multiresolution signal decomposition: the wavelet representation. IEEE Trans Pattern Anal Mach Intell. 1989; 11:674-693) wavelet transforms, Hilbert transform (Lyons RG. Understanding Digital Signal Processing. 2nd ed. Upper Saddle River, NJ: Prentice Hall PTR; 2004:688), and matching pursuits (Mallat S, Zhang Z. Matching pursuits with time-frequency dictionaries. IEEE Trans. Signal Proc. 1993; 41(12):3397-3415). Prototype analysis systems may be implemented using, for example, MatLab with the Wavelet Toolbox, www.mathworks.com/products/wavelet.html.

Single instruction, multiple data processors, such as graphic processing units including the nVidia CUDA environment or AMD Firepro high-performance computing environment are known, and may be employed for general purpose computing, finding particular application in data matrix transformations.

Statistical analysis may be presented in a form that permits parallelization, which can be efficiently implemented using various parallel processors, a common form of which is a SIMD (single instruction, multiple data) processor, found in typical graphics processors (GPUs).

Artificial neural networks have been employed to analyze EEG signals.

Principal Component Analysis Principal component analysis (PCA) is a statistical procedure that uses an orthogonal transformation to convert a set of observations of possibly correlated variables into a set of values of linearly uncorrelated variables called principal components. If there are n observations with p variables, then the number of distinct principal components is min(n-1,p). This transformation is defined in such a way that the first principal component has the largest possible variance (that is, accounts for as much of the variability in the data as possible), and each succeeding component in turn has the highest variance possible under the constraint that it is orthogonal to the preceding components. The resulting vectors are an uncorrelated orthogonal basis set. PCA is sensitive to the relative scaling of the original variables. PCA is the simplest of the true eigenvector-based multivariate analyses. Often, its operation can be thought of as revealing the internal structure of the data in a way that best explains the variance in the data. If a multivariate dataset is visualized as a set of coordinates in a high-dimensional data space (1 axis per variable), PCA can supply the user with a lower-dimensional picture, a projection of this object when viewed from its most informative viewpoint. This is done by using only the first few principal components so that the dimensionality of the transformed data is reduced. PCA is closely related to factor analysis. Factor analysis typically incorporates more domain specific assumptions about the underlying structure and solves eigenvectors of a slightly different matrix. PCA is also related to canonical correlation analysis (CCA). CCA defines coordinate systems that optimally describe the cross-covariance between two datasets while PCA defines a new orthogonal coordinate system that optimally describes variance in a single dataset. See, en.wikipedia.org/wiki/Principal_component_analysis.

A general model for confirmatory factor analysis is expressed as $x = \alpha + \Lambda\xi + \varepsilon$. The covariance matrix is expressed as $E[(x-\mu)(x-\mu)'] = \Lambda\Phi\Lambda' + \Theta$. If residual covariance matrix $\Theta = 0$ and correlation matrix

among latent factors $\boldsymbol{\Phi} = \boldsymbol{I}$, then factor analysis is equivalent to principal component analysis and the resulting covariance matrix is simplified to $\boldsymbol{\Sigma} = \boldsymbol{\Lambda}\boldsymbol{\Lambda}'$. When there are *p* number of variables and all *p* components (or factors) are extracted, this covariance matrix can alternatively be expressed into $\boldsymbol{\Sigma} = \boldsymbol{D}\boldsymbol{\Lambda}\boldsymbol{D}'$, or $\boldsymbol{\Sigma} = \boldsymbol{\lambda}\boldsymbol{D}\boldsymbol{A}\boldsymbol{D}'$, where $\boldsymbol{D}$ = *n* × *p* orthogonal matrix of eigenvectors, and $\boldsymbol{\Lambda} = \boldsymbol{\lambda}\boldsymbol{A}$, *p* ×*p* matrix of eigenvalues, where $\boldsymbol{\lambda}$ is a scalar and *A* is a diagonal matrix whose elements are proportional to the eigenvalues of $\boldsymbol{\Sigma}$. The following three components determine the geometric features of the observed data: $\boldsymbol{\lambda}$ parameterizes the *volume* of the observation, $\boldsymbol{D}$ indicates the *orientation*, and *A* represents the *shape* of the observation.

When population heterogeneity is explicitly hypothesized as in model-based cluster analysis, the observed covariance matrix is decomposed into the following general form $\sum_k = \lambda_k \boldsymbol{D}_k \boldsymbol{A}_k \boldsymbol{D}_k^T$,

where λ_k parameterizes the *volume* of the *k*th cluster, $\boldsymbol{D}_k$ indicates the *orientation* of that cluster, and $\boldsymbol{A}_k$ represents the *shape* of that cluster. The subscript *k* indicates that each component (or cluster) can have different volume, shape, and orientation.

Assume a random vector X, taking values in $\Re^m$, has a mean and covariance matrix of μ_X and Σ_X, respectively. $\lambda_1 > \lambda_2 > \cdots > \lambda_m > 0$ are ordered eigenvalues of Σ_X, such that the i-th eigenvalue of Σ_X means the i-th largest of them. Similarly, a vector α_i is the i-th eigenvector of Σ_X when it corresponds to the i-th eigenvalue of Σ_X. To derive the form of principal components (PCs), consider the optimization problem of maximizing $\mathrm{var}[\alpha_1^T X] = \alpha_1^T \Sigma_X \alpha_1$, subject to $\alpha_1^T \alpha_1 = 1$. The Lagrange multiplier method is used to solve this question.

$$L(\alpha_1, \phi_1) = \alpha_1^T \Sigma_X \alpha_1 + \phi_1(\alpha_1^T \alpha_1 - 1)$$

$$\frac{\partial L}{\partial \alpha_1} = 2\Sigma_X \alpha_1 + 2\phi_1 \alpha_1 = 0 \Rightarrow \Sigma_X \alpha_1 = -\phi_1 \alpha_1 \Rightarrow \mathrm{var}[\alpha_1^T X] = -\phi_1 \alpha_1^T \alpha_1 = -\phi_1 .$$

Because $-\phi_1$ is the eigenvalue of Σ_X, with α_1 being the corresponding normalized eigenvector, $\mathrm{var}[\alpha_1^T X]$ is maximized by choosing α_1 to be the first eigenvector of Σ_X. In this case, $z_1 = \alpha_1^T X$ is named the first PC of X, α_1 is the vector of coefficients for z_1, and $\mathrm{var}(z_1) = \lambda_1$.

To find the second PC, $z_2 = \alpha_2^T X$, we need to maximize $\mathrm{var}[\alpha_2^T X] = \alpha_2^T \Sigma_X \alpha_2$ subject to z_2 being uncorrelated with z_1. Because $\mathrm{cov}(\alpha_1^T X, \alpha_2^T X) = 0 \Rightarrow \alpha_1^T \Sigma_X \alpha_2 = 0 \Rightarrow \alpha_1^T \alpha_2 = 0$, this problem is equivalently set as maximizing $\alpha_2^T \Sigma_X \alpha_2$, subject to $\alpha_1^T \alpha_2 = 0$, and $\alpha_2^T \alpha_2 = 1$. We still make use of the

Lagrange multiplier method.

$$L(\alpha_2, \phi_1, \phi_2) = \alpha_2^T \Sigma_X \alpha_2 + \phi_1 \alpha_1^T \alpha_2 + \phi_2(\alpha_2^T \alpha_2 - 1)$$

$$\frac{\partial L}{\partial \alpha_2} = 2\Sigma_X \alpha_2 + \phi_1 \alpha_1 + 2\phi_2 \alpha_2 = 0 \Rightarrow$$

$$\alpha_1^T (2\Sigma_X \alpha_2 + \phi_1 \alpha_1 + 2\phi_2 \alpha_2) = 0 \Rightarrow \phi_1 = 0 \Rightarrow$$

$$\Sigma_X \alpha_2 = -\phi_2 \alpha_2 \Rightarrow \alpha_2^T \Sigma_X \alpha_2 = -\phi_2.$$

Because $-\phi_2$ is the eigenvalue of Σ_X, with α_2 being the corresponding normalized eigenvector, $\text{var}[\alpha_2^T X]$ is maximized by choosing α_2 to be the second eigenvector of Σ_X. In this case, $z_2 = \alpha_2^T X$ is named the second PC of X, α_2 is the vector of coefficients for z_2, and $\text{var}(z_2) = \lambda_2$. Continuing in this way, it can be shown that the i-th PC $z_i = \alpha_i^T X$ is constructed by selecting α_i to be the i-th eigenvector of Σ_X, and has variance of λ_i. The key result in regards to PCA is that the principal components are the only set of linear functions of original data that are uncorrelated and have orthogonal vectors of coefficients.

For any positive integer $p \le m$, let $B = [\beta_1, \beta_2, \ldots, \beta_p]$ be an real $m \times p$ matrix with orthonormal columns, i.e., $\beta_i^T \beta_j = \delta_{ij}$, and $Y = B^T X$. Then the trace of covariance matrix of Y is maximized by taking $B = [\alpha_1, \alpha_2, \ldots, \alpha_p]$, where α_i is the i-th eigenvector of Σ_X. Because Σ_X is symmetric with all distinct eigenvalues, so $\{\alpha_1, \alpha_2, \ldots, \alpha_m\}$ is an orthonormal basis with α_i being the i-th eigenvector of Σ_X, and we can represent the columns of B as $\beta_i = \sum_{j=1}^{m} c_{ji} \alpha_j$, $i = 1, \ldots, p$, So we have $B = PC$, where $P = [\alpha_1, \ldots, \alpha_m]$, $C = \{c_{ij}\}$ is an $m \times p$ matrix. Then, $P^T \Sigma_X P = \Lambda$, with Λ being a diagonal matrix whose k-th diagonal element is λ_k, and the covariance matrix of Y is,

$$\Sigma_Y = B^T \Sigma_X B = C^T P^T \Sigma_X PC = C^T \Lambda C = \lambda_1 c_1 c_1^T + \cdots + \lambda_m c_m c_m^T$$

where c_i^T is the i-th row of C. So,

$$trace(\Sigma_Y) = \sum_{i=1}^{m} \lambda_i trace(c_i c_i^T) = \sum_{i=1}^{m} \lambda_i trace(c_i^T c_i) = \sum_{i=1}^{m} \lambda_i c_i^T c_i = \sum_{i=1}^{m} (\sum_{j=1}^{p} c_{ij}^2) \lambda_i .$$

Because $C^T C = B^T P P^T B = B^T B = I$, so $trace(C^T C) = \sum_{i=1}^{m} \sum_{j=1}^{p} c_{ij}^2 = p$, and the columns of C are orthonormal. By the Gram-Schmidt method, C can expand to D, such that D has its columns as an orthonormal

basis of $\Re^m$ and contains C as its first p columns. D is square shape, thus being an orthogonal matrix and having its rows as another orthonormal basis of $\Re^m$. One row of C is a part of one row of D, so $\sum_{j=1}^{p} c_{ij}^2 \le 1$, $i = 1,\ldots,m$. Considering the constraints $\sum_{j=1}^{p} c_{ij}^2 \le 1$, $\sum_{i=1}^{m}\sum_{j=1}^{p} c_{ij}^2 = p$ and the objective $\sum_{i=1}^{m}(\sum_{j=1}^{p} c_{ij}^2)\lambda_i$. We derive that $trace(\Sigma_Y)$ is maximized if $\sum_{j=1}^{p} c_{ij}^2 = 1$ for $i = 1,\ldots,p$, and $\sum_{j=1}^{p} c_{ij}^2 = 0$ for $i = p+1,\ldots,m$. When $B = [\alpha_1, \alpha_2, \ldots, \alpha_p]$, straightforward calculation yields that C is an all-zero matrix except $c_{ii} = 1$, $i = 1,\ldots,p$. This fulfills the maximization condition. Actually, by taking $B = [\gamma_1, \gamma_2, \ldots, \gamma_p]$, where $\{\gamma_1, \gamma_2, \ldots, \gamma_p\}$ is any orthonormal basis of the subspace of $span\{\alpha_1, \alpha_2, \ldots, \alpha_p\}$, the maximization condition is also satisfied, yielding the same trace of covariance matrix of Y.

Suppose that we wish to approximate the random vector X by its projection onto a subspace spanned by columns of B, where $B = [\beta_1, \beta_2, \ldots, \beta_p]$ is a real $m \times p$ matrix with orthonormal columns, i.e., $\beta_i^T \beta_j = \delta_{ij}$. If σ_i^2 is the residual variance for each component of X, then $\sum_{i=1}^{m} \sigma_i^2$ is minimized if $B = [\alpha_1, \alpha_2, \ldots, \alpha_p]$, where $\{\alpha_1, \alpha_2, \ldots, \alpha_p\}$ are the first p eigenvectors of Σ_X. In other words, the trace of covariance matrix of $X - BB^T X$ is minimized if $B = [\alpha_1, \alpha_2, \ldots, \alpha_p]$. When $E(X) = 0$, which is a commonly applied preprocessing step in data analysis methods, this property is saying that $E\left\|X - BB^T X\right\|^2$ is minimized if $B = [\alpha_1, \alpha_2, \ldots, \alpha_p]$.

The projection of a random vector X onto a subspace spanned by columns of B is $\hat{X} = BB^T X$. Then the residual vector is $\varepsilon = X - BB^T X$, which has a covariance matrix

$\Sigma_\varepsilon = (I - BB^T)\Sigma_X (I - BB^T)$. Then,

$$\sum_{i=1}^{m} \sigma_i^2 = trace(\Sigma_\varepsilon) = trace(\Sigma_X - \Sigma_X BB^T - BB^T \Sigma_X + BB^T \Sigma_X BB^T)$$

.

Also, we know:

$$trace(\Sigma_X BB^T) = trace(BB^T \Sigma_X) = trace(B^T \Sigma_X B)$$

$$trace(BB^T \Sigma_X BB^T) = trace(B^T \Sigma_X BB^T B) = trace(B^T \Sigma_X B).$$

The last equation comes from the fact that B has orthonormal columns. So,

$$\sum_{i=1}^{m} \sigma_i^2 = trace(\Sigma_X) - trace(B^T \Sigma_X B)$$

To minimize $\sum_{i=1}^{m} \sigma_i^2$, it suffices to maximize $trace(B^T \Sigma_X B)$. This can be done by choosing $B = [\alpha_1, \alpha_2, \ldots, \alpha_p]$, where $\{\alpha_1, \alpha_2, \ldots, \alpha_p\}$ are the first p eigenvectors of Σ_X, as above.

See, Pietro Amenta, Luigi D'Ambra, "Generalized Constrained Principal Component Analysis with External Information," (2000). We assume that data on *K* sets of explanatory variables and *S* criterion variables of *n* statistical units are collected in matrices $X_k \ (k = 1, \ldots, K)$ and $Y_s \ (s = 1, \ldots, S)$ of orders $(n \times p_1), \ldots, (n \times p_K)$ and $(n \times q_1), \ldots, (n \times q_S)$, respectively. We suppose, without loss of generality, identity matrices for the metrics of the spaces of variables of X_k and Y_s with $D_n = diag(1/n)$, weight matrix of statistical units. We assume, moreover, that X_k's and Y_s's are centered as to the weights D_n.

Let $X = [X_1 | \ldots | X_K]$ and $Y = [Y_1 | \ldots | Y_S]$, respectively, be *K* and *S* matrices column linked of orders $(n \times \sum_k p_k)$ and $(n \times \sum_s q_s)$. Let be, also, $W_Y = YY'$ while we denote v_k the coefficients vector $(p_k, 1)$ of the linear combination for each X_k such that $z_k = X_k v_k$. Let C_k be the matrix of dimension $p_k \times m \ (m \leq p_k)$, associated to the external information explanatory variables of set *k*.

Generalized CPCA (GCPCA) (Amenta, D'Ambra, 1999) with external information consists in seeking for *K* coefficients vectors v_k (or, in same way, *K* linear combinations z_k) subject to the restriction $C_k' v_k = 0$ simultaneously, such that:

$$\begin{cases} \max \sum_{i=1}^{K} \sum_{j=1}^{K} \left\langle Y' X_i v_i, Y' X_j v_j \right\rangle \\ \text{with the constraints} \quad \sum_{k=1}^{K} \left\| X_k v_k \right\|^2 = 1 \\ \qquad\qquad\qquad\quad \sum_{k=1}^{K} C_k' v_k = 0 \end{cases} \tag{1}$$

or, in equivalent way,

$$\begin{cases} \max v'(A'A)v \\ \text{with the constraints} \quad v'Bv = 1 \\ \qquad\qquad\qquad\quad C'v = 0 \end{cases} \quad \text{or} \quad \begin{cases} \max f' B^{-0.5} A' A B^{-0.5} f \\ \text{with the constraints} \quad f'f = 1 \\ \qquad\qquad\qquad\quad C'v = 0 \end{cases}$$

where $A = Y'X$, $B = diag(X_1'X_1, \cdots, X_K'X_K)$, $C' = [C_1' | \ldots | C_k']$, $v' = (v_1' | \ldots | v_k')$ and

$$A'A = \begin{bmatrix} X_1'YY'X_1 & \ldots & X_1'YY'X_K \\ \vdots & \ddots & \vdots \\ X_K'YY'X_1 & \ldots & X_k'YY'X_k \end{bmatrix}.$$

$f = B^{0.5}v$, with

The constrained maximum problem turns out to be an extension of criterion $\sup_{\sum_k \|z_k\|^2 = 1} \sum_i \sum_k \langle z_i, z_k \rangle$ (Sabatier, 1993) with more sets of criterion variables with external information. The solution of this constrained maximum problem leads to solve the eigen-equation

$$(P_X - P_{XB^{-1}C})W_Y g = \lambda g$$

where $g = Xv$, $P_X - P_{XB^{-1}C} = \sum_{k=1}^{K} \left(P_{X_k} - P_{X_k (X_k' X_k)^{-1} C_k} \right)$ is the oblique projector operator associated to the direct sum decomposition of $\Re^n$

$$\Re^n = Im(P_X - P_{XB^{-1}C}) \oplus Im(P_C) \oplus Ker(P_X)$$

with $P_{X_k} = X_k (X_k' X_k)^{-1} X_k'$ and $P_C = C(C'B^{-1}C)^{-1}C'B^{-1}$, respectively, *I* and B^{-1} orthogonal projector operators onto the subspaces spanned by the columns of matrices X_k and *C*. Furthermore, $P_{XB^{-1}C} = XB^{-1}C(C'B^{-1}C)^{-1}C'B^{-1}X'$ is the orthogonal projector operator onto the subspace spanned the columns of the matrix $XB^{-1}C$. Starting from the relation

$$(P_{X_k} - P_{X_k (X_k' X_k)^{-1} C_k})W_Y g = \lambda X_k v_k$$

(which is obtained from the expression $(I - P_C)X'W_Y g = \lambda Bv$) the coefficients vectors v_k and the linear combinations $z_k = X_k v_k$ maximizing (1) can be given by the relations $v_k = \frac{1}{\lambda}(X_k' X_k)^{-1}(I - P_{C_k})X_k' W_Y Xv$ and $z_k = \frac{1}{\lambda}(P_{X_k} - P_{X_k (X_k' X_k)^{-1} C_k})W_Y Xv$, respectively.

The solution eigenvector *g* can be written, as sum of the linear combinations z_k: $g = \sum_k X_k v_k$. Notice that the eigenvalues associated to the eigen-system are, according to the Sturm theorem, lower or equal than those of GCPCA eigen-system: $\sum_{k=1}^{K} P_{X_k} W_Y g = \lambda g$.

Spatial Principal Component Analysis (Spatial PCA) Let $\mathbf{J}(t, i; \alpha, s)$ be the current density in voxel *i*, as estimated by LORETA, in condition α at *t* time-frames after stimulus onset for subject *s*. Let $\text{area}: Voxel \rightarrow fBA$ be a function, which assigns to each voxel $i \in Voxel$ the corresponding fBA $b \in fBA$. In a first pre-processing step, for

each subject *s*, the value of the current density averaged over each fBA is calculated:

$$x(t,b;\alpha,s)=\frac{1}{N_b}\sum_{i\in b}\mathbf{J}(t,i;\alpha,s) \qquad (4)$$

where N_b is the number of voxels in the fBA *b*, in condition α for subject *s*.

In the second analysis stage, the mean current density $x(t,b;\alpha,s)$ from each fBA *b*, for every subject *s* and condition α, was subjected to spatial PCA analysis of the correlation matrix and varimax rotation

The spatial PCA uses the above-defined fBAs as variables sampled along the time epoch for which EEG has been sampled (e.g., 0-1000 ms; 512 time-frames), and the inverse solution estimated. Spatial matrices (e.g., each matrix was sized *b* x *t* = 36 × 512 elements) for every subject and condition may be collected, and subjected to PCA analyses, including the calculation of the covariance matrix; eigenvalue decomposition and varimax rotation, in order to maximize factor loadings. In other words, the *spatial PCA analysis* approximates the mean current density for each subject in each condition as

$$\mathbf{x}(t;\alpha,s)\approx\mathbf{x}_0(\alpha,s)+\sum_k c_k(t)\mathbf{x}_k(\alpha,s), \qquad (5)$$

where here $\mathbf{x}(t;\alpha,s)\in R^{36}$ is a vector, which denotes the time-dependent activation of the fBAs, $\mathbf{x}_0(\alpha,s)$ is their mean activation, and $\mathbf{x}_k(\alpha,s)$ and c_k are the principal components and their corresponding coefficients (factor loadings) as computed using the principal component analysis.

Nonlinear Dimensionality Reduction High-dimensional data, meaning data that requires more than two or three dimensions to represent, can be difficult to interpret. One approach to simplification is to assume that the data of interest lie on an embedded non-linear manifold within the higher-dimensional space. If the manifold is of low enough dimension, the data can be visualized in the low-dimensional space. Non-linear methods can be broadly classified into two groups: those that provide a mapping (either from the high-dimensional space to the low-dimensional embedding or vice versa), and those that just give a visualization. In the context of machine learning, mapping methods may be viewed as a preliminary feature extraction step, after which pattern recognition algorithms are applied. Typically, those that just give a visualization are based on proximity data – that is, distance measurements. Related Linear Decomposition Methods include Independent component analysis (ICA), Principal component analysis (PCA) (also called Karhunen–Loève transform - KLT), Singular value decomposition (SVD), and Factor analysis.

The self-organizing map (SOM, also called Kohonen map) and its probabilistic variant generative topographic mapping (GTM) use a point representation in the embedded space to form a latent variable model based on a non-linear mapping from the embedded space to the high-dimensional space. These techniques are related to work on density networks, which also are based around the same probabilistic model.

Principal curves and manifolds give the natural geometric framework for nonlinear dimensionality reduction and extend the geometric interpretation of PCA by explicitly constructing an embedded manifold, and by encoding using

standard geometric projection onto the manifold. How to define the "simplicity" of the manifold is problem-dependent, however, it is commonly measured by the intrinsic dimensionality and/or the smoothness of the manifold. Usually, the principal manifold is defined as a solution to an optimization problem. The objective function includes a quality of data approximation and some penalty terms for the bending of the manifold. The popular initial approximations are generated by linear PCA, Kohonen's SOM or autoencoders. The elastic map method provides the expectation-maximization algorithm for principal manifold learning with minimization of quadratic energy functional at the "maximization" step.

An autoencoder is a feed-forward neural network which is trained to approximate the identity function. That is, it is trained to map from a vector of values to the same vector. When used for dimensionality reduction purposes, one of the hidden layers in the network is limited to contain only a small number of network units. Thus, the network must learn to encode the vector into a small number of dimensions and then decode it back into the original space. Thus, the first half of the network is a model which maps from high to low-dimensional space, and the second half maps from low to high-dimensional space. Although the idea of autoencoders is quite old, training of deep autoencoders has only recently become possible through the use of restricted Boltzmann machines and stacked denoising autoencoders. Related to autoencoders is the NeuroScale algorithm, which uses stress functions inspired by multidimensional scaling and Sammon mappings (see below) to learn a non-linear mapping from the high-dimensional to the embedded space. The mappings in NeuroScale are based on radial basis function networks.

Gaussian process latent variable models (GPLVM) are probabilistic dimensionality reduction methods that use Gaussian Processes (GPs) to find a lower dimensional non-linear embedding of high dimensional data. They are an extension of the Probabilistic formulation of PCA. The model is defined probabilistically and the latent variables are then marginalized and parameters are obtained by maximizing the likelihood. Like kernel PCA they use a kernel function to form a nonlinear mapping (in the form of a Gaussian process). However, in the GPLVM the mapping is from the embedded(latent) space to the data space (like density networks and GTM) whereas in kernel PCA it is in the opposite direction. It was originally proposed for visualization of high dimensional data but has been extended to construct a shared manifold model between two observation spaces. GPLVM and its many variants have been proposed specially for human motion modeling, e.g., back constrained GPLVM, GP dynamic model (GPDM), balanced GPDM (B-GPDM) and topologically constrained GPDM. To capture the coupling effect of the pose and gait manifolds in the gait analysis, a multi-layer joint gait-pose manifolds was proposed.

Curvilinear component analysis (CCA) looks for the configuration of points in the output space that preserves original distances as much as possible while focusing on small distances in the output space (conversely to Sammon's mapping which focus on small distances in original space). It should be noticed that CCA, as an iterative learning algorithm, actually starts with focus on large distances (like the Sammon algorithm), then gradually change focus to small distances. The small distance information will overwrite the large distance information, if compromises between the two have to be made. The stress function of CCA is related to a sum of right Bregman divergences. Curvilinear distance

analysis (CDA) trains a self-organizing neural network to fit the manifold and seeks to preserve geodesic distances in its embedding. It is based on Curvilinear Component Analysis (which extended Sammon's mapping), but uses geodesic distances instead. Diffeomorphic Dimensionality Reduction or Diffeomap learns a smooth diffeomorphic mapping which transports the data onto a lower-dimensional linear subspace. The method solves for a smooth time indexed vector field such that flows along the field which start at the data points will end at a lower-dimensional linear subspace, thereby attempting to preserve pairwise differences under both the forward and inverse mapping.

Perhaps the most widely used algorithm for manifold learning is Kernel principal component analysis (kernel PCA). It is a combination of Principal component analysis and the kernel trick. PCA begins by computing the covariance matrix of the M × n Matrix X. It then projects the data onto the first k eigenvectors of that matrix. By comparison, KPCA begins by computing the covariance matrix of the data after being transformed into a higher-dimensional space. It then projects the transformed data onto the first k eigenvectors of that matrix, just like PCA. It uses the kernel trick to factor away much of the computation, such that the entire process can be performed without actually computing Φ(x). Of course Φ must be chosen such that it has a known corresponding kernel.

The Fourier transform (FT) decomposes a function of time (a signal) into the frequencies that make it up. The Fourier transform of a function of time is itself a complex-valued function of frequency, whose absolute value represents the amount of that frequency present in the original function, and whose complex argument is the phase offset of the basic sinusoid in that frequency. The Fourier transform is called the frequency domain representation of the original signal. The term Fourier transform refers to both the frequency domain representation and the mathematical operation that associates the frequency domain representation to a function of time. The Fourier transform is not limited to functions of time, but in order to have a unified language, the domain of the original function is commonly referred to as the time domain. For many functions of practical interest, one can define an operation that reverses this: the inverse Fourier transformation, also called Fourier synthesis, of a frequency domain representation combines the contributions of all the different frequencies to recover the original function of time. See, en.wikipedia.org/wiki/Fourier_transform.

The Fourier transform of a finite Borel measure μ on $\mathbb{R}^n$ is given by: $\hat{\mu}(\zeta) = \int_{\mathbb{R}^n} e^{-2\pi i x\zeta} d\mu$. This transform continues to enjoy many of the properties of the Fourier transform of integrable functions. One notable difference is that the Riemann–Lebesgue lemma fails for measures. In the case that $d\mu = f(x)\,dx$, then the formula above reduces to the usual definition for the Fourier transform of f. In the case that μ is the probability distribution associated to a random variable X, the Fourier–Stieltjes transform is closely related to the characteristic function, but the typical conventions in probability theory take $e^{ix\xi}$ instead of $e^{-2\pi i x\xi}$. In the case when the distribution has a probability density function this definition reduces to the Fourier transform applied to the probability density function, again with a different choice of constants. The Fourier transform may be used to give a characterization of measures. Bochner's theorem characterizes which functions may arise as the Fourier–Stieltjes transform of a positive measure on the circle.

Furthermore, the Dirac delta function, although not a function, is a finite Borel measure. Its Fourier transform is a constant function (whose specific value depends upon the form of the Fourier transform used). See Pinsky, Mark (2002), Introduction to Fourier Analysis and Wavelets, Brooks/Cole, ISBN 978-0-534-37660-4; Katznelson, Yitzhak (1976), An Introduction to Harmonic Analysis, Dover, ISBN 978-0-486-63331-2.

The Fourier transform is also a special case of Gelfand transform. In this particular context, it is closely related to the Pontryagin duality map. Given an abelian locally compact Hausdorff topological group *G*, as before we consider space $L^1(G)$, defined using a Haar measure. With convolution as multiplication, $L^1(G)$ is an abelian Banach algebra. Taking the completion with respect to the largest possibly *C**-norm gives its enveloping *C**-algebra, called the group *C**-algebra $C^*(G)$ of *G*. (Any *C**-norm on $L^1(G)$ is bounded by the L^1 norm, therefore their supremum exists.) 8 is the involution operator. Given any abelian *C**-algebra *A*, the Gelfand transform gives an isomorphism between *A* and $C_0(A\hat{})$, where $A\hat{}$ is the multiplicative linear functionals, i.e. one-dimensional representations, on *A* with the weak-* topology. The multiplicative linear functionals of $C^*(G)$, after suitable identification, are exactly the characters of *G*, and the Gelfand transform, when restricted to the dense subset $L^1(G)$ is the Fourier–Pontryagin transform.

The Laplace transform is very similar to the Fourier transform. While the Fourier transform of a function is a complex function of a real variable (frequency), the Laplace transform of a function is a complex function of a complex variable. Laplace transforms are usually restricted to functions of t with $t \geq 0$. A consequence of this restriction is that the Laplace transform of a function is a holomorphic function of the variable s. The Laplace transform of a distribution is generally a well-behaved function. As a holomorphic function, the Laplace transform has a power series representation. This power series expresses a function as a linear superposition of moments of the function. The Laplace transform is invertible on a large class of functions. The inverse Laplace transform takes a function of a complex variable s (often frequency) and yields a function of a real variable t (time). Given a simple mathematical or functional description of an input or output to a system, the Laplace transform provides an alternative functional description that often simplifies the process of analyzing the behavior of the system, or in synthesizing a new system based on a set of specifications. So, for example, Laplace transformation from the time domain to the frequency domain transforms differential equations into algebraic equations and convolution into multiplication. See, en.wikipedia.org/wiki/Laplace_transform.

The short-time Fourier transform (STFT), is a Fourier-related transform used to determine the sinusoidal frequency and phase content of local sections of a signal as it changes over time. In practice, the procedure for computing STFTs is to divide a longer time signal into shorter segments of equal length and then compute the Fourier transform separately on each shorter segment. This reveals the Fourier spectrum on each shorter segment. One then usually plots the changing spectra as a function of time. The signal may be windowed using, e.g., a Hann window or a Gaussian window. See, en.wikipedia.org/wiki/Short-time_Fourier_transform.

The fractional Fourier transform (FRFT), is a generalization of the classical Fourier transform. The FRFT of a

signal can also be interpreted as a decomposition of the signal in terms of chirps. The FRFT can be used to define fractional convolution, correlation, and other operations, and can also be further generalized into the linear canonical transformation (LCT). See: en.wikipedia.org/wiki/Fractional_Fourier_transform.

Laplacian Eigenmaps, (also known as Local Linear Eigenmaps, LLE) are special cases of kernel PCA, performed by constructing a data-dependent kernel matrix. KPCA has an internal model, so it can be used to map points onto its embedding that were not available at training time. Laplacian Eigenmaps uses spectral techniques to perform dimensionality reduction. This technique relies on the basic assumption that the data lies in a low-dimensional manifold in a high-dimensional space. This algorithm cannot embed out of sample points, but techniques based on Reproducing kernel Hilbert space regularization exist for adding this capability. Such techniques can be applied to other nonlinear dimensionality reduction algorithms as well. Traditional techniques like principal component analysis do not consider the intrinsic geometry of the data. Laplacian eigenmaps builds a graph from neighborhood information of the data set. Each data point serves as a node on the graph and connectivity between nodes is governed by the proximity of neighboring points (using e.g. the k-nearest neighbor algorithm). The graph thus generated can be considered as a discrete approximation of the low-dimensional manifold in the high-dimensional space. Minimization of a cost function based on the graph ensures that points close to each other on the manifold are mapped close to each other in the low-dimensional space, preserving local distances. The eigenfunctions of the Laplace–Beltrami operator on the manifold serve as the embedding dimensions, since under mild conditions this operator has a countable spectrum that is a basis for square integrable functions on the manifold (compare to Fourier series on the unit circle manifold). Attempts to place Laplacian eigenmaps on solid theoretical ground have met with some success, as under certain nonrestrictive assumptions, the graph Laplacian matrix has been shown to converge to the Laplace–Beltrami operator as the number of points goes to infinity. In classification applications, low dimension manifolds can be used to model data classes which can be defined from sets of observed instances. Each observed instance can be described by two independent factors termed 'content' and 'style', where 'content' is the invariant factor related to the essence of the class and 'style' expresses variations in that class between instances. Unfortunately, Laplacian Eigenmaps may fail to produce a coherent representation of a class of interest when training data consist of instances varying significantly in terms of style. In the case of classes which are represented by multivariate sequences, Structural Laplacian Eigenmaps has been proposed to overcome this issue by adding additional constraints within the Laplacian Eigenmaps neighborhood information graph to better reflect the intrinsic structure of the class. More specifically, the graph is used to encode both the sequential structure of the multivariate sequences and, to minimize stylistic variations, proximity between data points of different sequences or even within a sequence, if it contains repetitions. Using dynamic time warping, proximity is detected by finding correspondences between and within sections of the multivariate sequences that exhibit high similarity.

Like LLE, Hessian LLE is also based on sparse matrix techniques. It tends to yield results of a much higher

quality than LLE. Unfortunately, it has a very costly computational complexity, so it is not well-suited for heavily sampled manifolds. It has no internal model. Modified LLE (MLLE) is another LLE variant which uses multiple weights in each neighborhood to address the local weight matrix conditioning problem which leads to distortions in LLE maps. MLLE produces robust projections similar to Hessian LLE, but without the significant additional computational cost.

Manifold alignment takes advantage of the assumption that disparate data sets produced by similar generating processes will share a similar underlying manifold representation. By learning projections from each original space to the shared manifold, correspondences are recovered and knowledge from one domain can be transferred to another. Most manifold alignment techniques consider only two data sets, but the concept extends to arbitrarily many initial data sets. Diffusion maps leverages the relationship between heat diffusion and a random walk (Markov Chain); an analogy is drawn between the diffusion operator on a manifold and a Markov transition matrix operating on functions defined on the graph whose nodes were sampled from the manifold. Relational perspective map is a multidimensional scaling algorithm. The algorithm finds a configuration of data points on a manifold by simulating a multi-particle dynamic system on a closed manifold, where data points are mapped to particles and distances (or dissimilarity) between data points represent a repulsive force. As the manifold gradually grows in size the multi-particle system cools down gradually and converges to a configuration that reflects the distance information of the data points. Local tangent space alignment (LTSA) is based on the intuition that when a manifold is correctly unfolded, all of the tangent hyperplanes to the manifold will become aligned. It begins by computing the k-nearest neighbors of every point. It computes the tangent space at every point by computing the d-first principal components in each local neighborhood. It then optimizes to find an embedding that aligns the tangent spaces. Local Multidimensional Scaling performs multidimensional scaling in local regions, and then uses convex optimization to fit all the pieces together.

Maximum Variance Unfolding was formerly known as Semidefinite Embedding. The intuition for this algorithm is that when a manifold is properly unfolded, the variance over the points is maximized. This algorithm also begins by finding the k-nearest neighbors of every point. It then seeks to solve the problem of maximizing the distance between all non-neighboring points, constrained such that the distances between neighboring points are preserved. Nonlinear PCA (NLPCA) uses backpropagation to train a multi-layer perceptron (MLP) to fit to a manifold. Unlike typical MLP training, which only updates the weights, NLPCA updates both the weights and the inputs. That is, both the weights and inputs are treated as latent values. After training, the latent inputs are a low-dimensional representation of the observed vectors, and the MLP maps from that low-dimensional representation to the high-dimensional observation space. Manifold Sculpting uses graduated optimization to find an embedding. Like other algorithms, it computes the k-nearest neighbors and tries to seek an embedding that preserves relationships in local neighborhoods. It slowly scales variance out of higher dimensions, while simultaneously adjusting points in lower dimensions to preserve those relationships.

Ruffini (2015) discusses Multichannel transcranial current stimulation (tCS) systems that offer the possibility of EEG-guided optimized, non-invasive brain stimulation. A tCS electric field realistic brain model is used to create a

forward "lead-field" matrix and, from that, an EEG inverter is employed for cortical mapping. Starting from EEG, 2D cortical surface dipole fields are defined that could produce the observed EEG electrode voltages.

Schestatsky et al. (2017) discuss transcranial direct current stimulation (tDCS), which stimulates through the scalp with a constant electric current that induces shifts in neuronal membrane excitability, resulting in secondary changes in cortical activity. Although tDCS has most of its neuromodulatory effects on the underlying cortex, tDCS effects can also be observed in distant neural networks. Concomitant EEG monitoring of the effects of tDCS can provide valuable information on the mechanisms of tDCS. EEG findings can be an important surrogate marker for the effects of tDCS and thus can be used to optimize its parameters. This combined EEG-tDCS system can also be used for preventive treatment of neurological conditions characterized by abnormal peaks of cortical excitability, such as seizures. Such a system would be the basis of a non-invasive closed-loop device. tDCS and EEG can be used concurrently.

EEG analysis approaches have emerged, in which event-related changes in EEG dynamics in single event-related data records are analyzed. See Allen D. Malony et al., Computational Neuroinformatics for Integrated Electromagnetic Neuroimaging and Analysis, PAR-99-138. Pfurtscheller, reported a method for quantifying the average transient suppression of alpha band (circa 10-Hz) activity following stimulation. Event-related desynchronization (ERD, spectral amplitude decreases), and event-related synchronization (ERS, spectral amplitude increases) are observed in a variety of narrow frequency bands (4-40 Hz) which are systematically dependent on task and cognitive state variables as well as on stimulus parameters. Makeig (1993) was reported event-related changes in the full EEG spectrum, yielding a 2-D time/frequency measure he called the event-related spectral perturbation (ERSP). This method avoided problems associated with analysis of a priori narrow frequency bands, since bands of interest for the analysis could be based on significant features of the complete time/frequency transform. Rappelsburger et al. introduced event-related coherence (ERCOH). A wide variety of other signal processing measures have been tested for use on EEG and/or MEG data, including dimensionality measures based on chaos theory and the bispectrum. Use of neural networks has also been proposed for EEG pattern recognition applied to clinical and practical problems, though usually these methods have not been employed with an aim of explicitly modeling the neurodynamics involved. Neurodynamics is the mobilization of the nervous system as an approach to physical treatment. The method relies on influencing pain and other neural physiology via mechanical treatment of neural tissues and the non-neural structures surrounding the nervous system. The body presents the nervous system with a mechanical interface via the musculoskeletal system. With movement, the musculoskeletal system exerts non-uniform stresses and movement in neural tissues, depending on the local anatomical and mechanical characteristics and the pattern of body movement. This activates an array of mechanical and physiological responses in neural tissues. These responses include neural sliding, pressurization, elongation, tension and changes in intraneural microcirculation, axonal transport and impulse traffic.

The availability of and interest in larger and larger numbers of EEG (and MEG) channels led immediately to the

question of how to combine data from different channels. Donchin advocated the use of linear factor analysis methods based on principal component analysis (PCA) for this purpose. Temporal PCA assumes that the time course of activation of each derived component is the same in all data conditions. Because this is unreasonable for many data sets, spatial PCA (usually followed by a component rotation procedure such as Varimax or Promax) is of potentially greater interest. To this end, several variants of PCA have been proposed for ERP decomposition.

Bell and Sejnowski published an iterative algorithm based on information theory for decomposing linearly mixed signals into temporally independent by minimizing their mutual information. First approaches to blind source separation minimized third and fourth-order correlations among the observed variables and achieved limited success in simulations. A generalized approach uses a simple neural network algorithm that used joint information maximization or 'infomax' as a training criterion. By using a compressive nonlinearity to transform the data and then following the entropy gradient of the resulting mixtures, ten recorded voice and music sound sources were unmixed. A similar approach was used for performing blind deconvolution, and the 'infomax' method was used for decomposition of visual scenes.

EEG source analysis may be accomplished using various techniques. Grech, Roberta, Tracey Cassar, Joseph Muscat, Kenneth P. Camilleri, Simon G. Fabri, Michalis Zervakis, Petros Xanthopoulos, Vangelis Sakkalis, and Bart Vanrumste. "Review on solving the inverse problem in EEG source analysis." Journal of neuroengineering and rehabilitation 5, no. 1 (2008): 25.

The first applications of blind decomposition to biomedical time series analysis applied the infomax independent component analysis (ICA) algorithm to decomposition of EEG and event-related potential (ERP) data and reported the use of ICA to monitor alertness. This separated artifacts, and EEG data into constituent components defined by spatial stability and temporal independence. ICA can also be used to remove artifacts from continuous or event-related (single-trial) EEG data prior to averaging. Vigario et al. (1997), using a different ICA algorithm, supported the use of ICA for identifying artifacts in MEG data. Meanwhile, widespread interest in ICA has led to multiple applications to biomedical data as well as to other fields (Jung et al., 2000b). Most relevant to EEG/MEG analysis, ICA is effective in separating functionally independent components of functional magnetic resonance imaging (fMRI) data

Since the publication of the original infomax ICA algorithm, several extensions have been proposed. Incorporation of a ‘natural gradient’ term avoided matrix inversions, greatly speeding the convergence of the algorithm and making it practical for use with personal computers on large data EEG and fMRI data sets. An initial ‘sphering’ step further increased the reliability of convergence of the algorithm. The original algorithm assumed that sources have ‘sparse' (super-Gaussian) distributions of activation values. This restriction has recently been relaxed in an ‘extended-ICA’ algorithm that allows both super-Gaussian and sub-Gaussian sources to be identified. A number of variant ICA algorithms have appeared in the signal processing literature. In general, these make more specific assumptions about the temporal or spatial structure of the components to be separated, and typically are more

computationally intensive than the infomax algorithm.

Since individual electrodes (or magnetic sensors) each record a mixture of brain and non-brain sources, spectral measures are difficult to interpret and compare across scalp channels. For example, an increase in coherence between two electrode signals may reflect the activation of a strong brain source projecting to both electrodes, or the deactivation of a brain generator projecting mainly to one of the electrodes. If independent components of the EEG (or MEG) data can be considered to measure activity within functionally distinct brain networks, however, event-related coherence between independent components may reveal transient, event-related changes in their coupling and decoupling (at one or more EEG/MEG frequencies). ERCOH analysis has been applied to independent EEG components in a selective attention task.

Relational Database A database management system (DBMS) is the software which controls the storage, retrieval, deletion, security, and integrity of data within a database. A relational database management system (BDBMS) stores data in tables. Tables are organized into columns, and each column stores one type of data (integer, real number, character strings, date, …). The data for a single "instance" of a table is stored as a row. For example, an emotional neural correlate table would have columns such as EmotionLabel, NeuralCorrelate1_under_condition1, NeuralCorrelate2_under_condition2, NeuralCorrelate3_under_condition3, NeuralCorrelate4_under_condition4, etc. Tables typically have keys, one or more columns that uniquely identify a row within the table, in the case of the Emlational neural correlate table the key would be EmotionLabel. To improve access time to a data table an index on the table is defined. An index provides a quick way to look up data based on one or more columns in the table. The most common use of RDBMSs is to implement simple Create, Read, Update, and Delete. A relational database may be manipulated using Structured Query Language (SQL) statements. en.wikipedia.org/wiki/Relational_database. The relational database may be a SQL or noSQL database.

SUMMARY OF THE INVENTION

In other embodiments, the processing of the brain activity patterns does not seek to classify or characterize it, but rather to filter and transform the information to a form suitable for control of the stimulation of the second subject. In particular, according to this embodiment, the subtleties that are not yet reliably classified in traditional brain activity pattern analysis are respected. For example, it is understood that all brain activity is reflected in synaptic currents and other neural modulation and, therefore, theoretically, conscious and subconscious information is, in theory, accessible through brain activity pattern analysis. Since the available processing technology generally fails to distinguish a large number of different brain activity patterns, that available processing technology, is necessarily deficient, but improving. However, just because a computational algorithm is unavailable to extract the information, does not mean that the information is absent. Therefore, this embodiment employs relatively raw brain activity pattern data, such as filtered or unfiltered EEGs, to control the stimulation of the second subject, without a full comprehension or understanding of exactly what information of significance is present. In one embodiment, brainwaves are recorded and "played back" to another subject, similar to recoding and playing back music. Such recording-playback may be digital or analog. Typically, the stimulation may include a low dimensionality stimulus, such as stereo-optic, binaural, isotonic tones, tactile, or other sensory stimulation, operating bilaterally, and with control over frequency and phase and/or waveform and/or transcranial stimulation such as TES, tDCS, HD-tDCS, tACS, or TMS. A plurality of different types of stimulation may be applied concurrently, e.g., visual, auditory, other sensory, magnetic, electrical.

Likewise, a present lack of understanding of the essential characteristics of the signal components in the brain activity patterns does not prevent their acquisition, storage, communication, and processing (to some extent). The stimulation may be direct, i.e., a visual, auditory, or tactile stimulus corresponding to the brain activity pattern, or a derivative or feedback control based on the second subject's brain activity pattern.

To address the foregoing problems, in whole or in part, and/or other problems that may have been observed by persons skilled in the art, the present disclosure provides methods, processes, systems, apparatus, instruments, and/or devices, as described by way of example in implementations set forth below.

While mental states are typically considered internal to the individual, and subjective, in fact, such states are common across individuals and have determinable physiological and electrophysiological population characteristics. Further, mental states may be externally changed or induced in a manner that bypasses the normal cognitive processes. In some cases, the triggers for the mental state are subjective, and therefore the particular subject-dependent sensory or excitation scheme required to induce a particular state will differ. For example, olfactory stimulation can have different effects on different people, based on differences in history of exposure, social and cultural norms, and the like. On the other hand, some mental state response triggers are normative, for example "tear jerker" media.

Mental states are represented in brainwave patterns, and in normal humans, the brainwave patterns and

metabolic (e.g. blood flow, oxygen consumption, etc.) follow prototypical patterns. Therefore, by monitoring brainwave patterns in an individual, a state or series of mental states in that person may be determined or estimated. However, the brainwave patterns may be interrelated with context, other activity, and past history. Further, while prototypical patterns may be observed, there are also individual variations in the patterns. The brainwave patterns may include characteristic spatial and temporal patterns indicative of mental state. The brainwave signals of a person may be processed to extract these patterns, which, for example, may be represented as hemispheric signals within a frequency range of 3-100 Hz. These signals may then be synthesized or modulated into one or more stimulation signals, which are then employed to induce a corresponding mental state into a recipient, in a manner seeking to achieve a similar brainwave pattern from the source. The brainwave pattern to be introduced need not be newly acquired for each case. Rather, signals may be acquired from one or more individuals, to obtain an exemplar for various respective mental state. Once determined, the processed signal representation may be stored in a non-volatile memory for later use. However, in cases of complex interaction between a mental state and a context or content or activity, it may be appropriate to derived the signals from a single individual whose context or content-environment or activity is appropriate for the circumstances. Further, in some cases, a single mental state, emotion or mood is not described or fully characterized, and therefore acquiring signals from a source is an efficient exercise.

With a library of target brainwave patterns, a system and method is provided in which a target subject may be immersed in a presentation, which includes not only multimedia content, but also a series of defined mental states, emotional states or moods that accompany the multimedia content. In this way, the multimedia presentation becomes fully immersive. The stimulus in this case may be provided through a headset, such as a virtual reality or augmented reality headset. This headset is provided with a stereoscopic display, binaural audio, and a set of EEG and transcranial stimulatory electrodes. These electrodes (if provided) typically deliver a subthreshold signal, which is not painful, which is typically an AC signal which corresponds to the desired frequency, phase, and spatial location of the desired target pattern. The electrodes may also be used to counteract undesired signals, by destructively interfering with them while concurrently imposing the desired patterns. The headset may also generate visual and/or auditory signals which correspond to the desired state. For example, the auditory signals may induce binaural beats, which cause brainwave entrainment. The visual signals may include intensity fluctuations or other modulation patterns, especially those which are subliminal, that are also adapted to cause brainwave entrainment or induction of a desired brainwave pattern.

The headset preferably includes EEG electrodes for receiving feedback from the user. That is, the stimulatory system seeks to achieve a mental state, emotion or mood response from the user. The EEG electrodes permit determination of whether that state is achieved, and if not, what the current state is. It may be that achieving a desired brainwave pattern is state dependent, and therefore that characteristics of the stimulus to achieve a desired state depend on the starting state of the subject. Other ways of determining mental state, emotion, or mood include

analysis of facial expression, electromyography (EMG) analysis of facial muscles, explicit user feedback, etc.

An authoring system is provided which permits a content designer to determine what mental states are desired, and then encode those states into media, which is then interpreted by a media reproduction system in order to generate appropriate stimuli. As noted above, the stimuli may be audio, visual, multimedia, other senses, or electrical or magnetic brain stimulation, and therefore a VR headset with transcranial electrical or magnetic stimulation is not required. Further, in some embodiments, the patterns may be directly encoded into the audiovisual content, subliminally encoded.

In some cases, the target mental state may be derived from an expert, actor or professional exemplar. The states may be read based on facial expressions, EMG, EEG, or other means, from the actor or exemplar. For example, a prototype exemplar engages in an activity that triggers a response, such as viewing the Grand Canyon or artworks within the Louvre. The responses of the exemplar are then recorded or represented, and preferably brainwave patterns recorded that represent the responses. A representation of the same experience is then presented to the target, with a goal of the target also experiencing the same experience as the exemplar. This is typically a voluntary and disclosed process, so the target will seek to willingly comply with the desired experiences. In some cases, the use of the technology is not disclosed to the target, for example in advertising presentations or billboards. In order for an actor to serve as the exemplar, the emotions achieved by that person must be authentic. However, so-called “method actors” do authentically achieve the emotions they convey. However, in some cases, for example where facial expressions are used as the indicator of mental state, an actor can present desired facial expressions with inauthentic mental states. The act of making a face corresponding to an emotion often achieves the targeted mental state.

In order to calibrate the system, the brain pattern of a person may be measured while in the desired state. The brain patterns acquired for calibration or feedback need not be of the same quality, or precision, or data depth, and indeed may represent responses rather than primary indicia. That is, there may be some asymmetry in the system, between the brainwave patterns representative of a mental state, and the stimulus patterns appropriate for inducing the brain state.

The present invention generally relates to achieving a mental state in a subject by conveying to the brain of the subject patterns of brainwaves. These brainwaves may be artificial or synthetic, or derived from the brain of a second subject (e.g., a person experiencing an authentic experience or engaged in an activity). Typically, the wave patterns of the second subject are derived while the second subject is experiencing an authentic experience.

A special case is where the first and second subjects are the same individual. For example, brainwave patterns are recorded while a subject is in a particular mental state. That same pattern may assist in achieving the same mental state at another time. Thus, there may be a time delay between acquisition of the brainwave information from the second subject, and exposing the first subject to corresponding stimulation. The signals may be recorded and transmitted.

The temporal pattern may be conveyed or induced non-invasively via light (visible or infrared), sound (or ultrasound), transcranial direct or alternating current stimulation (tDCS or tACS), transcranial magnetic stimulation (TMS), Deep transcranial magnetic stimulation (Deep TMS, or dTMS), Repetitive Transcranial Magnetic Stimulation (rTMS) olfactory stimulation, tactile stimulation, or any other means capable of conveying frequency patterns. In a preferred embodiment, normal human senses are employed to stimulate the subject, such as light, sound, smell and touch. Combinations of stimuli may be employed. In some cases, the stimulus or combination is innate, and therefore largely pan-subject. In other cases, response to a context is learned, and therefore subject-specific. Therefore, feedback from the subject may be appropriate to determine the triggers and stimuli appropriate to achieve a mental state.

This technology may be advantageously used to enhance mental response to a stimulus or context. Still another aspect provides for a change in the mental state. The technology may be used in humans or animals.

The present technology may employ an event-correlated EEG time and/or frequency analysis performed on neuronal activity patterns. In a time-analysis, the signal is analyzed temporally and spatially, generally looking for changes with respect to time and space. In a frequency analysis, over an epoch of analysis, the data, which is typically a time-sequence of samples, is transformed, using e.g., a Fourier transform (FT, or one implementation, the Fast Fourier Transform, FFT), into a frequency domain representation, and the frequencies present during the epoch are analyzed. The window of analysis may be rolling, and so the frequency analysis may be continuous. In a hybrid time-frequency analysis, for example, a wavelet analysis, the data during the epoch is transformed using a “wavelet transform”, e.g., the Discrete Wavelet Transform (DWT) or continuous wavelet transform (CWT), which has the ability to construct a time-frequency representation of a signal that offers very good time and frequency localization. Changes in transformed data over time and space may be analyzed. In general, the spatial aspect of the brainwave analysis is anatomically modelled. In most cases, anatomy is considered universal, but in some cases, there are significant differences. For example, brain injury, psychiatric disease, age, race, native language, training, sex, handedness, and other factors may lead to distinct spatial arrangement of brain function, and therefore when transferring mood from one individual to another, it is preferred to normalize the brain anatomy of both individuals by experiencing roughly the same experiences, and measuring spatial parameters of the EEG or MEG. Note that spatial organization of the brain is highly persistent, absent injury or disease, and therefore this need only be performed infrequently. However, since electrode placement may be inexact, a spatial calibration may be performed after electrode placement.

Different aspects of EEG magnitude and phase relationships may be captured, to reveal details of the neuronal activity. The “time-frequency analysis” reveals the brain’s parallel processing of information, with oscillations at various frequencies within various regions of the brain reflecting multiple neural processes co-occurring and interacting. See, Lisman J, Buzsaki G. A neural coding scheme formed by the combined function of gamma and theta oscillations.

Schizophr Bull. June 16, 2008; doi:10.1093/schbul/sbn060. Such a time-frequency analysis may take the form of a wavelet transform analysis. This may be used to assist in integrative and dynamically adaptive information processing. Of course, the transform may be essentially lossless and may be performed in any convenient information domain representation. These EEG-based data analyses reveal the frequency-specific neuronal oscillations and their synchronization in brain functions ranging from sensory processing to higher-order cognition. Therefore, these patterns may be selectively analyzed, for transfer to or induction in, a subject.

A statistical clustering analysis may be performed in high dimension space to isolate or segment regions which act as signal sources, and to characterize the coupling between various regions. This analysis may also be used to establish signal types within each brain region, and decision boundaries characterizing transitions between different signal types. These transitions may be state dependent, and therefore the transitions may be detected based on a temporal analysis, rather than merely a concurrent oscillator state.

The various measures make use of the magnitude and/or phase angle information derived from the complex data extracted from the EEG during spectral decomposition and/or temporal/spatial/spectral analysis. Some measures estimate the magnitude or phase consistency of the EEG within one channel across trials, whereas others estimate the consistency of the magnitude or phase differences between channels across trials. Beyond these two families of calculations, there are also measures that examine the coupling between frequencies, within trials and recording sites. Of course, in the realm of time-frequency analysis, many types of relationships can be examined beyond those already mentioned.

These sensory processing specific neuronal oscillations, e.g., brainwave patterns, e.g., of a subject (a “source”) or to a person trained (for example, an actor trained in “the method”) to create a desired state, and can be stored on a tangible medium and/or can be simultaneously conveyed to a recipient making use of the brain’s frequency following response nature. See, Galbraith, Gary C., Darlene M. Olfman, and Todd M. Huffman. “Selective attention affects human brain stem frequency-following response.” Neuroreport 14, no. 5 (2003): 735-738, journals.lww.com/neuroreport/Abstract/2003/04150/Selective_attention_affects_human_brain_stem.15.aspx.

Of course, in some cases, one or more components of the stimulation of the target subject (recipient) may be represented as abstract or semantically defined signals, and, more generally, the processing of the signals to define the stimulation will involve high level modulation or transformation between the source signal received from the first subject (donor) or plurality of donors, to define the target signal for stimulation of the second subject (recipient).

Preferably, each component represents a subset of the neural correlates reflecting brain activity that have a high autocorrelation in space and time, or in a hybrid representation such as wavelet. These may be separated by optimal filtering (e.g., spatial PCA), once the characteristics of the signal are known, and bearing in mind that the signal is accompanied by a modulation pattern, and that the two components themselves may have some weak coupling and interaction.

For example, if the first subject (donor) is listening to music, there will be significant components of the neural correlates that are synchronized with the particular music. On the other hand, the music per se may not be part of the desired stimulation of the target subject (recipient). Further, the target subject (recipient) may be in a different acoustic environment, and it may be appropriate to modify the residual signal dependent on the acoustic environment of the recipient, so that the stimulation is appropriate for achieving the desired effect, and does not represent phantoms, distractions, or irrelevant or inappropriate content. In order to perform signal processing, it is convenient to store the signals or a partially processed representation, though a complete real-time signal processing chain may be implemented.

The stimulation may be one or more stimulus applied to the second subject (trainee or recipient), which may be an electrical or magnetic transcranial stimulation (tDCS, HD-tDCS, tACS, osc-tDCS, or TMS), sensory stimulation (e.g., visual, auditory, or tactile), mechanical stimulation, ultrasonic stimulation, etc., and controlled with respect to waveform, frequency, phase, intensity/amplitude, duration, or controlled via feedback, self-reported effect by the second subject, manual classification by third parties, automated analysis of brain activity, behavior, physiological parameters, etc. of the second subject (recipient).

Typically, the first and the second subjects are spatially remote from each other and may be temporally remote as well. In some cases, the first and second subject are the same subject (human or animal), temporally displaced. In other cases, the first and the second subject are spatially proximate to each other. These different embodiments differ principally in the transfer of the signal from at least one first subject (donor) to the second subject (recipient). However, when the first and the second subjects share a common environment, the signal processing of the neural correlates and, especially of real-time feedback of neural correlates from the second subject, may involve interactive algorithms with the neural correlates of the first subject.

According to another embodiment, the first and second subjects are each subject to stimulation. In one particularly interesting embodiment, the first subject and the second subject communicate with each other in real-time, with the first subject receiving stimulation based on the second subject, and the second subject receiving feedback based on the first subject. This can lead to synchronization of neural correlates (e.g., neuronal oscillations, or brainwaves) and, consequently, of emotional or mental state between the two subjects. The neural correlates may be neuronal oscillations resulting in brainwaves that are detectable as, for example, EEG, qEEG, or MEG signals. Traditionally, these signals are found to have dominant frequencies, which may be determined by various analyses, such as spectral analysis, wavelet analysis, or principal component analysis (PCA), for example. One embodiment provides that the modulation pattern of a brainwave of at least one first subject (donor) is determined independent of the dominant frequency of the brainwave (though, typically, within the same class of brainwaves), and this modulation imposed on a brainwave corresponding to the dominant frequency of the second subject (recipient). That is, once the second subject achieves that same brainwave pattern as the first subject (which may be achieved by means other

than electromagnetic, mechanical, or sensory stimulation), the modulation pattern of the first subject is imposed as a way of guiding the emotional or mental state of the second subject.

According to another embodiment, the second subject (recipient) is stimulated with a stimulation signal, which faithfully represents the frequency composition of a defined component of the neural correlates of at least one first subject (donor). The defined component may be determined based on a principal component analysis, independent component analysis (ICI), eigenvector-based multivariable analysis, factor analysis, canonical correlation analysis (CCA), nonlinear dimensionality reduction (NLDR), or related technique.

The stimulation may be performed, for example, by using a TES device, such as a tDCS device, a high-definition tDCS device, an osc-tDCS device, a pulse-tDCS ("electrosleep") device, an osc-tDCS, a tACS device, a CES device, a TMS device, rTMS device, a deep TMS device, a light source, or a sound source configured to modulate the dominant frequency on respectively the light signal or the sound signal. The stimulus may be a light signal, a sonic signal (sound), an electric signal, a magnetic field, olfactory or a tactile stimulation. The current signal may be a pulse signal or an oscillating signal. The stimulus may be applied via a cranial electric stimulation (CES), a transcranial electric stimulation (TES), a deep electric stimulation, a transcranial magnetic stimulation (TMS), a deep magnetic stimulation, a light stimulation, a sound stimulation, a tactile stimulation, or an olfactory stimulation. An auditory stimulus may be, for example, binaural beats or isochronic tones.

The technology also provides a processor configured to process the neural correlates of emotional or mental state from the first subject (donor), and to produce or define a stimulation pattern for the second subject (recipient) selectively dependent on a waveform pattern of the neural correlates from the first subject. The processor may also perform a PCA, a spatial PCA, an independent component analysis (ICA), eigenvalue decomposition, eigenvector-based multivariate analyses, factor analysis, an autoencoder neural network with a linear hidden layer, linear discriminant analysis, network component analysis, nonlinear dimensionality reduction (NLDR), or another statistical method of data analysis.

A signal is presented to a second apparatus, configured to stimulate the second subject (recipient), which may be an open loop stimulation dependent on a non-feedback-controlled algorithm, or a closed loop feedback dependent algorithm. The second apparatus produces a stimulation intended to induce in the second subject (recipient) the desired emotional or mental state).

A typically process performed on the neural correlates is a filtering to remove noise. In some embodiments, noise filters may be provided, for example, at 50 Hz, 60 Hz, 100 Hz, 120 Hz, and additional overtones (e.g., tertiary and higher harmonics). The stimulator associated with the second subject (recipient) would typically perform decoding, decompression, decryption, inverse transformation, modulation, etc.

Alternately, an authentic wave or hash thereof may be authenticated via a blockchain, and thus authenticatable by an immutable record. In some cases, it is possible to use the stored encrypted signal in its encrypted form, without

decryption.

Due to different brain sizes, and other anatomical, morphological, and/or physiological differences, dominant frequencies associated with the same emotional or mental state may be different in different subjects. Consequently, it may not be optimal to forcefully impose on the recipient the frequency of the donor that may or may not precisely correspond to the recipient's frequency associated with the same emotional or mental state. Accordingly, in some embodiments, the donor's frequency may be used to start the process of inducing the desired emotional or mental state in a recipient. As some point, when the recipient is close to achieving the desired emotional or mental state, the stimulation is either stopped or replaced with neurofeedback allowing the brain of the recipient to find its own optimal frequency associated with the desired emotional or mental state.

In one embodiment, the feedback signal from the second subject may be correspondingly encoded as per the source signal, and the error between the two minimized. According to one embodiment, the processor may perform a noise reduction distinct from a frequency-band filtering. According to one embodiment, the neural correlates are transformed into a sparse matrix, and in the transform domain, components having a high probability of representing noise are masked, while components having a high probability of representing signal are preserved. That is, in some cases, the components that represent modulation that are important may not be known a priori. However, dependent on their effect in inducing the desired response in the second subject (recipient), the "important" components may be identified, and the remainder filtered or suppressed. The transformed signal may then be inverse-transformed and used as a basis for a stimulation signal.

According to another embodiment, a method of emotional or mental state modification, e.g., brain entrainment, is provided, comprising: ascertaining an emotional or mental state in a plurality of first subjects (donors); acquiring brainwaves of the plurality of first subjects (donors), e.g., using one of EEG and MEG, to create a dataset containing brainwaves corresponding to different emotional or mental states. The database may be encoded with a classification of emotional or mental states, activities, environment, or stimulus patterns, applied to the plurality of first subjects, and the database may include acquired brainwaves across a large number of emotional or mental states, activities, environment, or stimulus patterns, for example. In many cases, the database records will reflect a characteristic or dominate frequency of the respective brainwaves.

The record(s) thus retrieved are used to define a stimulation pattern for the second subject (recipient). As a relatively trivial example, a female recipient could be stimulated principally based on records from female donors. Similarly, a child recipient of a certain age could be stimulated principally based on the records from children donors of a similar age. Likewise, various demographic, personality, and/or physiological parameters may be matched to ensure a high degree of correspondence to between the source and target subjects. In the target subject, a guided or genetic algorithm may be employed to select modification parameters from the various components of the signal, which best achieve the desired target state based on feedback from the target subject.

Of course, a more nuanced approach is to process the entirety of the database and stimulate the second subject based on a global brainwave-stimulus model, though this is not required, and also, the underlying basis for the model may prove unreliable or inaccurate. In fact, it may be preferred to derive a stimulus waveform from only a single first subject (donor), in order to preserve micro-modulation aspects of the signal, which, as discussed above, have not been fully characterized. However, the selection of the donor(s) need not be static and can change frequently. The selection of donor records may be based on population statistics of other users of the records, i.e., whether or not the record had the expected effect, filtering donors whose response pattern correlates highest with a given recipient, etc. The selection of donor records may also be based on feedback patterns from the recipient.

The process of stimulation typically seeks to target a desired emotional or mental state in the recipient, which is automatically or semi-automatically determined or manually entered. In one embodiment, the records are used to define a modulation waveform of a synthesized carrier or set of carriers, and the process may include a frequency domain multiplexed multi-subcarrier signal (which is not necessarily orthogonal). A plurality of stimuli may be applied concurrently, through the different subchannels and/or though different stimulator electrodes, electric current stimulators, magnetic field generators, mechanical stimulators, sensory stimulators, etc. The stimulus may be applied to achieve brain entrainment (i.e., synchronization) of the second subject (recipient) with one or more first subjects (donors). If the plurality of donors is mutually entrained, then each will have a corresponding brainwave pattern dependent on the basis of brainwave entrainment. This link between donors may be helpful in determining compatibility between a respective donor and the recipient. For example, characteristic patterns in the entrained brainwaves may be determined, even for different target emotional or mental states, and the characteristic patterns may be correlated to find relatively close matches and to exclude relatively poor matches.

This technology may also provide a basis for a social network, dating site, employment, mission (e.g., space or military), or vocational testing, or other interpersonal environments, wherein people may be matched with each other based on entrainment characteristics. For example, people who efficiently entrain with each other may have better compatibility and, therefore, better marriage, work, or social relationships than those who do not. The entrainment effect need not be limited to emotional or mental states, and may arise across any context.

As discussed above, the plurality of first subjects (donors) may have their respective brainwave patterns stored in separate database records. Data from a plurality of first subjects (donors) is used to train the neural network, which is then accessed by inputting the target stage and/or feedback information, and which outputs a stimulation pattern or parameters for controlling a stimulator(s). When multiple first subject (donors) form the basis for the stimulation pattern, it is preferred that the neural network output parameters of the stimulation, derived from and comprising features of the brainwave patterns or other neural correlates of the emotional or mental state from the plurality of first subject (donors), which are then used to control a stimulator which, for example, generates its own carrier wave(s) which are then modulated based on the output of the neural network. A trained neural network need not periodically

retrieve records, and therefore may operate in a more time-continuous manner, rather than the more segmented scheme of record-based control.

In any of the feedback dependent methods, the brainwave patterns or other neural correlates of emotional or mental states may be processed by a neural network, to produce an output that guides or controls the stimulation. The stimulation is, for example, at least one of a light signal, a sound signal, an electric signal, a magnetic field, an olfactory signal, a chemical signal, and a vibration or mechanical stimulus. The process may employ a relational database of emotional or mental states and brainwave patterns, e.g., frequencies/neural correlate waveform patterns associated with the respective emotional or mental states. The relational database may comprise a first table, the first table further comprising a plurality of data records of brainwave patterns, and a second table, the second table comprising a plurality of emotional or mental states, each of the emotional or mental states being linked to at least one brainwave pattern. Data related to emotional or mental states and brainwave patterns associated with the emotional or mental states are stored in the relational database and maintained. The relational database is accessed by receiving queries for selected (existing or desired) emotional or mental states, and data records are returned representing the associated brainwave pattern. The brainwave pattern retrieved from the relational database may then be used for modulating a stimulator seeking to produce an effect selectively dependent on the desired emotional or mental state.

A further aspect of the technology provides a computer apparatus for creating and maintaining a relational database of emotional or mental states and frequencies associated with the emotional or mental state. The computer apparatus may comprise a non-volatile memory for storing a relational database of emotional or mental states and neural correlates of brain activity associated with the emotional or mental states, the database comprising a first table comprising a plurality of data records of neural correlates of brain activity associated with the emotional or mental states, and a second table comprising a plurality of emotional or mental states, each of the emotional or mental states being linked to one or more records in the first table; a processor coupled with the non-volatile memory, and being configured to process relational database queries, which are then used for searching the database; RAM coupled with the processor and the non-volatile memory for temporary holding database queries and data records retrieved from the relational database; and an IO interface configured to receive database queries and deliver data records retrieved from the relational database. A structured query language (SQL) or alternate to SQL (e.g., noSQL) database may also be used to store and retrieve records. A relational database described above maintained and operated by a general-purpose computer, improves the operations of the general-purpose computer by making searches of specific emotional or mental states and brainwaves associated therewith more efficient thereby, inter alia, reducing the demand on computing power.

A further aspect of the technology provides a method of brain entrainment comprising: ascertaining an emotional or mental state in at least one first subject (donor), recording brainwaves of said at least one first subject (donor) using

at least one channel of EEG and/or MEG; storing the recorded brainwaves in a physical memory device, retrieving the brainwaves from the memory device, applying a stimulus signal comprising a brainwave pattern derived from at least one-channel of the EEG and/or MEG to a second subject (recipient) via transcranial electrical and/or magnetic stimulation, whereby the emotional or mental state desired by the second subject (recipient) is achieved. The stimulation may be of the same dimension (number of channels) as the EEG or MEG, or a different number of channels, typically reduced. For example, the EEG or MEG may comprise 64, 128 or 256 channels, while the transcranial stimulator may have 32 or fewer channels. The placement of electrodes used for transcranial stimulation may be approximately the same as the placement of electrodes used in recording of EEG or MEG to preserve the topology of the recorded signals and, possibly, use these signals for spatial modulation.

One of the advantages of transforming the data is the ability to select a transform that separates the information of interest represented in the raw data, from noise or other information. Some transforms preserve the spatial and state transition history, and may be used for a more global analysis. Another advantage of a transform is that it can present the information of interest in a form where relatively simple linear or statistical functions of low order may be applied. In some cases, it is desired to perform an inverse transform on the data. For example, if the raw data includes noise, such as 50 or 60 Hz interference, a frequency transform may be performed, followed by a narrow band filtering of the interference and its higher order intermodulation products. An inverse transform may be performed to return the data to its time-domain representation for further processing. (In the case of simple filtering, a finite impulse response (FIR) or infinite impulse response (IIR) filter could be employed). In other cases, the analysis is continued in the transformed domain.

Transforms may be part of an efficient algorithm to compress data for storage or analysis, by making the representation of the information of interest consume fewer bits of information (if in digital form) and/or allow it to be communication using lower bandwidth. Typically, compression algorithms will not be lossless, and as a result, the compression is irreversible with respect to truncated information.

Typically, the transformation(s) and filtering of the signal are conducted using traditional computer logic, according to defined algorithms. The intermediate stages may be stored and analyzed. However, in some cases, neural networks or deep neural networks may be used, convolutional neural network architectures, or even analog signal processing. According to one set of embodiments, the transforms (if any) and analysis are implemented in a parallel processing environment. Such as using an SIMD processor such as a GPU (or GPGPU). Algorithms implemented in such systems are characterized by an avoidance of data-dependent branch instructions, with many threads concurrently executing the same instructions.

EEG signals are analyzed to determine the location (e.g., voxel or brain region) from which an electrical activity pattern is emitted, and the wave pattern characterized. The spatial processing of the EEG signals will typically precede the content analysis, since noise and artifacts may be useful for spatial resolution. Further, the signal from

one brain region will typically be noise or interference in the signal analysis from another brain region; so the spatial analysis may represent part of the comprehension analysis. The spatial analysis is typically in the form of a geometrically and/or anatomically-constrained statistical model, employing all of the raw inputs in parallel. For example, where the input data is transcutaneous electroencephalogram information, from 32 EEG electrodes, the 32 input channels, sampled at e.g., 500 sps, 1 ksps or 2 ksps, are processed in a four or higher dimensional matrix, to permit mapping of locations and communication of impulses over time, space and state.

The matrix processing may be performed in a standard computing environment, e.g., an i7-7920HQ, i7-8700K, or i9-7980XE processor, under the Windows 10 operating system, executing MatLab (MathWorks, Woburn MA) software platform. Alternately, the matrix processing may be performed in a computer cluster or grid or cloud computing environment. The processing may also employ parallel processing, in either a distributed and loosely coupled environment, or asynchronous environment. One preferred embodiment employs a single instruction, multiple data processors, such as a graphics processing unit such as the nVidia CUDA environment or AMD Firepro high-performance computing environment.

Artificial intelligence (AI) and machine learning methods, such as artificial neural networks, deep neural networks, etc., may be implemented to extract the signals of interest. Neural networks act as an optimized statistical classifier and may have arbitrary complexity. A so-called deep neural network having multiple hidden layers may be employed. The processing is typically dependent on labeled training data, such as EEG data, or various processed, transformed, or classified representations of the EEG data. The label represents the emotion, mood, context, or state of the subject during acquisition. In order to handle the continuous stream of data represented by the EEG, a recurrent neural network architecture may be implemented. Depending preprocessing before the neural network, formal implementations of recurrence may be avoided. A four or more dimensional data matrix may be derived from the traditional spatial-temporal processing of the EEG and fed to a neural network. Since the time parameter is represented in the input data, a neural network temporal memory is not required, though this architecture may require a larger number of inputs. Principal component analysis (PCA, en.wikipedia.org/wiki/Principal_component_analysis), spatial PCA (arxiv.org/pdf/1501.03221v3.pdf, adegenet.r-forge.r-project.org/files/tutorial-spca.pdf, www.ncbi.nlm.nih.gov/pubmed/1510870); and clustering analysis may also be employed (en.wikipedia.org/wiki/Cluster_analysis, see US 9,336,302, 9,607,023 and cited references).

In general, a neural network of this type of implementation will, in operation, be able to receive unlabeled EEG data, and produce the output signals representative of the predicted or estimated task, performance, context, or state of the subject during acquisition of the unclassified EEG. Of course, statistical classifiers may be used rather than neural networks.

The analyzed EEG, either by conventional processing, neural network processing, or both, serves two purposes. First, it permits one to deduce which areas of the brain are subject to which kinds of electrical activity under which

conditions. Second, it permits feedback during training of a trainee (assuming proper spatial and anatomical correlates between the trainer and trainee), to help the system achieve the desired state, or as may be appropriate, desired series of states and/or state transitions. According to one aspect of the technology, the applied stimulation is dependent on a measured starting state or status (which may represent a complex context and history dependent matrix of parameters), and therefore the target represents a desired complex vector change. Therefore, this aspect of the technology seeks to understand a complex time-space-brain activity associated with an activity or task in a trainer, and to seek a corresponding complex time-space-brain activity associated with the same activity or task in a trainee, such that the complex time-space-brain activity state in the trainer is distinct from the corresponding state sought to be achieved in the trainee. This permits transfer of training paradigms from qualitatively different persons, in different contexts, and, to some extent, to achieve a different result.

The conditions of data acquisition from the trainer will include both task data, and sensory-stimulation data. That is, a preferred application of the system is to acquire EEG data from a trainer or skilled individual, which will then be used to transfer learning, or more likely, learning readiness states, to a naïve trainee. The goal for the trainee is to produce a set of stimulation parameters that will achieve, in the trainee, the corresponding neural activity resulting in the EEG state of the trainer at the time of or preceding the learning of a skill or a task, or performance of the task.

It is noted that EEG is not the only neural or brain activity or state data that may be acquired, and of course any and all such data may be included within the scope of the technology, and therefore EEG is a representative example only of the types of data that may be used. Other types include fMRI, magnetoencephalogram, motor neuron activity, PET, etc.

While mapping the stimulus-response patterns distinct from the task is not required in the trainer, it is advantageous to do so, because the trainer may be available for an extended period, the stimulus of the trainee may influence the neural activity patterns, and it is likely that the trainer will have correlated stimulus-response neural activity patterns with the trainee(s). It should be noted that the foregoing has suggested that the trainer is a single individual, while in practice, the trainer may be a population of trainers or skilled individuals. The analysis and processing of brain activity data may, therefore, be adaptive, both for each respective individual and for the population as a whole.

For example, the system may determine that not all human subjects have common stimulus-response brain activity correlates, and therefore that the population needs to be segregated and clustered. If the differences may be normalized, then a normalization matrix or other correction may be employed. On the other hand, if the differences do not permit feasible normalization, the population(s) may be segmented, with different trainers for the different segments. For example, in some tasks, male brains have different activity patterns and capabilities than female brains. This, coupled with anatomical differences between the sexes, implies that the system may provide gender-specific implementations. Similarly, age differences may provide a rational and scientific basis for segmentation of the

population. However, depending on the size of the information base and matrices required, and some other factors, each system may be provided with substantially all parameters required for the whole population, with a user-specific implementation based on a user profile or initial setup, calibration, and system training session.

According to one aspect of the present invention, a source subject is instrumented with sensors to determine localized brain activity during experiencing an event. The objective is to identify regions of the brain involved in processing this response.

The sensors will typically seek to determine neuron firing patterns and brain region excitation patterns, which can be detected by implanted electrodes, transcutaneous electroencephalograms, magnetoencephalograms, fMRI, and other technologies. Where appropriate, transcutaneous EEG is preferred, since this is non-invasive and relatively simple.

The source is observed with the sensors in a quiet state, a state in which he or she is experiencing an event, and various control states in which the source is at rest or engaged in different activities resulting in different states. The data may be obtained for a sufficiently long period of time and over repeated trials to determine the effect of duration. The data may also be a population statistical result, and need not be derived from only a single individual at a single time.

The sensor data is then processed using a 4D (or higher) model to determine the characteristic location-dependent pattern of brain activity over time associated with the state of interest. Where the data is derived from a population with various degrees of arousal, the model maintains this arousal state variable dimension.

A recipient is then prepared for receipt of the mental state. The mental state of the recipient may be assessed. This can include responses to a questionnaire, sell-assessment, or other psychological assessment method. Further, the transcutaneous EEG (or other brain activity data) of the recipient may be obtained, to determine the starting state for the recipient, as well as activity during experiencing the desired mental state.

In addition, a set of stimuli, such as visual patterns, acoustic patterns, vestibular, smell, taste, touch (light touch, deep touch, proprioception, stretch, hot, cold, pain, pleasure, electric stimulation, acupuncture, etc.), vagus nerve (e.g., parasympathetic), are imposed on the subject, optionally over a range of baseline brain states, to acquire data defining the effect of individual and various combinations of sensory stimulation on the brain state of the recipient. Population data may also be used for this aspect.

The data from the source or population of sources (see above) may then be processed in conjunction with the recipient or population of recipient data, to extract information defining the optimal sensory stimulation over time of the recipient to achieve the desired brain state resulting in the desired emotional or mental state.

In general, for populations of sources and recipients, the data processing task is immense. However, the statistical analysis will generally be of a form that permits parallelization of mathematical transforms for processing the data, which can be efficiently implemented using various parallel processors, a common form of which is a SIMD

(single instruction, multiple data) processor, found in typical graphics processors (GPUs). Because of the cost-efficiency of GPUs, it is referred to implement the analysis using efficient parallelizable algorithms, even if the computational complexity is nominally greater than a CISC-type processor implementation.

During emotional arousal of the recipient, the EEG pattern may be monitored to determine if the desired state is achieved through the sensory stimulation. A closed loop feedback control system may be implemented to modify the stimulation seeking to achieve the target. An evolving genetic algorithm may be used to develop a user model, which relates the emotional or mental state, arousal and valence, sensory stimulation, and brain activity patterns, both to optimize the current session of stimulation and learning, as well as to facilitate future sessions, where the emotional or mental states of the recipient have further enhanced, and to permit use of the system for a range of emotional or mental states.

The stimulus may comprise a chemical messenger or stimulus to alter the subject's level of consciousness or otherwise alter brain chemistry or functioning. The chemical may comprise a hormone or endocrine analog molecule, (such as adrenocorticotropic hormone (ACTH) (4-11)), a stimulant (such as cocaine, caffeine, nicotine, phenethylamines), a psychoactive drug, psychotropic or hallucinogenic substance (a chemical substance that alters brain function, resulting in temporary changes in perception, mood, consciousness and behavior such as pleasantness (e.g. euphoria) or advantageousness (e.g., increased alertness).

While typically, controlled or "illegal" substances are to be avoided, in some cases, these may be appropriate for use. For example, various drugs may alter the state of the brain to enhance or selectively enhance the effect of the stimulation. Such drugs include stimulants (e.g., cocaine, methylphenidate (Ritalin), ephedrine, phenylpropanolamine, amphetamines), narcotics/opiates (opium, morphine, heroin, methadone, oxymorphine, oxycodone, codeine, fentanyl), hallucinogens (lysergic acid diethylamide (LSD), PCP, MDMA (ecstasy), mescaline, psilocybin, magic mushroom (Psilocybe cubensis), Amanita muscaria mushroom, marijuana/cannabis), Salvia divinorum, diphenhydramine (Benadryl), flexeril, tobacco, nicotine, bupropion (Zyban), opiate antagonists, depressants, gamma aminobutyric acid (GABA) agonists or antagonists, NMDA receptor agonists or antagonists, depressants (e.g., alcohol, Xanax; Valium; Halcion; Librium; other benzodiazepines, Ativan; Klonopin; Amytal; Nembutal; Seconal; Phenobarbital, other barbiturates), psychedelics, disassociatives, and deliriants (e.g., a special class of acetylcholine-inhibitor hallucinogen). For example, Carhart-Harris showed using fMRI that LSD and psilocybin caused synchronization of different parts of the brain that normally work separately by making neurons fire simultaneously. This effect can be used to induce synchronization of various regions of the brain to heighten the emotional state.

It is noted that a large number of substances, natural and artificial, can alter mood or arousal and, as a result, may impact emotions or non-target mental states. Typically, such substances will cross the blood-brain barrier, and exert a psychotropic effect. Often, however, this may not be necessary or appropriate. For example, a painful stimulus can alter mood, without acting as a psychotropic drug; on the other hand, a narcotic can also alter mood by dulling

emotions. Further, sensory stimulation can induce mood and/or emotional changes, such as smells, sights, sounds, various types of touch and proprioception sensation, balance and vestibular stimulation, etc. Therefore, peripherally acting substances that alter sensory perception or stimulation may be relevant to mood. Likewise, pharmacopsychotropic drugs may alter alertness, perceptiveness, memory, and attention, which may be relevant to task-specific mental state control.

It is an object to provide a method for inducing an emotional state in a subject, comprising: determining a desired emotional state; selecting a profile from a plurality of profiles stored in a memory, the plurality of profiles each corresponding to a brain activity pattern of at least one exemplar subject under a respective emotional state (the "source"); and exposing a target subject (the "recipient") to a stimulus modulated according to the selected profile, wherein the exposure, stimulus, and modulation are adapted to induce, in the target subject the desired emotional state.

The brain activity pattern may be an electroencephalographic brainwave pattern, a magnetoencephalographic brainwave pattern, an electrical brainwave pattern, or a metabolic rate pattern, for example.

The stimulus comprises may visual stimulus, an auditory stimulus; an olfactory stimulus; a tactile stimulus; a proprioceptive stimulus; an electrical stimulus; or a magnetic stimulus.

The desired emotional state is may be happiness, joy, gladness, cheerfulness, bliss, delight, ecstasy, optimism, exuberance, merriment, joviality; vivaciousness, pleasure, excitement, sexual arousal, relaxation, harmony, or peace, for example.

The exemplar subject and the target subject may be the same human at different times, or different humans, or different species.

The stimulus may comprise an auditory stimulus adapted to induce binaural beats.

The stimulus may comprise a dynamically changing electromagnetic field adapted synchronize brainwave patterns corresponding to the brain activity pattern of at least one exemplar subject under the desired emotional state.

The selected profile may be derived from measurements of brainwave patterns in the exemplar subject selectively acquired during the desired emotional state.

The selected profile may comprise a model derived from at least spatial, frequency and phase analysis of the measured brainwave patterns.

The stimulus may comprise an auditory or visual stimulus frequency corresponding to a frequency pattern in a brainwave pattern of the exemplar subject.

The target subject may be concurrently exposed to the stimulus and a primary audio or visual presentation which does not induce the desired emotional state, wherein the stimulus does not substantially interfere with the target subject appreciation of the audio or visual presentation.

The method may further comprise recording EEG signals of the exemplar subject in the desired emotional state;

decoding at least one of a temporal and a spatial pattern from the recorded EEG signals; and storing the decoded at least one of temporal and spatial pattern in a non-volatile memory.

The method may further comprise selectively modifying the pattern based on differences between the exemplar subject and the target subject.

The stimulus may comprise applying a spatial electrical stimulation pattern to the target subject via transcranial electrical stimulation (tES) to induce the desired emotional state. The spatial electrical stimulation pattern comprises a direct current or an alternating current. The transcranial electrical stimulation (tES) may be at least one of a transcranial direct current stimulation (tDCS), a transcranial alternating current stimulation (tACS), a transcranial pulsed current stimulation (tPCS) transcranial pulsed current stimulation (tPCS), and a transcranial random noise stimulation (tRNS).

The brain activity pattern of the at least one exemplar subject may comprise a magnetoencephalogram (MEG), and the stimulus comprises applying a spatial magnetic stimulation pattern to the target subject via transcranial magnetic stimulation (tMS) to induce the desired emotional state.

The stimulus may achieve brain entrainment in the target subject.

The method may further comprise determining a second desired emotional state; selecting a second profile from the plurality of profiles stored in a memory; and exposing a target subject to a stimulus modulated according to the selected second profile, wherein the exposure, stimulus, and modulation are adapted to induce, in the target subject the desired second emotional state, the second emotional state being different from the first subsequent state and being induced in succession after the emotional state.

It is another object to provide a method of brainwave entrainment comprising the steps of: recording EEG of the brainwaves of a first subject in an emotional state; decoding at least one of a temporal and a spatial pattern from the EEG; storing a representation of the pattern in a non-volatile memory; retrieving said pattern from the non-volatile memory modulating the temporal and spatial patterns on a stimulus signal; and applying the stimulus signal to a second subject. The stimulus signal may be an alternating current, and said applying comprises applying the alternating current to the second subject via transcranial alternating current stimulation (tACS) to induce the emotional state.

It is a further object to provide a method of brainwave entrainment comprising the steps of: recording EEG of the brainwaves of a first subject in a respective emotional state; decoding at least one of temporal and spatial pattern from the recorded EEG; storing said at least one of temporal and spatial pattern in a non-volatile memory; retrieving said at least one of temporal and spatial pattern from the non-volatile memory; modulating the temporal and spatial patters on a light signal; and projecting the light signal to the second subject to induce the respective emotional state. The light signal may be selected from the group consisting of an ambient light signal, a directional light signal, a laser beam signal, a visible spectrum light signal and an infrared light signal.

It is another object to provide a method of brainwave entrainment comprising the steps of: recording EEG of the brainwaves of a first subject in an emotional state; decoding at least one of a temporal and a spatial pattern from the EEG; storing said at least one of the temporal and the spatial pattern in a non-volatile memory; retrieving the at least one of the temporal and the spatial pattern from the non-volatile memory; modulating the temporal and spatial patters on an isotonic sound signal; and projecting the isotonic sound signal to a second subject to induce the emotional state.

A still further object provides a method of brainwave entrainment comprising the steps of: recording EEG of the brainwaves of a first subject in an emotional state; decoding temporal frequency pattern from the EEG; storing the decoded temporal frequency pattern in a memory; retrieving the temporal frequency pattern from the memory; computing a first set of frequencies by adding a predetermined delta to the frequencies of the temporal frequency pattern; computing a second set of frequencies by subtracted the delta from the frequencies of the temporal frequency pattern; modulating the first set of frequencies on a first acoustical signal; modulating the second set of frequencies on a second acoustical signal; projecting the first set of frequencies into a first ear of the second subject; and projecting the second set of frequencies into a second ear of the second subject, thereby producing binaural stimulation to induce the emotional state.

Another object provides a method for modifying an emotional state or mood in a subject, comprising: selecting an emotional state or mood profile from a memory, corresponding to a brain activity pattern of at least one exemplar subject in a respective emotional state or mood; and exposing a target subject to a stimulus signal modulated according to the selected emotional state or mood profile, to induce, in the target subject the selected emotional state or mood. The brain activity pattern may be acquired through at least one of an electroencephalogram (EEG) and a magnetoencephalogram (EEG). The stimulus signal may be selected from the group consisting of a light, a sound, a touch, a smell, an electric current, and a magnetic field. The emotional state or mood may be selected from the group consisting of a state of happiness, a state of joy, a state of gladness, a state of cheerfulness, a state of bliss, a state of delight, a state of ecstasy, a state of optimism, a state of exuberance, a state of merriment, a jovial state, a state of vivaciousness, a state of pleasure, a state of excitement, a state of relaxation, a state of harmony, and a state of peace. The exemplar subject and the target subject may be the same subject at different times or different subjects.

A further object provides a method of brainwave entrainment comprising the steps of: recording EEG of a first subject in a positive emotional state; storing a spatial-temporal pattern corresponding to the EEG in a memory; modulating a stimulus pattern according to the spatial-temporal pattern; and stimulating a second subject with the modulated stimulus pattern, to induce the positive emotional state. The modulated stimulus pattern may comprise a binaural audio stimulus. The modulated stimulus pattern may comprise a transcranial electrical stimulation, e.g., a direct current stimulus, an alternating current stimulus, a transcranial direct current stimulation (tDCS), a transcranial alternating current stimulation (tACS), a transcranial pulsed current stimulation (tPCS) transcranial pulsed current

stimulation (tPCS), or a transcranial random noise stimulation (tRNS).

It is a still further object to provide a method of brainwave entrainment comprising the steps of: modulating a predefined temporal and spatial pattern on a magnetic field; and applying the modulated magnetic field to the brain of a subject via transcranial magnetic stimulation (tMS) to selectively induce an emotional state corresponding to the predefined temporal and spatial pattern.

It is an object to provide a system and method for enhancing emotional response to a stimulus in a subject.

It is another object to provide a system and method for enhancing the experience virtual reality by enhancing the emotional response in a subject.

It is a further object to provide a system and method for enhancing cinematographic experience by enhancing the emotional response in viewers while watching a movie.

It is yet another object to provide a system and method for improving users' interaction with a computer.

It is still another object to provide a system and method for improving users' interaction with a robot.

It is a further object to provide a system and method for accelerating memory-retention and recall by inducing a desired emotional state in a subject.

It is yet another object to provide a system and method for treatment of patients with dementia.

It is an object to provide a system and method for facilitating an emotional state achievement process, compromising: determining a neuronal activity pattern, of a subject while engaged in a respective emotion; processing the determined neuronal activity pattern with at least one automated processor; and subjecting a subject seeking to achieve the respective emotion to a stimulus selected from the group consisting of one or more of a sensory excitation, a peripheral excitation, a transcranial excitation, and a deep brain stimulation, dependent on the processed electromagnetic determined neuronal activity pattern.

It is yet another object to provide a system and method for facilitating a mental process, compromising: determining a neuronal activity pattern of a skilled subject having the mental process; processing the determined neuronal activity pattern with at least one automated processor; and subjecting a subject seeking a corresponding mental process to a stimulus selected from the group consisting of one or more of a sensory excitation, a peripheral excitation, a transcranial excitation, and a deep brain stimulation, dependent on the processed electromagnetic determined neuronal activity pattern.

It is still another object to provide a system and method for improving achieving a mental state, compromising: determining a neuronal activity pattern, of a subject while having the mental state; processing the determined neuronal activity pattern with at least one automated processor; and subjecting a subject seeking to achieve the mental state to a stimulus selected from the group consisting of one or more of a sensory excitation, a peripheral excitation, a transcranial excitation, and a deep brain stimulation, dependent on the processed electromagnetic determined neuronal activity pattern. The mental state is, e.g., an emotional state, a mood, or other subjective state.

It is also an object to provide an apparatus for facilitating control over an emotional state, compromising: an input, configured to receive data representing a neuronal activity pattern of a subject while having an emotional state; at least one automated processor, configured to process the determined neuronal activity pattern, to determine neuronal activity patterns selectively associated with the emotional state, configured to subject a subject emotional arousal in control over the emotional state to a stimulus selected from the group consisting of one or more of a sensory excitation, a peripheral excitation, a transcranial excitation, and a deep brain stimulation, dependent on the processed determined neuronal activity pattern.

It is further an object to provide an apparatus for facilitating an emotional skill or emotional learning process, compromising: an input, configured to receive data representing a neuronal activity pattern of a subject while engaged in an emotional skill or emotional learning process; at least one automated processor, configured to process the determined neuronal activity pattern, to determine neuronal activity patterns selectively associated with successful learning of the emotional skill or emotional learning process; and a stimulator, configured to subject a subject emotional arousal in the respective emotional skill or emotional learning process to a stimulus selected from the group consisting of one or more of a sensory excitation, a peripheral excitation, a transcranial excitation, and a deep brain stimulation, dependent on the processed determined neuronal activity pattern.

It is also an object to provide an apparatus for inducing of a desired emotional state, compromising: an input, configured to receive data representing a neuronal activity pattern of a skilled subject while experiencing the desired emotional state; at least one automated processor, configured to process the determined neuronal activity pattern, to determine neuronal activity patterns selectively associated with the desired emotional state; and a stimulator, configured to subject a recipient desiring to attain the same emotional state to a stimulus selected from the group consisting of one or more of a sensory excitation, a peripheral excitation, a transcranial excitation, and a deep brain stimulation, dependent on the processed determined neuronal activity pattern.

It is a further object to provide a system for influencing a brain electrical activity pattern of a subject during emotional arousal, comprising: an input, configured to determine a target brain activity state for the subject, dependent on the emotional state; at least one processor, configured to generate a stimulation pattern profile adapted to achieve the target brain activity state for the subject, dependent on the emotional state; and a stimulator, configured to output at least one stimulus, proximate to the subject, dependent on the generated stimulation pattern profile.

It is yet a further object to provide a system for influencing a brain electrical activity pattern of a subject during experiencing information, comprising: an input, configured to determine a target brain activity state for the subject, dependent on the nature of the respective information; at least one processor, configured to generate a stimulation pattern profile adapted to achieve the target brain activity state for the subject, dependent on the emotion; and a stimulator, configured to output at least one stimulus, proximate to the subject, dependent on the generated stimulation pattern profile.

It is still a further object to provide a system for influencing a brain electrical activity pattern of a subject during a state of emotional arousal, comprising: an input, configured to determine a target brain emotional state for the subject, dependent on the desired emotional state; at least one processor, configured to generate a stimulation pattern profile adapted to achieve the target brain emotional state for the subject, dependent on the emotional state; and a stimulator, configured to output at least one stimulus, proximate to the subject, dependent on the generated stimulation pattern profile.

It is a still further object to provide a system for determining a target brain activity state for a subject, dependent on an emotion state, comprising: a first monitor, configured to acquire a brain activity of a first subject during the emotion state; at least one first processor, configured to analyze a spatial brain activity state over time of the first subject; and determine spatial brain activity states of the first subject, which represent readiness for emotion state; a second monitor, configured to acquire a brain activity of a second subject during performance of a variety of activities, under a variety of stimuli; and at least one second processor, configured to: analyze a spatial brain activity state over time of the second subject; and translate the determined spatial brain activity states of the first subject which represent readiness for the emotion state, into a stimulus pattern for the second subject to achieve a spatial brain activity state in the second subject corresponding to emotion state.

It is a still further object to provide a system for determining a target brain activity state for a subject, dependent on an emotion or mood, comprising: a first monitor, configured to acquire a brain activity of a first subject during experiencing the emotion or mood; at least one first processor, configured to analyze a spatial brain activity state over time of the first subject; and determine spatial brain activity states of the first subject, which represent the emotion or mood; a second monitor, configured to acquire a brain activity of a second subject during the emotion or mood, under a variety of stimuli; and at least one second processor, configured to: analyze a spatial brain activity state over time of the second subject; and translate the determined spatial brain activity states of the first subject which represent the emotion or mood, into a stimulus pattern for the second subject to achieve a spatial brain activity state in the second subject corresponding to the emotion or mood.

It is a further object to provide a method of enhancing an emotional state of a first subject, the method comprising: recording a second subject's brainwaves EEG while at rest; having the second subject experience or enact an emotionally charged experience to induce an emotional state or mood; recording the second subject's brainwaves EEG while experiencing or enacting said emotionally charged experience; extracting a predominant temporal pattern associated with said emotional state from the recorded brainwaves by comparing them with the brainwaves at rest; encoding said temporal pattern as a digital code stored in a tangible media; and using said digital code to modulate the temporal pattern on a signal perceptible to the first subject while said first subject is trying to attain the said emotional state, whereby said perceptible signal stimulates in the second subject brainwaves having said temporal pattern to induce the emotional state or mood.

It is still a further object to provide a method of enhancing an emotional state of a first person, the method comprising: recording a second person's brainwaves or EEG while at rest or prior to achieving a desired emotional state; subjecting having the second person to the performance; recording the second person's brainwaves or EEG while subject to the performance; extracting a predominant temporal pattern associated with said performance from the recorded brainwaves or EEG by comparing them with the brainwaves or EEG at rest or prior to achieving the desired emotional state; encoding said temporal pattern as a digital code stored in a tangible media; and using said digital code to modulate the temporal pattern on a signal perceptible to the first person while said first person is seeking to achieve said desired emotional state, whereby said light signal stimulates in the first subject brainwaves or EEG having said temporal pattern to enhance the achievement of the desired emotional state.

A still further object provides a method of assisted appreciation of art by a first subject, the method comprising: recording a second subject's brainwaves EEG while at rest, wherein the second subject is knowledgeable in the art; having the second subject experience the art; recording the second subject's brainwaves (e.g., EEG, or MEG) while experiencing the art; extracting a predominant temporal pattern associated with appreciating the art from the recorded brainwaves by comparing them with the brainwaves at rest; encoding said temporal pattern as a digital code stored in a tangible media; and using said digital code to modulate the temporal pattern on a signal perceptible to the first subject while the first subject is seeking to appreciate the art, whereby said signal stimulates in the first subject brainwaves having said temporal pattern.

It is another object to provide a computer readable medium, storing therein non-transitory instructions for a programmable processor to perform a process, comprising the computer-implemented steps: synchronizing brain activity data of a subject with at least one event involving the subject; analyzing the brain activity data to determine a selective change in the brain activity data corresponding to an emotional correlate of the event; and determine a stimulation pattern adapted to induce a brain activity having a correspondence to the brain activity data associated with the emotion, based on at least a brain activity model.

The at least one of a sensory excitation, peripheral excitation, and transcranial excitation may be generated based on a digital code. The subjecting of the subject having the emotion or mood to the sensory excitation increases a rate of achieving the emotion in the target subject. Similarly, the subjecting of the subject seeking to achieve the emotion or mood to the sensory excitation increases a rate of achieving the emotion or mood in the target. Likewise, the subjecting of the subject seeking to achieve the respective emotional state to the sensory excitation improves the quality or intensity of the emotional state in the subject.

The method may further comprise determining a neuronal baseline activity of the skilled subject while not engaged in the emotion, a neuronal baseline activity of the subject, a neuronal activity of the skilled subject while engaged in the emotion, and/or a neuronal activity of the subject while engaged in the emotion.

The representation of the processed the determined neuronal activity pattern may be stored in memory. The

storage could be on a tangible medium as an analog or digital representation. It is possible to store the representation in a data storage and access system either for a permanent backup or further processing the respective representation. The storage can also be in a cloud storage and/or processing system.

The neuronal activity pattern may be obtained by electroencephalography, magnetoencephalography, MRI, fMRI, PET, low-resolution brain electromagnetic tomography, or other electrical or non-electrical means.

The neuronal activity pattern may be obtained by at least one implanted central nervous system (cerebral, spinal) or peripheral nervous system electrode. An implanted neuronal electrode can be either within the peripheral nervous system or the central nervous system. The recording device could be portable or stationary. Either with or without onboard electronics such as signal transmitters and/or amplifiers, etc. The at least one implanted electrode can consist of a microelectrode array featuring more than one recording site. Its main purpose can be for stimulation and/or recoding.

The neuronal activity pattern may be obtained by at least a galvanic skin response. Galvanic skin response or resistance is often also referred as electrodermal activity (EDA), psychogalvanic reflex (PGR), skin conductance response (SCR), sympathetic skin response (SSR) and skin conductance level (SCL) and is the property of the human body that causes continuous variation in the electrical characteristics of the skin.

The stimulus may comprise a sensory excitation. The sensory excitation may by either sensible or insensible. It may be either peripheral or transcranial. It may consist of at least one of a visual, an auditory, a tactile, a proprioceptive, a somatosensory, a cranial nerve, a gustatory, an olfactory, a pain, a compression and a thermal stimulus or a combination of the aforesaid. It can, for example, consist of light flashes either within ambient light or aimed at the subject's eyes, 2D or 3D picture noise, modulation of intensity, within the focus of the subjects eye the visual field or within peripheral sight. Within a video presentation, intensity variations may be provided around a periphery of the presentation, globally throughout a presentation (i.e., modulating a backlight or display intensity), or programmed to modulate a brightness of individual objects.

The stimulus may comprise a peripheral excitation, a transcranial excitation, a sensible stimulation of a sensory input, an insensible stimulation of a sensory input, a visual stimulus, an auditory stimulus, a tactile stimulus, a proprioceptive stimulus, a somatosensory stimulus, a cranial nerve stimulus, a gustatory stimulus, an olfactory stimulus, a pain stimulus, an electric stimulus, a magnetic stimulus, or a thermal stimulus.

The stimulus may comprise transcranial magnetic stimulation (TMS), cranial electrotherapy stimulation (CES), transcranial direct current stimulation (tDCS), comprise transcranial alternating current stimulation (tACS), transcranial random noise stimulation (tRNS), comprise transcranial pulsed current stimulation (tPCS), pulsed electromagnetic field, or noninvasive or invasive deep brain stimulation (DBS), for example. The stimulus may comprise transcranial pulsed ultrasound (TPU). The stimulus may comprise a cochlear implant stimulus, spinal cord stimulation (SCS) or a vagus nerve stimulation (VNS), or other direct or indirect cranial or peripheral nerve stimulus. The stimulus may

comprise or achieve brainwave entrainment. The stimulus may comprise electrical stimulation of the retina, a pacemaker, a stimulation microelectrode array, electrical brain stimulation (EBS), focal brain stimulation (FBS), light, sound, vibrations, an electromagnetic wave. The light stimulus may be emitted by at least one of a light bulb, a light emitting diode (LED), and a laser. The signal may be one of a ray of light, a sound wave, and an electromagnetic wave. The signal may be a light signal projected onto the first subject by one of a smart bulb generating ambient light, at least one LED position near the eyes of the first subject and laser generating low-intensity pulses.

The mental state may be associated with learning or performing a skill. The skill may comprise a mental skill, e.g., cognitive, alertness, concentration, attention, focusing, memorization, visualization, relaxation, meditation, speedreading, creative skill, "whole-brain-thinking", analytical, reasoning, problem-solving, critical thinking, intuitive, leadership, learning, speedreading, patience, balancing, perception, linguistic or language, language comprehension, quantitative, "fluid intelligence", pain management, skill of maintaining positive attitude, a foreign language, musical, musical composition, writing, poetry composition, mathematical, science, art, visual art, rhetorical, emotional control, empathy, compassion, motivational skill, people, computational, science skill, or an inventorship skill. See, U.S. Patent and Pub. App. Nos. 6,435,878, 5,911,581, and 20090069707. The skill may comprise a motor skill, e.g., fine motor, muscular coordination, walking, running, jumping, swimming, dancing, gymnastics, yoga; an athletic or sports, massage skill, martial arts or fighting, shooting, self-defense; speech, singing, playing a musical instrument, penmanship, calligraphy, drawing, painting, visual, auditory, olfactory, game-playing, gambling, sculptor's, craftsman, massage, or assembly skill. Where a skill is to be enhanced, and an emotion to be achieved (or suppressed), concurrently, the stimulus to the recipient may be combined in such a way as to achieve the result. In some cases, the component is universal, while in others, it is subjective. Therefore, the combination may require adaptation based on the recipient characteristics.

The technology may be embodied in apparatuses for acquiring the brain activity information from the source, processing the brain activity information to reveal a target brain activity state and a set of stimuli, which seek to achieve that state in a recipient, and generating stimuli for the recipient to achieve and maintain the target brain activity state over a period of time and potential state transitions. The generated stimuli may be feedback controlled. A general-purpose computer may be used for the processing of the information, a microprocessor, a FPGA, an ASIC, a system-on-a-chip, or a specialized system, which employs a customized configuration to efficiently achieve the information transformations required. Typically, the source and recipient act asynchronously, with the brain activity of the source recorded and later processed. However, real-time processing and brain activity transfer are also possible. In the case of a general purpose programmable processor implementation or portions of the technology, computer instructions may be stored on a nontransient computer readable medium. Typically, the system will have special-purpose components, such as a transcranial stimulator, or a modified audio and/or display system, and therefore the system will not be a general purpose system. Further, even in a general purpose system the operation per se is

enhanced according to the present technology.

It is another object to provide a method of teaching one of an emotion-dependent mental skill and a motor skill to a first subject, the method comprising: recording a second subject's brainwaves EEG while at rest; having the second subject perform said one of a mental skill and a motor skill; recording the second subject's brainwaves while performing said one of a mental skill and a motor skill; extracting a predominant temporal pattern associated with said one of a mental skill and a motor skill from the recorded brainwaves by comparing them with the brainwaves at rest; encoding said temporal pattern together with an emotional state targeting stimulus pattern, as a digital code stored in a tangible media; and using said digital code to modulate the temporal pattern on a signal perceptible to the first subject while the first subject is learning said one of a mental and a motor skill, whereby said light signal stimulates in the first subject brainwaves having said temporal pattern to accelerate learning of said one if a mental skill and a motor skill. The emotional state targeting stimulus pattern may be derived from the first subject, the second subject, or a one or more different subjects. The stimulation pattern may thus be modified from the second subject pattern to bias the first subject toward a desired emotional state.

It is a further object to provide a high-definition transcranial alternating current stimulation (HD-tACS) stimulation of a target, having a stimulation frequency, amplitude pattern, spatial pattern, dependent on an existing set of states in the target, and a set of brainwave patterns from a target engaged in a mood, adapted to improve an emotional state or mood of the recipient.

It is yet another object to provide a system and method for facilitating a mental process, compromising: determining a neuronal activity pattern, of a subject while engaged in an emotional process; processing the determined neuronal activity pattern with at least one automated processor; and subjecting a subject targeting the emotional process to a stimulus selected from the group consisting of one or more of a sensory excitation, a peripheral excitation, a transcranial excitation, and a deep brain stimulation, dependent on the processed electromagnetic determined neuronal activity pattern while the subject is subjected to tES, a psychedelic and/or other pharmaceutical agents.

It is a still further object to provide a method of facilitating a skill learning process, comprising: determining a neuronal activity pattern of a skilled subject while engaged in a respective skill; processing the determined neuronal activity pattern with at least one automated processor; modifying the determined neuronal activity pattern according to an emotional state neuronal activity pattern; and subjecting a subject training in the respective skill to a stimulus selected from the group consisting of one or more of a sensory excitation, a peripheral excitation, a transcranial excitation, and a deep brain stimulation, dependent on the modified processed determined neuronal activity pattern. The transcranial electric stimulation (tES) may be one of transcranial direct current stimulation (tDCS), transcranial alternative current stimulation (tACS), and high-definition transcranial alternative current stimulation (tES). The emotional state neuronal activity pattern may be a pattern that increases alertness and focus, for example.

Another object provides a method of facilitating a skill learning process, compromising: determining a respective neuronal activity pattern of a skilled subject while engaged in a respective skill and having an emotional state appropriate for learning the skill and while engaged in the respective skill and not having the emotional state appropriate for learning the skill; processing the determined neuronal activity pattern with at least one automated processor; subjecting a subject training in the respective skill to one of a pharmaceutical agent and a psychedelic agent; and subjecting a subject training in the respective skill to a stimulus selected from the group consisting of one or more of a sensory excitation, a peripheral excitation, a transcranial excitation, and a deep brain stimulation, dependent on the processed determined neuronal activity pattern while engaged in a respective skill and having an emotional state appropriate for learning the skill, and adapting the stimulus based on feedback based on a measurement of a neuronal activity pattern of the subject training in the respective skill to determine an emotional state of the subject training in the respective skill.

It is another object to provide a method of inducing an emotional state in a target subject, comprising determining a desired emotional state; selecting a profile from a plurality of profiles stored in a memory, the plurality of profiles each corresponding to a brain activity pattern of a donor subject having a respective emotional state; and exposing the target subject to at least one stimulus modulated according to the selected profile representing and being adapted to induce, in the target subject, the desired emotional state. The brain activity pattern may be at least one of an electroencephalographic brainwave pattern and a magnetoencephalographic brainwave pattern. The at least one stimulus may stimulate a cranial nerve of the target subject. The at least one stimulus may comprise at least one of a visual stimulus, and an auditory stimulus, a two-channel auditory stimulus adapted to induce binaural beats, at least one of a tactile stimulus and a proprioceptive stimulus, an at least one of a direct electrical current and an alternating electrical current, and/or a magnetic field. The stimulus may comprise at least one of an auditory stimulus and a visual stimulus with a frequency corresponding to at least a frequency pattern in a brainwave pattern of the donor subject.

The desired emotional state may be one of happiness, joy, gladness, cheerfulness, bliss, delight, ecstasy, optimism, exuberance, merriment, joviality; vivaciousness, pleasure, excitement, sexual arousal, relaxation, harmony, and peace.

The target subject may be the same as or different from the donor subject. The target subject may be identical with the donor subject, wherein the brain activity pattern of the donor subject was recorded prior to the exposing the target subject to at least one stimulus.

The at least one stimulus may comprise a dynamically changing electromagnetic field adapted to synchronize the target subject's brainwave pattern with a brainwave pattern of the donor subject having the desired emotional state.

The selected profile may be derived from recording of brainwave patterns of the donor subject selectively acquired during the desired emotional state. The selected profile may comprise a model derived from at least one of a

spatial, a frequency and a phase analysis of the recorded brainwave patterns.

The method may further comprise recording EEG signals of the donor subject in the desired emotional state; decoding at least one of a temporal and a spatial pattern from the recorded EEG signals; and storing the decoded at least one of temporal and spatial pattern in a non-volatile memory as at least one profile.

The method may comprise selectively modifying stimulus based on differences between the donor subject, from which the profile may be derived, and the target subject.

The stimulus may comprise applying at least one of a temporal and a spatial electrical stimulation pattern to the target subject via transcranial electrical stimulation (TES) to induce the desired emotional state. The transcranial electrical stimulation (TES) may be at least one of a transcranial direct current stimulation (tDCS), an oscillating transcranial direct current stimulation (osc-tDCS), a transcranial alternating current stimulation (tACS), a transcranial pulsed current stimulation (tPCS), and a transcranial random noise stimulation (tRNS).

The profile may be derived from brain activity pattern of the donor subject comprising a magnetoencephalogram (MEG), and the stimulus may comprise applying a spatial magnetic stimulation pattern to the target subject via transcranial magnetic stimulation (TMS) to induce the desired emotional state.

The stimulus may achieve brain entrainment in the target subject.

The method may further comprise determining a second desired emotional state; selecting a second profile from the plurality of profiles stored in a memory; and exposing the target subject to a stimulus modulated according to the selected second profile, representing and being adapted to induce, in the target subject, the second desired emotional state, the second emotional state being different from the emotional state and being induced in succession after the emotional state.

At least one profile may correspond to consensus brain activity pattern of a plurality of donor subjects, each of the plurality of donor subjects having the respective emotional state

It is a further object to provide a method of brainwave entrainment comprising: recording brainwaves of a first subject in a desired emotional state; decoding at least one of a temporal and a spatial pattern from the brainwaves; storing a representation of the pattern in a memory; retrieving said pattern from the memory; modulating the decoded at least one of the temporal and the spatial pattern on at least one stimulus signal; and applying said at least one stimulus signal to a second subject, to induce the second subject to assume the emotional state. The step of recording brainwaves comprise recording of at least one of electroencephalogram and magnetoencephalogram of the brainwaves. The stimulus signal may be at least one of a direct current and an alternating current, and said applying may comprise applying said at least one of a direct current and an alternating current to the second subject via respectively a transcranial direct current stimulation (tDCS) or transcranial alternating current stimulation (tACS) to induce the desired emotional state.

It is a still further object to provide a method of brainwave entrainment comprising: recording the brainwaves of a

first subject in a desired emotional state; decoding at least one of temporal and spatial pattern from the recorded brainwaves; storing said at least one of the temporal and spatial pattern in a memory; retrieving said at least one of the temporal and spatial pattern from the memory; modulating the at least one of the temporal and spatial pattern on at least one of a current, a magnetic field, a light signal, and an acoustic signal; and exposing the second subject to the at least one of the current, the magnetic field, the light signal, and the acoustic signal, to induce the desired emotional state.

The step of recording the brainwaves may comprise recording of at least one of an electroencephalogram and a magnetoencephalogram of the brainwaves.

Another object provides a method of recording a desired emotional state from a donor, comprising: determining an emotional state of the donor; if the donor may be in the desired emotional state, recording neural correlates of the emotional state of the donor; analyzing neural correlates of the desired emotional state of the donor to decode at least one of a temporal and a spatial pattern corresponding to the desired emotional state; converting said at least one of a temporal and a spatial pattern corresponding to the desired emotional state into a neurostimulation pattern; and storing the neurostimulation pattern in the nonvolatile memory. The neural correlates may be brainwaves of the donor.

The step of analyzing neural correlates may comprise identifying principal components of the brainwaves. The identifying of principal components may comprise performing one of a principal component analysis (PCA), a curvilinear principal component analysis, an independent component analysis (ICA), a Karhunen–Loève transform (KLT), a singular value decomposition (SVD), and a Factor analysis. The step of analyzing neural correlates may comprise performing a frequency domain analysis. The step of performing the frequency analysis may comprise performing one of a Fourier Transform, a Laplace Transform, a Fourier–Stieltjes transform, a Gelfand transform, time-frequency analysis, a short-time Fourier transform, and a fractional Fourier transform.

The desired emotional state may be one of of happiness, joy, gladness, cheerfulness, bliss, delight, ecstasy, optimism, exuberance, merriment, joviality; vivaciousness, pleasure, excitement, sexual arousal, relaxation, harmony, and peace.

The method may further comprise retrieving the neurostimulation pattern from the nonvolatile memory; and stimulating the recipient's brain with at least one stimulus modulated with the neurostimulation pattern to induce the desired emotional state in the recipient.

The at least one stimulus may be one of a direct current, an alternating current, a magnetic field, a light, a sound, a tactile signal and an olfactory signal.

The recipient may be the donor at a point in time subsequent to the time of recording the neural correlates of the emotional state of the donor.

The method may further comprise determining an emotional state of the recipient to confirm that the recipient

may be in the desired emotional state. The methodmay further comprise developing a brain model of the recipient; and adjusting said at least one stimulus in accordance with the model to adjust for the differences between the recipient's brain and the donor's brain. The method may further comprise the step of administering a pharmacological agent to the recipient to facilitate response of the recipient to the at least one stimulus to induce the desired emotional state. The method may further comprise performing, by the recipient, a physical exercise in conjunction with the at least one stimulus.

It is another object ot provide a relational database of neural correlates of emotional states, comprising a first table storing a plurality of respective emotional states, linked with a second table storing information associated with respective emotional states obtained by: recording neural correlates of the repective emotional state of each of a plurality of donors while in the respective emotional state; decoding from the recorded neural correlates at least one of a temporal and a spatial pattern corresponding to the plurality of respective emotional states; and storing information selectively derived from the at least one of the temporal and the spatial pattern corresponding to the plurality of respective emotional states in the second table. The neural correlates of each respective emotional state may be brainwaves. The recording of neural correlates may be done by using one of an electroencephalogram and a magnetoencephalogram. The relational database may be accessible by receipt of a respective emotional state and responsive by providing information linked to the respective emotional state.

Another object provides a method of increasing emotional emersion in a presentation, comprising: defining a target emotional state associated with at least a portion of the presentation; retrieving a record from a database associated with the target emotional state, derived from recorded neural correlates of donors engaged in the target emotional state; defining a neurostimulation pattern based on the record retrieved from the database; and subjecting a recipient to the defined neurostimulation pattern concurrent with being presented with the at least a portion of the presentation.

The defining a target emotional state associated with at least a portion of the presentation may comprise defining a series of emotional states synchronized with activity or objects depicted in the presentation. The retrieving of the record from the database associated with the target emotional state may comprise retrieving a plurality of records corresponding to the series of emotional states. The defining of the neurostimulation pattern may comprise defining a series of neurostimilation patterns based on the retrieved plurality of records. The subjecting the recipient to the defined neurostimulation pattern concurrent with being presented with the at least a portion of the presentation may comprise subjecting the recipient to the defined series of neuostimulation patterns, temporally synchronized with the portions of presentation, in an order defined by the presentation.

The target emotional state may be defined by an author of the presentation, or automatically derived from the presentation.

The database may be a relational database, having a first table of respective emotional states, and a second table of information relating to neural correlates of the respective emotional states, the first table and the second table being linked together and searchable based on respective emotional state.

At least one record of the database may be derived from recorded neural correlates of a plurality of different donors engaged in a common respective target emotional state. The at least one record may comprise a consensus of the plurality of different donors. The at least one record may comprise a plurality of sub-records, each sub-record being derived from a distinct subpopulation of the plurality of different donors, further comprising determining a characteristic of the recipient, and selecting a respective sub-record from the record based on the determined characteristic.

The neurostimulation pattern may be at least one of an electrical current, a magnetic field, a light signal, and an acoustic signal. The neurostimulation pattern may be encoded in the record and/or may be defined by at least one automated processor after retrieving the record, and in selective dependence on at least one characteristic of the recipient. The presentation may comprise an audiovisual presentation, e.g., a virtual reality presentation. The defined neurostimulation pattern may be encoded as at least one of an audio and a visual stimulus within the audiovisual presentation. The defined neurostimulation pattern may be encoded as the at least one of the audio and the visual stimulus within the audiovisual presentation dependent on at least one characteristic of the recipient. The defined neurostimulation pattern may be dependent on automatically generated or manual feedback from the recipient.

Another object provides a system for increasing emotional response to a presentation, comprising: a database comprising a record associated with a target emotional state, the record being derived from recorded neural correlates of at least one donor engaged in the respective target emotional state; at least one input configured to receive an association of the target emotional state with a portion of a presentation; at least one automated processor configured to define a neurostimulation pattern based on the record retrieved from the database; and a neurostimulator, configured to emit the defined neurostimulation pattern concurrent with presention of the portion of the presentation.

The input may be configured to receive a series of associations of respective target emotional states with respective portions of the presentation, and the neurostimulator may be configured to emit a series of the defined neurostimulation patterns synchronized with the received series of associations of the respective target emotional states with the respective portions of the presentation. The database may be a relational database, having a first table of respective emotional states, and a second table of information relating to neural correlates of the respective emotional states, the first table and the second table being linked together and searchable based on respective emotional state. At least one record may be derived from recorded neural correlates of a plurality of different donors engaged in a common respective target emotional state. The at least one record may comprise a consensus of the plurality of different donors. The at least one record may comprise a plurality of sub-records, each sub-record being

derived from a distinct subpopulation of the plurality of different donors, a respective sub-record being selectable from the record based on the determined characteristic. The neurostimulator may be at least one of an electrical current stimulator, a magnetic field stimulator, a light signal stimulator, and an acoustic signal stimulator. The neurostimulation pattern may be encoded in the record, and/or may be defined by the at least one automated processor dependent on the record, and in selective dependence on at least one characteristic of the recipient. The presentation may comprise an audiovisual presentation, e.g., a virtual reality presentation, and optionally the defined neurostimulation pattern may be encoded as at least one of an audio and a visual stimulus within the audiovisual presentation. The defined neurostimulation pattern may be encoded as the at least one of the audio and the visual stimulus within the audiovisual presentation dependent on at least one characteristic of the recipient. The defined neurostimulation pattern may be dependent on automatically or manually generated feedback from the recipient.

Other objects will become apparent from a review of disclosure hereof.

BRIEF DESCRIPTION OF THE DRAWINGS

The detailed description is described with reference to the accompanying figures. In the figures, the left-most digit(s) of a reference number identifies the figure in which the reference number first appears. The use of the same reference number in different figures indicates similar or identical items.

Figure 1 shows the electric activity of a neuron contributing to a brainwave.

Figure 2 shows transmission of an electrical signal generated by a neuron through the skull, skin and other tissue to be detectable by an electrode transmitting this signal to EEG amplifier.

Figure 3 shows an illustration of a typical EEG setup with a subject wearing a cup with electrodes connected to the EEG machine, which is, in turn, connected to a computer screen displaying the EEG.

Figure 4 shows a typical EEG reading.

Figure 5 shows one second of a typical EEG signal.

Figure 6 shows main brainwave patterns.

Figures 7-13 shows a flowchart according to embodiments of the invention.

Figure 14 shows a schematic representation of an apparatus according to one embodiment of the invention.

Figure 15 shows brainwave real-time BOLD (Blood Oxygen Level Dependent) fMRI studies acquired with synchronized stimuli.

Figure 16 shows Brain Entrainment Frequency Following Response (or FFR).

Figure 17 shows brainwave entrainment before and after synchronization.

Figure 18 shows brainwaves during inefficient problem solving and stress.

Figures 19 and 20 show how binaural beats work.

Figure 21 shows Functional Magnetic Resonance Imaging (Mental states may be induced in a subject)

Figure 22 shows a photo of a brain forming a new idea.

Figure 23 shows 3D T2 CUBE (SPACE/VISTA) FLAIR & DSI tractography

Figure 24 shows an EEG tracing.

Figures 25-29 show flowcharts according to embodiments of the invention.

Figure 30 shows human brain anatomy.

Figure 31 shows a brain map.

Figure 32 shows an image depicting neuron anatomy.

Figure 33 shows graphs representing a dimensional view of emotions.

Figure 34 shows a representation of neural activity with respect to emotional state.

Figures 35-41 show flowcharts according to embodiments of the invention.

Figure 42 shows graphs of tDCS. tRNS, and tACS stimulation patterns.

Figures 43 and 44 show representations of tDCS neural stimulation.

Figure 45 shows a representation of tACS or tRNS neural stimulation.

Figure 46 shows a representation of intracranial electrode implantation.

Figure 47 shows a representation of tDCS electrode location.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Hereinafter, embodiments of the present disclosure will be described in detail with reference to the accompanying drawings so that the present disclosure may be readily implemented by those skilled in the art. However, it is to be noted that the present disclosure is not limited to the embodiments but can be embodied in various other ways. In drawings, parts irrelevant to the description are omitted for the simplicity of explanation, and like reference numerals denote like parts through the whole document.

Through the whole document, the term "connected to" or "coupled to" that is used to designate a connection or coupling of one element to another element includes both a case that an element is "directly connected or coupled to" another element and a case that an element is "electronically connected or coupled to" another element via still another element. Further, it is to be understood that the term "comprises or includes" and/or "comprising or including" used in the document means that one or more other components, steps, operation and/or existence or addition of elements are not excluded in addition to the described components, steps, operation and/or elements unless context dictates otherwise.

Through the whole document, the term "unit" or "module" includes a unit implemented by hardware or software and a unit implemented by both of them. One unit may be implemented by two or more pieces of hardware, and two or more units may be implemented by one piece of hardware.

Other devices, apparatus, systems, methods, features and advantages of the invention will be or will become apparent to one with skill in the art upon examination of the following figures and detailed description. It is intended that all such additional systems, methods, features and advantages be included within this description, be within the scope of the invention, and be protected by the accompanying claims.

The present invention generally relates to enhancing emotional response by a subject in connection with the received information by conveying to the brain of the subject temporal patterns of brainwaves of a second subject who had experienced such emotional response, said temporal pattern being provided non-invasively via light, sound, transcranial direct current stimulation (tDCS), transcranial alternating current stimulation (tDAS) or HD-tACS, transcranial magnetic stimulation (TMS) or other means capable of conveying frequency patterns.

The transmission of the brainwaves can be accomplished through direct electrical contact with the electrodes implanted in the brain or remotely employing light, sound, electromagnetic waves and other non-invasive techniques. Light, sound, or electromagnetic fields may be used to remotely convey the temporal pattern of prerecorded brainwaves to a subject by modulating the encoded temporal frequency on the light, sound or electromagnetic filed signal to which the subject is exposed.

Every activity, mental or motor, and emotion is associated with unique brainwaves having specific spatial and temporal patterns, i.e., a characteristic frequency or a characteristic distribution of frequencies over time and space. Such waves can be read and recorded by several known techniques, including electroencephalography (EEG),

magnetoencephalography (MEG), exact low-resolution brain electromagnetic tomography (eLORETA), sensory evoked potentials (SEP), fMRI, functional near-infrared spectroscopy (fNIRS), etc. The cerebral cortex is composed of neurons that are interconnected in networks. Cortical neurons constantly send and receive nerve impulses-electrical activity-even during sleep. The electrical or magnetic activity measured by an EEG or MEG (or another device) device reflects the intrinsic activity of neurons in the cerebral cortex and the information sent to it by subcortical structures and the sense receptors.

An EEG electrode mainly detects the neuronal activity in the brain region just beneath it. However, the electrodes receive the activity from thousands of neurons. One square millimeter of cortex surface, for example, has more than 100,000 neurons. It is only when the input to a region is synchronized with electrical activity occurring at the same time that simple periodic waveforms in the EEG become distinguishable.

The spatial and temporal pattern associated with specific brainwaves can be digitized and encoded in software code. It has been observed that “playing back the brainwaves” to another animal or person by providing decoded temporal pattern through transcranial direct current stimulation (tDCS), transcranial alternating current stimulation (tACS), high definition transcranial alternating current stimulation (HD-tDCS), transcranial magnetic stimulation (TMS), or through electrodes implanted in the brain allows the recipient to achieve the emotional or mental state at hand or to increase a speed of achievement. For example, if the brainwaves of a mouse navigated a familiar maze are decoded (by EEG or via implanted electrodes), playing this temporal pattern to another mouse unfamiliar with this maze will allow it to learn to navigate this maze faster.

Similarly, recording brainwaves associated with a specific emotional or mental response of one subject and later “playing back” this response to another subject will induce a similar emotional or mental response in the second subject. More generally, when one animal assumes an emotional or mental state, parts of the brain will have characteristic activity patterns. Further, by “artificially” inducing the same pattern in another animal, the other animal will have the same emotional or mental state, or more easily be induced into that state. The pattern of interest may reside deep in the brain, and thus be overwhelmed in an EEG signal by cortical potentials and patterns. However, techniques other than surface electrode EEG may be used to determine and spatially discriminate deep brain activity, e.g., from the limbic system. For example, various types of magnetic sensors may sense deep brain activity. See, e.g., 9,618,591; 9,261,573; 8,618,799; and 8,593,141.

In some cases, EEGs dominated by cortical excitation patterns may be employed to sense the emotional or mental state, since the cortical patterns may correlate with lower-level brain activity. Note that the determination of a state representation of an emotional or mental need not be performed each time the system is used; rather, once the brain spatial and temporal activity patterns and synchronization states associated with a particular emotional or mental states are determined, those patterns may be used for multiple targets and over time.

Similarly, while the goal is, for example, to trigger the target to assume the same brain activity patterns are the

exemplar, this can be achieved in various ways, and these methods of inducing the desired patterns need not be invasive. Further, user feedback, especially in the case of a human emotional or mental state transferee, may be used to tune the process. Finally, using the various senses, especially sight, sound, vestibular, touch, proprioception, taste, smell, vagus afferent, other cranial nerve afferent, etc. can be used to trigger high level mental activity, that in a particular subject achieves the desired metal state, emotion or mood.

Thus, in an experimental subject, which may include laboratory scale and/or invasive monitoring, a set of brain electrical activity patterns that correspond to particular emotions or emotional or mental states is determined. Preferably, these are also correlated with surface EEG findings. For the transferee, a stimulation system is provided that is non-hazardous and non-invasive. For example, audiovisual stimulation may be exclusively used. A set of EEG electrodes is provided to measure brain activity, and an adaptive or genetic algorithm scheme is provided to optimize the audiovisual presentation, seeking to induce in the transferee the target pattern found in the experimental subject. After the stimulation patterns, which may be path dependent, are determined, it is likely that these patterns will be persistent, though over longer time periods, there may be some desensitization to the stimulation pattern(s). In some cases, audiovisual stimulation is insufficient, and TMS or other electromagnetic stimulation (superthreshold, or preferably subthreshold) is employed to assist in achieving the desired state and maintaining it for the desired period.

Such technology can be used to significantly enhance the emotional response to viewing photos, reproduction of art, virtual reality, TV, listening to music, reading a book, etc. The user's emotional state may be primed for the secondary stimulation, to enhance the results.

For example, when a movie is filmed, actors get into their roles and experience real emotions. If we record these emotions by recording their brainwaves during acting and later playing them back to viewers or otherwise induce in the viewers the same emotional states, while they are watching the film, this would significantly enhance the experience. As discussed above, the emotional state of an actor may be determined based on a script, facial recognition, explicit statement of the actor, etc., and need not be deciphered from the EEG.

Similarly, while producing virtual reality, we can couple digital files containing video with files of brainwaves of people present during the recording, who see the nature in real time and experience emotions first hand, which would dramatically enhance VR experience.

In another example, a book or an eBook can be coupled with a file of recorded brainwaves of the writer or an experienced actor who is trained to evoke an emotional response while reading a script may provide the stimulus.

One of the challenges of adapting robotic technology and artificial intelligence (AI) is a typical lack of an emotional response by a human subject to a robot or an AI software agent. Using brainwaves can help evoke a positive emotional response in humans while interacting with robots and/or AI agents.

One purpose of this invention is to enhance an emotional response by a subject while engaged in mood. Yet another purpose of this invention is to enhance an emotional response by a subject while engaged in entertainment.

Still another purpose of this invention is to enhance an emotional response by a subject while engaged with a robot or an artificial intelligence, another purpose of this invention is to assist a person with recalling a past experience, still another purpose of this invention is to assist a person suffering from a form of dementia to recognize the person's family members and friends.

It may be difficult for many to experience the emotional response to a representation of an experience as to the genuine experience. Looking at a photograph of a Grand Canyon does not elicit the same emotional response as seeing the Grand Canyon itself. Looking at a reproduction of Mona Lisa does not elicit the same emotional response as seeing the original painting in Louvre. An immersive experience achieved through virtual reality (VR) applications goes a long way in simulating the reality, but still falls short of eliciting the emotional response comparable with the one associated with real experience.

Elderly people suffering from Alzheimer's disease or other forms of dementia have difficult recalling their past experiences and recognized family members and friends. While in the early stages of the disease they may have difficulty recalling the person's name or identity, but they still recognize a family member as a loved one responding to seeing a family member with a positive emotion. In later stages, however, the patients no longer feel the emotional response upon seeing a family member and are frightened as if seeing a total stranger.

Recording brainwaves while a person is experiencing a strong emotional response to a genuine experience and later transmitting these recorded brainwaves to another or same individual may help experience stronger emotional response. For example, recording brainwaves of a person seeing for the first time the Grand Canyon and transmitting these brainwaves to another (or the same) person who is viewing a photograph of the Grand Canyon or viewing it through VR glasses would enhance the emotional response of that person and help create more genuine immersive experience. Similarly, recording brainwaves of a person seeing for the first time the original painting of Mona Lisa in the Louvre and transmitting these brainwaves to another (or the same) person who is viewing a reproduction of this painting or on a virtual museum tour of the Louvre viewing it through VR glasses would enhance the emotional response of that person and help create more genuine immersive experience.

In another example, recording brainwaves of a musician playing the music in a concert and transmitting these brainwaves to another person who is listening to a recording of this music would enhance the emotional response of that person and help create more genuine immersive experience.

In a further example, recording brainwaves of actors while acting in movie and transmitting these brainwaves to viewers who are watching the movie in a theater, on a television, on a computer, or through VR glasses would enhance the emotional response of that person and help create more genuine immersive experience.

A further example provides that brainwaves associated with specific emotions may be recorded from actors asked to experience these emotions. A library of brainwaves corresponding to specific emotions can be assembled and used to enhance emotional response, for example, of a gamer playing a computer game, with sequences of

emotions triggered in the gamer according to the context or paradigm of the game. There are many applications where such library of brainwaves can be use. Examples include use by law enforcement in helping deescalate a conflict or diffuse a situation by calming down people involved in the conflict or situation. It can be used by health care providers in the hospitals to help patients maintain positive attitude so important to their recovery. It can be used by personnel in psychiatric wards in calming down psychiatric patient without the use of psychotropic medications. It can be used in spas and meditation retreats or by individuals wishing to achieve the relaxation response to induce feeling of peace and calm or, perhaps, even the altered state of consciousness. It can be used by athletes, creative people, scientists and other wishing to get into the "zone" to achieve pick performance or creative inspiration.

In another example, recording brainwaves of a passionate teacher enthusiastically explaining a difficult subject and transmitting these brainwaves to a student who is studying the same subject would enhance the emotional response of that person and help maintain focus, concentration, interest and may even help understand the subject of study.

In a further example, recording brainwaves associated with the emotional response of a person to his family members or friends while in the initial stages of the Alzheimer's disease or another form of dementia and later transmitting these brainwaves to the same person while in a later stages of the disease may help the patient recognize the familiar faces or, at least, create a positive emotional response upon seeing family members reducing the fear and anxiety associate with inability to recognize familiar faces typical for the later stages of Alzheimer's disease and dementia.

The transmission of the brainwaves can be accomplished through direct electrical contact with the electrodes implanted in the brain or remotely employing light, sound, electromagnetic waves and other non-invasive techniques.

Light, sound or invisible electromagnetic fields may be used to remotely convey the temporal pattern of prerecorded brainwaves to a subject, by modulating the encoded temporal frequency on the light, sound or electromagnetic filed signal to which the subject is exposed.

Another embodiment is combining a text with the code encoding the temporal pattern of brainwaves of a person reading the text who has normal or accentuated affect. Say a user is reading a lengthy text (a legal brief or an eBook) on a computer screen. While displaying the text computer monitor (or another light source) generates light frequency corresponding to the temporal pattern of brainwaves of another person reading the same text, prerecorded and embedded with the text. The result is speed reading and improved comprehension and retention of the information while achieving the same emotional states as the other person. This may have use in persons with abnormal psyche, who fail to achieve normal emotional response to media.

Employing light, sound or electromagnetic field to remotely convey the temporal pattern of brainwaves (which may be prerecorded) to a subject by modulating the encoded temporal frequency on the light, sound or electromagnetic filed signal to which the subject is exposed.

When a group of neurons fires simultaneously, the activity appears as a brainwave. Different brainwave-frequencies are linked to different emotional or mental states in the brain.

The EEG pattern may be derived from another individual or individuals, the same individual at a different time, or an in vivo animal model of the desired metal state. The method may therefore replicate a mental state of a first subject in a second subject. The mental state typically is not a state of consciousness or an idea, but rather a subconscious (in a technical sense) state, representing an emotion, readiness, receptivity, or other state, often independent of particular thoughts or ideas. In essence, a mental state of the first subject (a "trainer" or "donor" who is in a desired mental state) is captured by recording neural correlates of the mental state, e.g., as expressed by brain activity patterns, such as EEG or MEG signals. The neural correlates of the first subject, either as direct or recorded representations, may then be used to control a stimulation of the second subject (a "trainee" or "recipient"), seeking to induce the same brain activity patterns in the second subject (recipient/trainee) as were present in the first subject (donor/trainer) to assist the second subject (recipient/trainee) to attain the desired mental state that had been attained by the donor/trainer. In an alternative embodiment, the signals from the first subject (donor/trainer) being in the first mental state are employed to prevent the second subject (recipient/trainee) from achieving a second mental state, wherein the second mental state is an undesirable one.

The source brain wave pattern may be acquired through multichannel EEG or MEG, from a human in the desired brain state. A computational model of the brain state is difficult to create. However, such a model is not required according to the present technology. Rather, the signals may be processed by a statistical process (e.g., PCA or a related technology), or a statistically trained process (e.g., a neural network). The processed signals preferably retain information regarding signal source special location, frequency, and phase. In stimulating the recipient's brain, the source may be modified to account for brain size differences, electrode locations, etc. Therefore, the preserved characteristics are normalized spatial characteristics, frequency, phase, and modulation patterns.

The normalization may be based on feedback from the target subject, for example based on a comparison of a present state of the target subject and a corresponding state of the source subject, or other comparison of known states between the target and source. Typically, the excitation electrodes in the target subject do not correspond to the feedback electrodes or the electrodes on the source subject. Therefore, an additional type of normalization is required, which may also be based on a statistical or statistically trained algorithm.

According to one embodiment, the stimulation of the second subject is associated with a feedback process, to verify that the second subject has appropriately responded to the stimulation, e.g., has a predefined similarity to the mental state as the first subject, has a mental state with a predefined difference from the first subject, or has a desire change from a baseline mental state. Advantageously, the stimulation may be adaptive to the feedback. In some cases, the feedback may be functional, i.e., not based on brain activity per se, or neural correlates of mental state, but rather physical, psychological, or behavioral effects that may be reported or observed.

The feedback typically is provided to a computational model-based controller for the stimulator, which alters stimulation parameters to optimize the stimulation in dependence on a brain and brain state model applicable to the target.

For example, it is believed that brainwaves represent a form of resonance, where ensembles of neurons interact in a coordinated fashion as a set of coupled or interacting oscillators. The frequency of the wave is related to neural responsivity to neurotransmitters, distances along neural pathways, diffusion limitations, etc., and perhaps pacemaker neurons or neural pathways. That is, the same mental state may be represented by different frequencies in two different individuals, based on differences in the size of their brains, neuromodulators present, physiological differences, etc. These differences may be measured in microseconds or less, resulting in fractional changes in frequency. However, if the stimulus is different from the natural or resonant frequency of the target process, the result may be different from that expected. Therefore, the model-based controller can determine the parameters of neural transmission and ensemble characteristics, vis-à-vis stimulation, and resynthesize the stimulus wave to match the correct waveform, with the optimization of the waveform adaptively determined. This may not be as simple as speeding up or slowing down playback of the signal, as different elements of the various waveforms representing neural correlates of mental state may have different relative differences between subjects. Therefore, according to one set of embodiments, the stimulator autocalibrates for the target, based on a correspondence (error) of a measured response to the stimulation and the desired mental state sought by the stimulation. In cases where the results are chaotic or unpredictable based on existing data, a genetic algorithm may be employed to explore the range of stimulation parameters, and determine the response of the target. In some cases, the target has an abnormal or unexpected response to stimulation based on a model maintained within the system. In this case, when the deviance from the expected response is identified, the system may seek to new model, such as from a model repository that may be on-line, such as through the Internet. If the models are predictable, a translation may be provided between an applicable model of a source or trainer, and the applicable model of the target, to account for differences. In some cases, the desired mental state is relatively universal, such as sleep and awake. In this case, the brain response model may be a statistical model, rather than a neural network or deep neural network type implementation.

Thus, in one embodiment, a hybrid approach is provided, with use of donor-derived brainwaves, on one hand, which may be extracted from the brain activity readings (e.g., EEG or MEG) of the first at least one subject (donor), preferably processed by principal component analysis, or spatial principal component analysis, autocorrelation, or other statistical processing technique (clustering, PCA, etc.) or statistically trained technique (backpropagation of errors, etc.) that separates components of brain activity, which can then be modified or modulated based on high-level parameters, e.g., abstractions. See, ml4a.github.io/ml4a/how_neural_networks_are_trained/. Thus, the stimulator may be programmed to induce a series of brain states defined by name (e.g., emotional or mental state 1,

emotional or mental state 2, etc.) or as a sequence of "abstract" semantic labels, icons, or other representations, each corresponding to a technical brain state or sequence of sub-states. The sequence may be automatically defined, based on biology and the system training, and thus relieve the programmer of low-level tasks. However, in a general case, the present technology maintains use of components or subcomponents of the donor's brain activity readings, e.g., EEG or MEG, and does not seek to characterize or abstract them to a semantic level.

According to the present technology, a neural network system or statistical classifier may be employed to characterize the brain wave activity and/or other data from a subject. In addition to the classification or abstraction, a reliability parameter is presented, which predicts the accuracy of the output. Where the accuracy is high, a model-based stimulator may be provided to select and/or parameterize the model, and generate a stimulus for a target subject. Where the accuracy is low, a filtered representation of the signal may be used to control the stimulator, bypassing the model(s). The advantage of this hybrid scheme is that when the model-based stimulator is employed, many different parameters may be explicitly controlled independent of the source subject. On the other hand, where the data processing fails to yield a highly useful prediction of the correct model-based stimulator parameters, the model itself may be avoided, in favor of a direct stimulation type system.

Of course, in some cases, one or more components of the stimulation of the target subject may be represented as abstract or semantically defined signals, and more generally the processing of the signals to define the stimulation will involve high level modulation or transformation between the source signal received from the first subject, to define the target signal for stimulation of the second subject.

Preferably, each component represents a subset of the neural correlates reflecting brain activity that have a high spatial autocorrelation in space and time, or in a hybrid representation such as wavelet. For example, one signal may represent a modulated 10.2 Hz signal, while another signal represents a superposed modulated 15.7 Hz signal, with respectively different spatial origins. These may be separated by optimal filtering, once the spatial and temporal characteristics of the signal are known, and bearing in mind that the signal is accompanied by a modulation pattern, and that the two components themselves may have some weak coupling and interaction.

In some cases, the base frequency, modulation, coupling, noise, phase jitter, or other characteristic of the signal may be substituted. For example, if the first subject is listening to music, there will be significant components of the neural correlates that are synchronized with the particular music. On the other hand, the music per se may not be part of the desired stimulation of the target subject. Therefore, through signal analysis and decomposition, the components of the signal from the first subject, which have a high temporal correlation with the music, may be extracted or suppressed from the resulting signal. Further, the target subject may be in a different acoustic environment, and it may be appropriate to modify the residual signal dependent on the acoustic environment of the target subject, so that the stimulation is appropriate for achieving the desired effect, and does not represent phantoms, distractions, or irrelevant or inappropriate content. In order to perform processing, it is convenient to store

the signals or a partially processed representation, though a complete real-time signal processing chain may be implemented. Such a real-time signal processing chain is generally characterized in that the average size of a buffer remains constant, i.e., the lag between output and input is relatively constant, bearing in mind that there may be periodicity to the processing.

The mental state of the first subject may be identified, and the neural correlates of brain activity captured. The second subject is subject to stimulation based on the captured neural correlates and the identified mental state. The mental state may be represented as a semantic variable, within a limited classification space. The mental state identification need not be through analysis of the neural correlates signal, and may be a volitional self-identification by the first subject, a manual classification by third parties, or an automated determination. The identified mental state is useful, for example, because it represents a target toward (or against) which the second subject can be steered.

The stimulation may be one or more inputs to the second subject, which may be an electrical or magnetic transcranial stimulation, sensors stimulation, mechanical stimulation, ultrasonic stimulation, etc., and controlled with respect to waveform, intensity/amplitude, duration, feedback, self-reported effect by the second subject, manual classification by third parties, automated analysis of brain activity, behavior, physiological parameters, etc. of the second subject.

The process may be used to induce in the target subject neural correlates of the desired mental state, which are derived from a different time for the same person, or a different person at the same or a different time. For example, one seeks to induce the neural correlates of the first subject in a desired mental state in a second subject, through the use of stimulation parameters comprising a waveform over a period of time derived from the neural correlates of mental state of the first subject.

The first and second subjects may be spatially remote from each other, and may be temporally remote as well. In some cases, the first and second subject are the same animal (e.g., human), temporally displaced. In other cases, the first and second subject are spatially proximate to each other. In some cases, neural correlates of a desired mental state are derived from a mammal having a simpler brain, which are then extrapolated to a human brain. (Animal brain stimulation is also possible, for example to enhance training and performance). When the first and second subjects share a common environment, the signal processing of the neural correlates, and especially of real-time feedback of neural correlates from the second subject may involve interactive algorithms with the neural correlates of the first subject.

The first and second subjects may each be subject to stimulators. The first subject and the second subject may communicate with each other in real-time, with the first subject receiving stimulation based on the second subject, and the second subject receiving feedback based on the first subject. This can lead to synchronization of mental state between the two subjects. However, the first subject need not receive stimulation based on real-time signals from the second subject, as the stimulation may derive from a third subject, or the first or second subjects at different points in

time.

The neural correlates may be, for example, EEG, qEEG, or MEG signals. Traditionally, these signals are found to have dominant frequencies, which may be determined by various analyses. One embodiment provides that the modulation pattern of a brainwave of the first subject is determined independent of the dominant frequency of the brainwave (though typically within the same class of brainwaves), and this modulation imposed on a wave corresponding to the dominant frequency of the second subject. That is, once the second subject achieves that same brainwave pattern as the first subject (which may be achieved by means other than electromagnetic, mechanical, or sensors stimulation), the modulation pattern of the first subject is imposed as a way of guiding the mental state of the second subject.

The second subject may be stimulated with a stimulation signal which faithfully represents the frequency composition of a defined component of the neural correlates of the first subject.

The stimulation may be performed, for example, by using a tDCS device, a high-definition tDCS device, a tACS device, a TMS device, a deep TMS device, and a source of one of a light signal and a sound signal configured to modulate the dominant frequency on the one of a light signal and a sound signal. The stimulus may be at least one of a light signal, a sound signal, an electric signal, and a magnetic field. The electric signal may be a direct current signal or an alternating current signal. The stimulus may be a transcranial electric stimulation, a transcranial magnetic stimulation, a deep magnetic stimulation, a light stimulation, or a sound stimulation. A visual stimulus may be ambient light or a direct light. An auditory stimulus may be binaural beats or isochronic tones.

The technology may also provide a processor configured to process the neural correlates of mental state from the first subject, and to produce or define a stimulation pattern for the second subject selectively dependent on a waveform pattern of the neural correlates from the first subject. Typically, the processor performs signal analysis and calculates at least a dominant frequency of the brainwaves of the first subject, and preferably also spatial and phase patterns within the brain of the first subject.

A signal is presented to a second apparatus, configured to stimulate the second subject, which may be an open loop stimulation dependent on a non-feedback controlled algorithm, or a closed loop feedback dependent algorithm. In other cases, analog processing is employed in part or in whole, wherein the algorithm comprises an analog signal processing chain. The second apparatus receives information from the processor (first apparatus), typically comprising a representation of a portion of a waveform represented in the neural correlates. The second apparatus produces a stimulation intended to induce in the second subject the desired mental state, e.g., representing the same mental state as was present in the first subject.

A typical process performed on the neural correlates is a filtering to remove noise. For example, notch filters may be provided at 50 Hz, 60 Hz, 100 Hz, 120 Hz, and additional overtones. Other environmental signals may also be filtered in a frequency-selective or waveform-selective (temporal) manner. Higher level filtering may also be

employed, as is known in the art. The neural correlates, after noise filtering, may be encoded, compressed (lossy or losslessly), encrypted, or otherwise processed or transformed. The stimulator associated with the second subject would typically perform decoding, decompression, decryption, inverse transformation, etc.

Information security and copy protection technology, similar to that employed for audio signals, may be employed to protect the neural correlate signals from copying or content analysis before use. In some cases, it is possible to use the stored encrypted signal in its encrypted for, without decryption. For example, with an asymmetric encryption scheme, which supports distance determination. See U.S. 7,269,277; Sahai and Waters (2005) Annual International Conference on the Theory and Applications of Cryptographic Techniques, pp. 457-473. Springer, Berlin, Heidelberg; Bringer et al. (2009) IEEE International Conference on Communications, pp. 1-6; Juels and Sudan (2006) Designs, Codes and Cryptography 2:237-257; Thaker et al. (2006) IEEE International Conference on Workload Characterization, pp. 142-149; Galil et al. (1987) Conference on the Theory and Application of Cryptographic Techniques, pp. 135-155.

Because the system may act intrusively, it may be desirable to authenticate the stimulator or parameters employed by the stimulator before use. For example, the stimulator and parameters it employs may be authenticated by a distributed ledger, e.g., a blockchain. On the other hand, in a closed system, digital signatures and other hierarchical authentication schemes may be employed. Permissions to perform certain processes may be defined according to smart contracts, which automated permissions (i.e., cryptographic authorization) provided from a blockchain or distributed ledger system. Of course, centralized management may also be employed.

In practice, the feedback signal from the second subject may be correspondingly encoded as per the source signal, and the error between the two minimized. In such an algorithm, the signal sought to be authenticated is typically brought within an error tolerance of the encrypted signal before usable feedback is available. One way to accomplish this is to provide a predetermined range of acceptable authenticatable signals which are then encoded, such that an authentication occurs when the putative signal matches any of the predetermined range. In the case of the neural correlates, a large set of digital hash patterns may be provided representing different signals as hash patterns. The net result is relatively weakened encryption, but the cryptographic strength may still be sufficiently high to abate the risks.

The processor may perform a noise reduction distinct from a frequency-band filtering. The neural correlates may be transformed into a sparse matrix, and in the transform domain, components representing high probability noise are masked, while components representing high probability signal are preserved. The distinction may be optimized or adaptive. That is, in some cases, the components which represent modulation that are important may not be known a priori. However, dependent on their effect in inducing the desired response in the second subject, the "important" components may be identified, and the remainder filtered or suppressed. The transformed signal may then be inverse-transformed, and used as a basis for a stimulation signal.

A mental state modification, e.g., brain entrainment, may be provided, which ascertains a mental state in a plurality of first subjects; acquires brainwaves of the plurality of first subjects, e.g., using one of EEG and MEG, to create a dataset containing representing brainwaves of the plurality of first subjects. The database may be encoded with a classification of mental state, activities, environment, or stimulus patterns, applied to the plurality of first subjects, and the database may include acquired brainwaves across a large number of mental states, activities, environment, or stimulus patterns, for example. In many cases, the database records will reflect a characteristic or dominate frequency of the respective brainwaves. As discussed above, the trainer or first subject is a convenient source of the stimulation parameters, but is not the sole available source. The database may be accessed according to its indexing, e.g., mental states, activities, environment, or stimulus patterns, for example, and a stimulation pattern for a second subject defined based on the database records of one or more subjects.

The record(s) thus retrieved are used to define a stimulation pattern for the second subject. The selection of records, and their use, may be dependent on the second subject and/or feedback from the second subject. As a relatively trivial example, a female second subject could be stimulated principally dependent on records from female first subjects. Of course, a more nuanced approach is to process the entirety of the database and stimulate the second subject based on a global brain wave-stimulus model, though this is not required, and also, the underlying basis for the model may prove unreliable or inaccurate. In fact, it may be preferred to derive a stimulus waveform from only a single first subject, in order to preserve micro-modulation aspects of the signal, which as discussed above have not been fully characterized. However, the selection of the first subject(s) need not be static, and can change frequently. The selection of first subject records may be based on population statistics of other users of the records (i.e., collaborative filtering, i.e., whose response pattern do I correlate highest with? etc.). The selection of first subject records may also be based on feedback patterns from the second user.

The process of stimulation may seek to target a desired mental state in the second subject, which is automatically or semi-automatically determined of manually entered. That target then represents a part of the query against the database to select the desired record(s). The selection of records may be a dynamic process, and reselection of records may be feedback dependent.

The records may be used to define a modulation waveform of a synthesized carrier or set of carriers, and the process may include a frequency domain multiplexed multi-subcarrier signal (which is not necessarily orthogonal). A plurality of stimuli may be applied concurrently, through the suffered subchannels and/or though different stimulator electrodes, magnetic field generators, mechanical stimulators, sensory stimulators, etc. The stimuli for the different subchannels or modalities need not be derived from the same records.

The stimulus may be applied to achieve the desired mental state, e.g., brain entrainment of the second subject with one or more first subjects. Brain entrainment is not the only possible outcome of this process. If the plurality of first subjects are mutually entrained, then each will have a corresponding brain wave pattern dependent on the basis

of brainwave entrainment. This link between first subject may be helpful in determining compatibility between a respective first subject and the second subject. For example, characteristic patterns in the entrained brainwaves may be determined, even for different target mental states, and the characteristic patterns correlated to find relatively close matches and to exclude relatively poor matches.

This technology may also provide a basis for a social network, dating site, employment or vocational testing, or other interpersonal environments, wherein people may be matched with each other based on entrainment characteristics. For example, people who efficiently entrain with each other may have better social relationships than those who do not. Thus, rather than seeking to match people based on personality profiles, the match could be made based on an ability of each party to efficiently entrain the brainwave pattern of the other party. This enhances non-verbal communication, and assists in achieving corresponding states during activities. This can be assessed by monitoring neural responses of each individual to video, and also by providing a test stimulation based on the other party's brainwave correlates of mental state, to see whether coupling is efficiently achieved. On the other hand, the technology could be used to assist in entrainment when natural coupling is inefficient, or to block coupling where the coupling is undesirable. An example of the latter is hostility; when two people are entrained in a hostile environment, emotional escalation ensures. However, if the entrainment is attenuated, undesired escalation may be impeded.

As discussed above, the plurality of first subjects may have their respective brain wave patterns stored in association with separate database records. However, they may also be combined into a more global model. One such model is a neural network or deep neural network. Typically, such a network would have recurrent features. Data from a plurality of first subjects is used to train the neural network, which is then accessed by inputting the target state and/or feedback information, and which outputs a stimulation pattern or parameters for controlling a stimulator. When multiple first subjects form the basis for the stimulation pattern, it is preferred that the neural network output parameters of the stimulation, derived from and comprising features of the brain wave patterns or other neural correlates of mental state from the plurality of first subjects, which are then used to control a stimulator which, for example, generates its own carrier wave(s) which are then modulated based on the output of the neural network. The neural network need not periodically retrieve records, and therefore may operate in a more time-continuous manner, rather than the more segmented scheme of record-based control.

In any of the feedback dependent methods, the brainwave patterns or other neural correlates of mental state may be processed by a neural network, to produce an output that guides or controls the stimulation. The stimulation, is, for example, at least one of a light (visual) signal, a sound signal, an electric signal, a magnetic field, and a vibration or mechanical stimulus, or other sensory input. The fields may be static or dynamically varying.

The process may employ a relational database of mental states and brainwave patterns, e.g., frequencies/neural correlate waveform patterns associated with the respective mental states. The relational database may comprise a first table, the first table further comprising a plurality of data records of brainwave patterns, and a second table, the

second table comprising a plurality of mental states, each of the mental states being linked to at least one brainwave pattern. Data related to mental states and brainwave patterns associated with the mental states are stored in the relational database and maintained. The relational database is accessed by receiving queries for selected mental states, and data records are returned representing the associated brainwave pattern. The brainwave pattern retrieved from the relational database may then be used for modulating a stimulator seeking to produce an effect selectively dependent on the mental state at issue.

A computer apparatus may be provided for creating and maintaining a relational database of mental states and frequencies associated with the mental states, the computer apparatus comprising: a non-volatile memory for storing a relational database of mental states and neural correlates of brain activity associated with the mental states, the database comprising a first table, the first table further comprising a plurality of data records of neural correlates of brain activity associated with the mental states, and a second table, the second table comprising a plurality of mental states, each of the mental states being linked to one or more records in the first table; a processor coupled with the non-volatile memory, configured to process relational database queries, which are then used for searching the database; RAM coupled with the processor and the non-volatile memory for temporary holding database queries and data records retrieved from the relational database; and an I/O interface configured to receive database queries and deliver data records retrieved from the relational database. A SQL or noSQL database may also be used to store and retrieve records.

A further aspect of the technology provides a method of brain entrainment comprising: ascertaining a mental state in a first subject; recording brainwaves of the plurality of subjects using at least one channel one of EEG and MEG; storing the recorded brainwaves in a physical memory device; retrieving the brainwaves from the memory device; applying a stimulus signal comprising a brainwave pattern derived from at least one-channel one of the EEG and MEG to a second subject via transcranial stimulation, whereby the mental state desired by the second subject is achieved. The stimulation may be of the same order (number of channels) as the EEG or MEG, or a different number of channels, typically reduced. For example, the EEG or MEG may comprise 128 or 256 channels, while the transcranial stimulator may have 8 or fewer channels. Sensory stimulation of various modalities and patterns may accompany the transcranial stimulation.

The at least one channel may be less than six channels and the placement of electrodes used for transcranial stimulation may be approximately the same as the placement of electrodes used in recording of said one of EEG and MEG.

The present technology may be responsive to chronobiology, and in particular to the subjective sense of time. For a subject, this may be determined volitionally subjectively, but also automatically, for example by judging attention span, using e.g., eye movements, and analyzing persistence of brainwave patterns or other physiological parameters after a discrete stimulus. Further, time-constants of the brain, reflected by delays and phase may also be analyzed.

Further, the contingent negative variation (CNV) preceding a volitional act may be used, both to determine (or measure) conscious action timing, and also the time relationships between thought and action more generally.

Typically, brainwave activity is measured with a large number of EEG electrodes, which each receive signals from a small area on the scalp, or in the case of a MEG, by a number of sensitive magnetic field detectors, which are responsive to local field differences. Typically, the brainwave capture is performed in a relatively high number of spatial dimensions, e.g., corresponding to the number of sensors. It is often unfeasible to process the brainwave signals to create a source model, given that the brainwaves are created by billions of neurons, connected through axons, which have long distances. Further, the neurons are generally non-linear, and interconnected. However, a source model is not required.

Various types of artificial intelligence techniques may be exploited to analyze the neural correlates of an emotional or mental state represented in the brain activity data of both the first subject (donor) (or plurality of donors) and the second subject (recipient). The algorithm or implementation need not be the same, though in some cases, it is useful to confirm the approach of the source processing and feedback processing so that the feedback does not achieve or seek a suboptimal target emotional or mental state. However, given the possible differences in conditions, resources, equipment, and purpose, there is no necessary coordination of these processes. The artificial intelligence may take the form of neural networks or deep neural networks, though rule/expert-based systems, hybrids, and more classical statistical analysis may be used. In a typical case, an artificial intelligence process will have at least one aspect, which is non-linear in its output response to an input signal, and thus at least the principle of linear superposition is violated. Such systems tend to permit discrimination, since a decision and the process of decision-making are, ultimately, non-linear. An artificially intelligent system requires a base of experience or information upon which to train. This can be a supervised (external labels applied to data), unsupervised (self-discrimination of classes), or semi-supervised (a portion of the data is externally labelled).

A self-learning or genetic algorithm may be used to tune the system, including both or either the signal processing at the donor system and the recipient system. In a genetic algorithm feedback-dependent self-learning system, the responsivity of a subject, e.g., the target, to various kinds of stimuli may be determined over a stimulus space. This stimulation may be in the context of use, with a specific target emotional or mental state provided, or unconstrained. The stimulator may operate using a library of stimulus patterns, or seek to generate synthetic patterns or modifications of patterns. Over a period of time, the system will learn to map a desired emotional or mental state to optimal context-dependent parameters of the stimulus pattern.

In some cases it may be appropriate to administer a drug or pharmacological agent, such as melatonin, hypnotic or soporific drug, a sedative (e.g., barbiturates, benzodiazepines, nonbenzodiazepine hypnotics, orexin antagonists, antihistamines, general anesthetics, cannabis and other herbal sedatives, methaqualone and analogues, muscle relaxants, opioids) that assists in achieving the target emotional or mental state, and for emotional states and/or

dreams, this may include certain psychotropic drugs, such as epinephrine, norepinephrine reuptake inhibitors, serotonin reuptake inhibitors, peptide endocrine hormones, such as oxytocin, ACTH fragments, insulin, etc. Combining a drug with stimulation may reduce the required dose of the drug and the associated side effects of the drug.

The technology may be used to modify or alter a mental state (e.g., from sleep to waking and vice versa) in a subject. Typically, the starting mental state, brain state, or brainwave pattern is assessed, such as by EEG, MEG, observation, stimulus-response amplitude and/or delay, or the like. Of particular interest in uncontrolled environments are automated mental state assessments, which do not rely on human observation or EEG signals, and rather may be acquired through MEG (e.g., SQID, optically-pumped magnetometer), EMG, MMG (magnetomyogram), mechanical (e.g., accelerometer, gyroscope, etc.), data from physiological sensors (e.g., AKG, heartrate, respiration rate, temperature, galvanic skim potential, etc.), or automated camera sensors.

For example, cortical stimulus-response pathways and reflexes may be exercised automatically, to determine their characteristics on a generally continuous basis. These characteristics may include, for example, a delay between stimulus and the observed central (e.g., EEG) or peripheral response (e.g., EMG, limb accelerometer, video). Typically, the same modality will be used to assess the pre-stimulation state, stimulus response, and post-stimulation state, though this is not a limitation.

In order to change the mental state, a stimulus is applied in a way designed to alter the mental state in a desired manner. A state transition table, or algorithm, may be employed to optimize the transition from a starting mental state to a desired mental state. The stimulus may be provided in an open loop (predetermined stimulus protocol) or closed loop (feedback adapted stimulus protocol), based on observed changes in a monitored variable.

Advantageously, a characteristic delay between application of stimulus and determination of response varies with the brain or mental state. For example, some mental states may lead to increased delay or greater variability in delay, while others may lead to decreased or lower variability. Further, some states may lead to attenuation of response, while others may lead to exaggerated response. In addition, different mental states can be associated with qualitatively different responses. Typically, the mere assessment of the brain or mental state should not itself alter the state, though in some cases the assessment and transition influence may be combined. For example, in seeking to assist in achieving a deep sleep state, excitation that disturbs sleep is contraindicated.

In cases where a brainwave pattern is itself determined by EEG (which may be limited to relatively controlled environments), brainwaves representing that pattern represent coherent firing of an ensemble of neurons, defining a phase. One way to change the state is to advance or retard the triggering of the neuronal excitation, which can be a direct or indirect excitation or inhibition, caused, for example, by electrical, magnetic, mechanical, or sensory stimulation. This stimulation may be time-synchronized with the detected (e.g., by EEG) brainwaves, for example with a phase lead or lag with respect to the detected pattern. Further, the excitation can steer the brainwave signal by

continually advancing to a desired state, which through the continual phase rotation represents a different frequency. After the desired new state is achieved, the stimulus may cease, or be maintained in a phase-locked manner to hold the desired state.

A predictive model may be used to determine the current mental state, optimal transition to a desired mental state, when the subject has achieved the desired mental state, and how to maintain the desired mental state. The desired mental state itself may represent a dynamic sequence (e.g., stage 1 → stage 2 → stage 3, etc.), such that the subject's mental state is held for a desired period in a defined condition. Accordingly, the stimulus may be time-synchronized with respect to the measured brainwave pattern.

Direct measurement or determination of brainwaves or their phase relationships is not necessarily required. Rather, the system may determine tremor or reflex patterns. Typically, the reflex patterns of interest involve central pathways, and more preferably brain reflex pathways, and not spinal cord mediated reflexes, which are less dependent on instantaneous brain state. The central reflex patterns can reflect a time delay between stimulation and motor response, an amplitude of motor response, a distribution of response through various afferent pathways, variability of response, tremor or other modulation of motor activity, etc. Combinations of these characteristics may be employed, and different subsets may be employed at different times or to reflect different states. Similar to evoked potentials, the stimulus may be any sense, especially sight, sound, touch/proprioception/pain/etc., though the other senses, such as taste, smell, balance, etc., may also be exercised. A direct electrical or magnetic excitation is also possible. As discussed, the response may be determined through EEG, MEG, or peripheral afferent pathways.

Normalization of brain activity information may be spatial and/or temporal. For example, the EEG electrodes between sessions or for different subject may be in different locations, leading to a distortion of the multichannel spatial arrangement. Further, head size and shape of different individuals is different, and this needs to be normalized and/or encoded as well. The size and shape of the head/skull and/or brain, may also lead to temporal differences in the signals, such as characteristic time delays, resonant or characteristic frequencies, etc.

One way to account for these effects is through use of a time-space transform, such as a wavelet-type transform. It is noted that, in a corresponding way that statistical processes are subject to frequency decomposition analysis through Fourier transforms, they are also subject to time-frequency decomposition through wavelet transforms. Typically, the wavelet transform is a discrete wavelet transform (DWT), though more complex and less regular transforms may be employed. As discussed above, principal component analysis (PCA) and spatial PCA may be used to analyze signals, presuming linearity (linear superposition) and statistical independence of components. However, these presumptions technically do not apply to brainwave data, and practically, one would normally expect interaction between brain wave components (non-independence) and lack of linearity (since "neural networks" by their nature are non-linear), defeating use of PCA or spatial PCA unmodified. However, a field of nonlinear dimensionality reduction provides various techniques to permit corresponding analyses under presumptions of non-

linearity and non-independence.

Therefore, statistical approaches are available for separating EEG signals from other signals, and for analyzing components of EEG signals themselves. According to the present invention, various components that might be considered noise in other contexts, e.g., according to prior technologies, such as a modulation pattern of a brainwave, are preserved. Likewise, interactions and characteristic delays between significant brainwave events are preserved. This information may be stored either integrated with the brainwave pattern in which it occurs, or as a separated modulation pattern that can then be recombined with an unmodulated brainwave pattern to approximate the original subject.

According to the present technology, lossy "perceptual" encoding (i.e., functionally optimized with respect to subjective response) of the brainwaves may be employed to process, store and communicate the brainwave information. In a testing scenario, the "perceptual" features may be tested, so that important information is preserved over information that does not strongly correspond to the effective signal. Thus, while one might not know a priori which components represent useful information, a genetic algorithm may empirically determine which features or data reduction algorithms or parameter sets optimize retention of useful information vs. information efficiency. It is noted that subjects may differ in their response to signal components, and therefore the "perceptual" encoding may be subjective with respect to the recipient. On the other hand, different donors may have different information patterns, and therefore each donor may also require individual processing. As a result, pairs of donor and recipient may require optimization, to ensure accurate and efficient communication of the relevant information. According to the present invention, sleep/wake mental states and their corresponding patterns are sought to be transferred. In the recipient, these patterns have characteristic brainwave patterns. Thus, the donor may be used, under a variety of alternate processing schemes, to stimulate the recipient, and the sleep/wake response of the recipient determined based on objective criteria, such as resulting brainwave patterns or expert observer reports, or subjective criteria, such as recipient self-reporting, survey or feedback. Thus, after a training period, an optimized processing of the donor, which may include filtering, dominant frequency resynthesis, feature extraction, etc., may be employed, which is optimized for both donor and recipient. In other cases, the donor characteristics may be sufficiently normalized, that only recipient characteristics need be compensated. In a trivial case, there is only one exemplar donor, and the signal is oversampled and losslessly recorded, leaving only recipient variation as a significant factor.

Because dominant frequencies tend to have low information content (as compared to the modulation of these frequencies and interrelation of various sources within the brain), one efficient way to encode the main frequencies is by location, frequency, phase, and amplitude. The modulation of a wave may also be represented as a set of parameters. By decomposing the brainwaves according to functional attributes, it becomes possible, during stimulation, to modify the sequence of "events" from the donor, so that the recipient need not experience the same events, in the same order, and in the same duration, as the donor. Rather, a high-level control may select states,

dwell times, and transitions between states, based on classified patterns of the donor brainwaves. The extraction and analysis of the brainwaves of the donors, and response of the recipient, may be performed using statistical processes, such as principle components analysis (PCA), independent component analysis (ICA), and related techniques; clustering, classification, dimensionality reduction and related techniques; neural networks and other known technologies. These algorithms may be implemented on general purpose CPUs, array processors such as GPUs, and other technologies.

In practice, a brainwave pattern of the first subject may be analyzed by a PCA technique that respects the non-linearity and non-independence of the brainwave signals, to extract the major cyclic components, their respective modulation patterns, and their respective interrelation. The major cyclic components may be resynthesized by a waveform synthesizer, and thus may be efficiently coded. Further, a waveform synthesizer may modify frequencies or relationships of components from the donor based on normalization and recipient characteristic parameters. For example, the brain of the second subject (recipient) may have characteristic classified brainwave frequencies 3% lower than the donor (or each type of wave may be separately parameterized), and therefore the resynthesis may take this difference into account. The modulation patterns and interrelations may then be reimposed onto the resynthesized patterns. The normalization of the modulation patterns and interrelations may be distinct from the underlying major cyclic components, and this correction may also be made, and the normalized modulation patterns and interrelations included in the resynthesis. If the temporal modifications are not equal, the modulation patterns and interrelations may be decimated or interpolated to provide a correct continuous time sequence of the stimulator. The stimulator may include one or more stimulation channels, which may be implemented as electrical, magnetic, auditory, visual, tactile, or other stimulus, and/or combinations.

The stimulator is preferably feedback controlled. The feedback may relate to the brainwave pattern of the recipient, and/or context or ancillary biometric basis. For example, if the second subject (recipient) begins to awaken from sleep, which differs from the first subject (donor) sleep pattern, then the stimulator may resynchronize based on this finding. That is, the stimulator control will enter a mode corresponding to the actual state of the recipient, and seek to guide the recipient to a desired state from a current state, using the available range and set of stimulation parameters. The feedback may also be used to tune the stimulator, to minimize error from a predicted or desired state of the recipient subject based on the prior and current stimulation.

The control for the stimulator is preferably adaptive, and may employ a genetic algorithm to improve performance over time. For example, if there are multiple first subjects (donors), the second subject (recipient) may be matched with those donors from whose brainwave signals (or algorithmically modified versions thereof) the predicted response in the recipient is best, and distinguished from those donors from whose brainwave signals the predicted response in the recipient subject poorly corresponds. Similarly, if the donors have brainwave patterns determined over a range of time and context and stored in a database, the selection of alternates from the database may be optimized to ensure

best correspondence of the recipient subject to the desired response.

It is noted that a resynthesizer-based stimulator is not required, if a signal pattern from a donor is available that properly corresponds to the recipient and permits a sufficiently low error between the desired response and the actual response. For example, if a donor and a recipient are the same subject at different times, a large database may be unnecessary, and the stimulation signal may be a minimally processed recording of the same subject at an earlier time. Likewise, in some cases, a deviation is tolerable, and an exemplar signal may be emitted, with relatively slow periodic correction. For example, a sleep signal may be derived from a single subject, and replayed with a periodicity of 90 minutes or 180 minutes, such as a light or sound signal, which may be useful in a dormitory setting, where individual feedback is unavailable or unhelpful.

In some cases, it is useful to provide a stimulator and feedback-based controller on the donor. This will better match the conditions of the donor and recipient, and further allow determination of not only the brainwave pattern of the donor, but also responsivity of the donor to the feedback. One difference between the donors and the recipients is that in the donor, the natural sleep pattern is sought to be maintained and not interrupted. Thus, the adaptive multi-subject database may include data records from all subject, whether selected ab initio as a useful exemplar or not. Therefore, the issue is whether a predictable and useful response can be induced in the recipient from the database record, and if so, that record may be employed. If the record would produce an unpredictable result, or a non-useful result, the use of that record should be avoided. The predictability and usefulness of the responses may be determined by a genetic algorithm, or other parameter-space searching technology.

Figure 1 shows the electric activity of a neuron contributing to a brainwave.

Figure 2 shows transmission of an electrical signal generated by a neuron through the skull, skin and other tissue to be detectable by an electrode transmitting this signal to EEG amplifier.

Figure 3 shows an illustration of a typical EEG setup with a subject wearing a cup with electrodes connected to the EEG machine, which is, in turn, connected to a computer screen displaying the EEG. Figure 4 shows a typical EEG reading. Figure 5 shows one second of a typical EEG signal. Figure 6 shows main brainwave patterns.

Figure 7 shows a flowchart according to one embodiment of the invention. Brainwaves from a subject who is in an emotional state are recorded. Brainwaves associated with the emotion are identified. A temporal pattern in the brainwave associated with the emotion is decoded. The decoded temporal pattern is used to modulate the frequency of at least one stimulus. The temporal pattern is transmitted to the second subject by exposing the second subject to said at least one stimulus.

Figure 8 shows a flowchart according to one embodiment of the invention. Brainwaves in a subject at rest and in an emotional state are recorded, and a brainwave characteristic associated with the emotion is separated by comparing with the brainwaves at rest. A temporal pattern in the brainwave associated with the emotion is decoded and stored. The stored code is used to modulate the temporal pattern on a stimulus, which is transmitted to the

second subject by exposing the second subject to the stimulus

Figure 9 shows a flowchart according to one embodiment of the invention. Brainwaves in a subject in an emotional state are recorded, and a Fourier Transform analysis performed. A temporal pattern in the brainwave associated with the emotion is then decoded and stored. The stored code is then used to modulate the temporal pattern on a stimulus, which is transmitted to the second subject by exposing the second subject to the stimulus.

Figure 10 shows a flowchart according to one embodiment of the invention. Brainwaves in a plurality of subjects in a respective emotional state are recorded. A neural network is trained on the recorded brainwaves associated with the emotion. After the neural network is defined, brainwaves in a first subject engaged in the emotion are recorded. The neural network is used to recognize brainwaves associated with the emotion. A temporal pattern in the brainwaves associated with the emotion is decoded and stored. The code is used to modulate the temporal pattern on a stimulus. Brainwaves associated with the emotion in a second subject are induced by exposing the second subject to the stimulus

Figure 11 shows a flowchart according to one embodiment of the invention. Brainwaves in a subject both at rest and in an emotional state are recorded. A brainwave pattern associated with the emotion is separated by comparing with the brainwaves at rest. For example, a filter or optimal filter may be designed to distinguish between the patterns. A temporal pattern in the brainwave associated with the emotion is decoded, and stored in software code, which is then used to modulate the temporal pattern of light, which is transmitted to the second subject, by exposing the second subject to the source of the light.

Figure 12 shows a flowchart according to one embodiment of the invention. Brainwaves in a subject at rest and in an emotion are recoded. A brainwave pattern associated with the emotion is separated by comparing with the brainwaves at rest. A temporal pattern in the brainwave associated with the emotion is decoded and stored as a temporal pattern in software code. The software code is used to modulate the temporal pattern on a sound signal. The temporal pattern is transmitted to the second subject by exposing the second subject to the sound signal.

Figure 13 shows a flowchart according to one embodiment of the invention. Brainwaves in a subject in an emotional state are recorded, and brainwaves selectively associated with the emotion are identified. A pattern, e.g., a temporal pattern, in the brainwave associated with the emotion, is decoded and used to entrain the brainwaves of the second subject.

Figure 14 shows a schematic representation of an apparatus according to one embodiment of the invention.

Figure 15 shows brainwave real time BOLD (Blood Oxygen Level Dependent) fMRI studies acquired with synchronized stimuli.

Figure 16 shows that a desired metal state may be induced in a target individual (e.g., human, animal), by providing selective stimulation according to a temporal pattern, wherein the temporal pattern is correlated with an EEG pattern of the target when in the desired mental state, or represents a transition which represents an

intermediate toward achieving the desired mental state. The temporal pattern may be targeted to a discrete spatial region within the brain, either by a physical arrangement of a stimulator, or natural neural pathways through which the stimulation (or its result) passes.

Figure 17 shows brainwave entrainment before and after synchronization. See, Understanding Brainwaves to Expand our Consciousness, fractalenlightenment.com/ 14794/spirituality/understanding-brainwaves-to-expand-our-consciousness

Figure 18 shows brainwaves during inefficient problem solving and stress.

Figures 19 and 20 show how binaural beats work. Binaural beats are perceived when two different pure-tone sine waves, both with frequencies lower than 1500 Hz, with less than a 40 Hz difference between them, are presented to a listener dichotically (one through each ear). See, for example, if a 530 Hz pure tone is presented to a subject's right ear, while a 520 Hz pure tone is presented to the subject's left ear, the listener will perceive the auditory illusion of a third tone, in addition to the two pure-tones presented to each ear. The third sound is called a binaural beat, and in this example would have a perceived pitch correlating to a frequency of 10 Hz, that being the difference between the 530 Hz and 520 Hz pure tones presented to each ear. Binaural-beat perception originates in the inferior colliculus of the midbrain and the superior olivary complex of the brainstem, where auditory signals from each ear are integrated and precipitate electrical impulses along neural pathways through the reticular formation up the midbrain to the thalamus, auditory cortex, and other cortical regions.

Figure 21 shows Functional Magnetic Resonance Imaging (fMRI)

Figure 22 shows a photo of a brain forming a new idea.

Figure 23 shows 3D T2 CUBE (SPACE/VISTA) FLAIR & DSI tractography.

Figure 24 shows The EEG activities for a healthy subject during a working memory task.

Figure 25 shows a flowchart according to one embodiment of the invention. Brainwaves in a subject in an emotional state are recorded. Brainwaves associated with the emotion are identified. A temporal pattern in the brainwave associated with the emotion is extracted. First and second dynamic audio stimuli are generated, whose frequency differential corresponds to the temporal pattern. Binaural beats are provided using the first and the second audio stimuli to stereo headphones worn by the second subject to entrain the brainwaves of the second subject.

Figure 25 shows a flowchart according to one embodiment of the invention. Brainwaves of a subject engaged in an emotional state are recorded, and brainwaves associated with the emotion identified. A pattern in the brainwave associated with the emotion is identified, having a temporal variation. Two dynamic audio stimuli whose frequency differential corresponds to the temporal variation are generated, and applied as a set of binaural bits to the second subject, to entrain the brainwaves of the second subject.

Figure 26 shows a flowchart according to one embodiment of the invention. Brainwaves of a subject in an emotional state are recorded, and brainwaves associated with the emotion identified. A pattern in the brainwave

associated with the emotion is identified, having a temporal variation. A series of isochronic tones whose frequency differential corresponds to the temporal variation is generated and applied as a set of stimuli to the second subject, to entrain the brainwaves of the second subject. See:

Figure 27 shows a flowchart according to one embodiment of the invention. Brainwaves of a subject in an emotional state are recorded, and brainwaves associated with the emotion identified. A pattern in the brainwave associated with the emotion is identified, having a temporal variation. Two dynamic light stimuli whose frequency differential corresponds to the temporal variation are generated, and applied as a set of stimuli to the second subject, wherein each eye sees only one light stimulus, to entrain the brainwaves of the second subject.

Figure 28 shows a flowchart according to one embodiment of the invention. Brainwaves of a subject in an emotional state are recorded, and brainwaves associated with the emotion identified. A pattern in the brainwave associated with the emotion is identified, having a temporal variation. Two dynamic electric stimuli whose frequency differential corresponds to the temporal variation are generated, and applied as transcranial stimulation to the second subject, wherein each electric signal is applied to the opposite side of the subject's head, to entrain the brainwaves of the second subject.

Figure 29 shows a flowchart according to one embodiment of the invention. Brainwaves of a subject are recorded at rest, and in an emotional state. A brainwave associated with the emotion is separated from the remainder of the signal by comparison with the brainwaves at rest. A temporal pattern if the brainwave associated with the emotion is decoded, and stored in software code, in a memory. The software code is then used to modulate a temporal pattern in light, which is transmitted to a second subject, who is exposed to the light.

Figure 30 shows picture of brain anatomy. Figure 31 shows a brain map. Figure 32 shows an image depicting neuron anatomy. Figure 33 shows graphs representing a dimensional view of emotions. Figure 34 shows a representation of neural activity with respect to emotional state.

In one embodiment, as shown in Figure 35, brainwaves of the first subject (donor) being in a positive emotional state are recorded 10. A temporal and spatial patterns are decoded from the recorded brainwaves 20 and stored in a non-volatile memory 30. At a later time, the temporal and spatial patters are retrieved from the non-volatile memory 40 and modulated on at least one stimulus 50, which is applied to the first subject via non-invasive brain stimulation technique 60 to induce the positive emotional state. The positive emotional state may be one of or a combination of the state of happiness, joy, gladness, cheerfulness, delight, optimism, merriment, jovialness, vivaciousness, pleasure, excitement, sexual arousal, exuberance, bliss, ecstasy, relaxation, harmony peacefulness.

In another embodiment, as shown in Figure 36, brainwaves of the first subject being in a positive emotional state are recorded using EEG 80. A temporal and spatial patterns are decoded from the EEG 70 and stored in a non-volatile memory 90. At a later time, the temporal and spatial patters are retrieved from the non-volatile memory 100 and modulated on a direct current 110, which is applied to the first subject via transcranial direct current stimulation

(tDCS) 120 to induce the positive emotional state. See Figure 42.

In further embodiment, as shown in Figure 37, brainwaves of the first subject being in a positive emotional state are recorded using EEG 130. A temporal and spatial patterns are decoded from the EEG 140 and stored in a non-volatile memory 150. At a later time, the temporal and spatial patters are retrieved from the non-volatile memory 160 and modulated on an alternating current 170, which is applied to the first subject via transcranial alternating current stimulation (tACS) 180 to induce the positive emotional state. It will be understood by a person skilled in the art that transcranial pulsed current stimulation (tPCS), transcranial random noise stimulation (tRNS), or any other type of transcranial electrical stimulation (tES) may be used. See Figures 43-47.

In certain embodiments, as shown in Figure 38, brainwaves of the first subject being in a positive emotional state are recorded using magnetoencephalogram (MEG) 190. A temporal and spatial patterns are decoded from the MEG 200 and stored in a non-volatile memory 210. At a later time, the temporal and spatial patters are retrieved from the non-volatile memory 220 and modulated on a magnetic field 230, which is applied to the second subject via transcranial magnetic stimulation (tMS) 240 to induce the positive emotional state.

In certain embodiments, as shown in Figure 39, brainwaves of the first subject being in a positive emotional state are recorded using electroencephalogram (EEG) 250. A temporal and spatial patterns are decoded from the EEG 260 and stored in a non-volatile memory 270. At a later time, the temporal and spatial patters are retrieved from the non-volatile memory 280 and modulated on a light signal 290, which is projected to the second subject 300 to induce the positive emotional state. The light signal may be an ambient light, a directed light or a laser beam. The light may be in a visible spectrum or an infrared light. In all embodiments the second subject may the same as the first subject.

In certain embodiments, as shown in Figure 40, brainwaves of the first subject being in a positive emotional state are recorded using electroencephalogram (EEG) 310. A temporal pattern is decoded from the EEG 320 and stored in a non-volatile memory 330. At a later time, the temporal patter is retrieved from the non-volatile memory 340 and modulated on an isotonic sound signal 350, which is projected to the second subject 360 to induce the positive emotional state. The isotonic sound signal may be imbedded in a music or an ambient noise. The sound may be in an audible spectrum, infrasound or ultrasound.

In certain embodiments, as shown in Figure 41, brainwaves of the first subject being in a positive emotional state are recorded using electroencephalogram (EEG) 370. A temporal spatial pattern is decoded from the EEG 380 and stored in a non-volatile memory 390. The first set of frequencies is computed by adding a predetermined delta to the frequencies of the temporal frequency pattern 400. The second set of frequencies is computed by subtracting the delta from the frequencies of the temporal frequency pattern 410. The first set of frequencies is modulated on the first acoustical signal 420. The second set of frequencies is modulated on the second acoustical signal 430. The first acoustic signal is played into an ear of the second subject 440. The second acoustic signal is played into another ear of the second subject 450 thereby producing binaural stimulation to induce the positive emotional state. The isotonic

sound signal may be imbedded in a music or an ambient noise. The sound may be in an audible spectrum, infrasound or ultrasound.

Figure 42 shows graphs of tDCS. tRNS, and tACS stimulation patterns.

Figures 43 and 44 show representations of tDCS neural stimulation.

Figure 45 shows a representation of tACS or tRNS neural stimulation.

Figure 46 shows a representation of intracranial electrode implantation.

Figure 47 shows a representation of tDCS electrode location.

EXAMPLE 1

We record EEG of a first person (source) experiencing an emotional arousal while seeing an authentic scenic view of nature (e.g., standing in front of the Grand Canyon, or Niagara Falls, or Giza Pyramids); then decode the dynamic spatial and/or temporal patterns of the EEG and encode them in software. If a second person (recipient) wants to experience the same emotional arousal while viewing a representation (e.g., a painting, a photograph or a video) of the same scenic view, the software with an encoded dynamic temporal pattern is used to drive “smart bulbs” or another source of light and/or sound while the second person is viewing the representation of the scenic view. The result is an enhanced emotional response and a deeper immersive experience. See Figure 1.

EXAMPLE 2

We record EEG of an actor (or actress) while the actor (or actress) is playing a particular role in a film or theatrical production; we then decode the temporal patterns of the EEG and encode them in software. If another person wants to experience enhanced emotional state while watch the same film or a recording of the theatrical production, the software with encoded temporal pattern is used to drive smart bulbs or another source of light and/or sound while the second person is watching the same film or a recording of the theatrical production. The result is an enhanced emotional response and a deeper immersive experience.

EXAMPLE 3

We record EEG of a first person (source) experiencing an emotional arousal while engaged in an activity (playing a game, sports, etc.); then decode the dynamic spatial and/or temporal patterns of the EEG and encode them in software coupled with the virtual reality representation of the activity. If a second person (recipient) wants to experience the same emotional arousal while viewing the virtual reality representation of the activity, the software with an encoded dynamic temporal pattern is used to drive a current a current used in transcranial electric or magnetic brain stimulation. The result is an enhanced emotional response and a deeper immersive experience.

EXAMPLE 4

A person is reading a book, and during the course of the reading, brain activity, including electrical or magnetic activity, and optionally other measurements, is acquired. The data is processed to determine the frequency and phase, and dynamic changes of brainwave activity, as well as the spatial location of emission. Based on a brain

model, a set of non-invasive stimuli, which may include any and all senses, magnetic nerve or brain stimulation, ultrasound, etc., is devised for a subject who is to read the same book. The set of non-invasive stimuli includes not only content-based components, but also emotional response components. The subject is provided with the book to read, and the stimuli are presented to the subject synchronized with the progress through the book. Typically, the book is presented to the subject through an electronic reader device, such as a computer or computing pad, to assist in synchronization. The same electronic reader device may produce the temporal pattern of stimulation across the various stimulus modalities. The result is that the subject will be guided to the same emotional states as the source of the target brain patterns.

In this description, several preferred embodiments were discussed. Persons skilled in the art will, undoubtedly, have other ideas as to how the systems and methods described herein may be used. It is understood that this broad invention is not limited to the embodiments discussed herein. Rather, the invention is limited only by the following claims.

The aspects of the invention are intended to be separable and may be implemented in combination, sub-combination, and with various permutations of embodiments. Therefore, the various disclosure herein, including that which is represented by acknowledged prior art, may be combined, sub-combined and permuted in accordance with the teachings hereof, without departing from the spirit and scope of the invention.

All references and information sources cited herein are expressly incorporated herein by reference in their entirety.

What is claimed is:

CLAIMS

1. A method for inducing an emotional state in a subject, comprising:

determining a desired emotional state;

selecting a profile from a plurality of profiles stored in a memory, the plurality of profiles each corresponding to a brain activity pattern of at least one exemplar subject under a respective emotional state; and

exposing a target subject to a stimulus modulated according to the selected profile, wherein the exposure, stimulus, and modulation are adapted to induce, in the target subject the desired emotional state.

2. The method according to claim 1, wherein the brain activity pattern is an electroencephalographic brainwave pattern.

3. The method according to claim 1, wherein the brain activity pattern is an magnetoencephalographic brainwave pattern.

4. The method according to claim 1, wherein the brain activity pattern is an electrical brainwave pattern.

5. The method according to claim 1, wherein the brain activity pattern is a metabolic rate pattern.

6. The method according to claim 1, wherein the stimulus comprises a visual stimulus.

7. The method according to claim 1, wherein the stimulus comprises an auditory stimulus.

8. The method according to claim 1, wherein the stimulus comprises an olfactory stimulus.

9. The method according to claim 1, wherein the stimulus comprises a tactile stimulus.

10. The method according to claim 1, wherein the stimulus comprises a proprioceptive stimulus.

11. The method according to claim 1, wherein the stimulus comprises an electrical stimulus.

12. The method according to claim 1, wherein the stimulus comprises a magnetic stimulus.

13. The method according to claim 1, wherein the desired emotional state is selected from the group consisting of happiness, joy, gladness, cheerfulness, bliss, delight, ecstasy, optimism, exuberance, merriment, joviality; vivaciousness, pleasure, excitement, relaxation, harmony, and peace.

14. The method according to claim 1, wherein the exemplar subject and the target subject are the same human at different times.

15. The method according to claim 1, wherein the exemplar subject and the target subject are different humans.

16. The method according to claim 1, wherein the exemplar subject and the target subject are of different species.

17. The method according to claim 1, wherein the stimulus comprises an auditory stimulus adapted to induce binaural beats.

18. The method according to claim 1, wherein the stimulus comprises a dynamically changing electromagnetic field adapted synchronize brainwave patterns corresponding to the brain activity pattern of at least one exemplar subject under the desired emotional state.

19. The method according to claim 1, wherein the selected profile is derived from measurements of brainwave patterns in the exemplar subject selectively acquired during the desired emotional state.

20. The method according to claim 19, wherein the selected profile comprises a model derived from at least spatial, frequency and phase analysis of the measured brainwave patterns.

21. The method according to claim 19, wherein the stimulus comprises an auditory or visual stimulus frequency corresponding to a frequency pattern in a brainwave pattern of the exemplar subject.

22. The method according to claim 1, wherein the target subject is concurrently exposed to the stimulus and a primary audio or visual presentation which does not induce the desired emotional state, wherein the stimulus does not substantially interfere with the target subject appreciation of the audio or visual presentation.

23. The method according to claim 1, further comprising:

recording EEG signals of the exemplar subject in the desired emotional state;

decoding at least one of a temporal and a spatial pattern from the recorded EEG signals; and

storing the decoded at least one of temporal and spatial pattern in a non-volatile memory.

24. The method according to claim 1, further comprising selectively modifying the pattern based on differences between the exemplar subject and the target subject.

25. The method according to claim 1, wherein the stimulus comprises applying a spatial electrical stimulation pattern to the target subject via transcranial electrical stimulation (tES) to induce the desired emotional state.

26. The method according to claim 25, where in the spatial electrical stimulation pattern comprises a direct current.

27. The method according to claim 25, where in the spatial electrical stimulation pattern comprises an alternating current.

28. The method according to claim 25, wherein the transcranial electrical stimulation (tES) is at least one of a transcranial direct current stimulation (tDCS), a transcranial alternating current stimulation (tACS), a transcranial pulsed current stimulation (tPCS) transcranial pulsed current stimulation (tPCS), and a transcranial random noise stimulation (tRNS).

29. The method according to claim 1, wherein the brain activity pattern of the at least one exemplar subject comprises a magnetoencephalogram (MEG), and the stimulus comprises applying a spatial magnetic stimulation pattern to the target subject via transcranial magnetic stimulation (tMS) to induce the desired emotional state.

30. The method according to claim 1, wherein the stimulus achieves brain entrainment in the target subject.

31. The method according to claim 1, further comprising

determining a second desired emotional state;

selecting a second profile from the plurality of profiles stored in a memory; and

exposing a target subject to a stimulus modulated according to the selected second profile, wherein the

exposure, stimulus, and modulation are adapted to induce, in the target subject the desired second emotional state, the second emotional state being different from the first subsequent state and being induced in succession after the emotional state.

32. A method of brainwave entrainment comprising the steps of:

recording EEG of the brainwaves of a first subject in an emotional state;

decoding at least one of a temporal and a spatial pattern from the EEG;

storing a representation of the pattern in a non-volatile memory;

retrieving said pattern from the non-volatile memory

modulating the temporal and spatial patterns on a stimulus signal; and

applying the stimulus signal to a second subject.

33. The method according to claim 32, wherein the stimulus signal is an alternating current, and said applying comprises applying the alternating current to the second subject via transcranial alternating current stimulation (tACS) to induce the emotional state.

34. A method of brainwave entrainment comprising the steps of:

recording EEG of the brainwaves of a first subject in a respective emotional state;

decoding at least one of temporal and spatial pattern from the recorded EEG;

storing said at least one of temporal and spatial pattern in a non-volatile memory;

retrieving said at least one of temporal and spatial pattern from the non-volatile memory;

modulating the temporal and spatial patters on a light signal; and

projecting the light signal to the second subject to induce the respective emotional state.

35. The method of claim 34, wherein the light signal is selected from the group consisting of an ambient light signal, a directional light signal, and a laser beam signal.

36. The method of claim 34, wherein the light signal is selected from the group consisting of a visible spectrum light signal and an infrared light signal.

37. A method of brainwave entrainment comprising the steps of:

recording EEG of the brainwaves of a first subject in an emotional state;

decoding at least one of a temporal and a spatial pattern from the EEG;

storing said at least one of the temporal and the spatial pattern in a non-volatile memory;

retrieving the at least one of the temporal and the spatial pattern from the non-volatile memory;

modulating the temporal and spatial patters on an isotonic sound signal; and

projecting the isotonic sound signal to a second subject to induce the emotional state.

38. A method of brainwave entrainment comprising the steps of:

recording EEG of the brainwaves of a first subject in an emotional state;

decoding temporal frequency pattern from the EEG;

storing the decoded temporal frequency pattern in a memory;

retrieving the temporal frequency pattern from the memory;

computing a first set of frequencies by adding a predetermined delta to the frequencies of the temporal frequency pattern;

computing a second set of frequencies by subtracted the delta from the frequencies of the temporal frequency pattern;

modulating the first set of frequencies on a first acoustical signal;

modulating the second set of frequencies on a second acoustical signal;

projecting the first set of frequencies into a first ear of the second subject; and

projecting the second set of frequencies into a second ear of the second subject,

thereby producing binaural stimulation to induce the emotional state.

39. A method for modifying an emotional state or mood in a subject, comprising:

selecting an emotional state or mood profile from a memory, corresponding to a brain activity pattern of at least one exemplar subject in a respective emotional state or mood; and

exposing a target subject to a stimulus signal modulated according to the selected emotional state or mood profile, to induce, in the target subject the selected emotional state or mood.

40. The method of claim 39, wherein the brain activity patern is acquired through at least one of an electroencephalogram (EEG) and a magnetoencephalogram (EEG).

41. The method of claim 39, wherein the stimulus signal selected from the group consisting of a light, a sound, a touch, a smell, an electric current, and a magnetic field.

42. The method of claim 39, wherein the emotional state or mood is selected from the group consisting of a state of happiness, a state of joy, a state of gladness, a state of cheerfulness, a state of bliss, a state of delight, a state of ecstasy, a state of optimism, a state of exuberance, a state of merriment, a jovial state, a state of vivaciousness, a state of pleasure, a state of excitement, a state of relaxation, a state of harmony, and a state of peace.

43. The method of claim 39, wherein the exemplar subject and the target subject are the same subject at different times.

44. A method of brainwave entrainment comprising the steps of:

recording EEG of a first subject in a positive emotional state;

storing a spatial-temporal pattern corresponding to the EEG in a memory;

modulating a stimulus pattern according to the spatial-temporal pattern; and

stimulating a second subject with the modulated stimulus pattern, to induce the positive emotional state.

45. The method of claim 44, wherein the modulated stimulus pattern comprises a binaural audio stimulus.

46. The method of claim 44, wherein the modulated stimulus pattern comprises a transcranial electrical stimulation.

47. The method of claim 46, wherein the transcranial electrical stimulation comprises a direct current stimulus.

48. The method of claim 46, wherein the transcranial electrical stimulation comprises an alternating current stimulus.

49. The method of claim 46, where in the transcranial electrical stimulation is at least one of a transcranial direct current stimulation (tDCS), a transcranial alternating current stimulation (tACS), a transcranial pulsed current stimulation (tPCS) transcranial pulsed current stimulation (tPCS), and a transcranial random noise stimulation (tRNS).

50. A method of brainwave entrainment comprising the steps of:

modulating a predefined temporal and spatial pattern on a magnetic field; and

applying the modulated magnetic field to the brain of a subject via transcranial magnetic stimulation (tMS) to selectively induce an emotional state corresponding to the predefined temporal and spatial pattern.

51. A method of enhancing emotional response to a presentation by neurostimulation of a subject concurrent with being presented with the at least a portion of the presentation, comprising:

defining information associated with the target emotional state associated with at least a portion of the presentation, derived from recorded brainwaves of donors in the target emotional state; and

generating a neurostimulation pattern based on the information.

52. The method according to claim 51, wherein:

the target emotional state associated with at least a portion of the presentation comprises a series of emotional states synchronized with activity or objects depicted in the presentation;

the information associated with the target emotional state comprises retrieving a plurality of sets of information corresponding to the series of emotional states; and

the neurostimulation pattern comprises defining a series of temporally synchronized neurostimulation patterns based on the plurality of sets of information.

53. The method according to claim 51, wherein the target emotional state is defined by an at least one of an author, a director, and a producer of the presentation.

54. The method according to claim 51, wherein the information is stored in a relational database, having a first table of respective emotional states, and a second table of information relating to neural correlates of the respective emotional states, the first table and the second table being linked together and searchable based on respective emotional state.

55. The method according to claim 51, wherein the information is derived from recorded neural correlates of mental states of a plurality of donors being in the defined emotional state.

56. The method according to claim 55, wherein the information comprises a consensus of brainwave patterns of the plurality of different donors.

57. The method according to claim 55, wherein for each target emotional state, a plurality of different neurostimulation patterns are defined, each different neurostimulation pattern record being derived from a distinct subpopulation of the plurality of different donors, further comprising determining a characteristic of the recipient, and selecting a respective one of the different neurostimulation patterns based on the determined characteristic.

58. The method according to claim 51, wherein the neurostimulation pattern is at least one of an electrical current, a magnetic field, a light signal, and an acoustic signal.

59. The method according to claim 51, wherein the neurostimulation pattern is encoded in the presentation.

60. The method according to claim 51, wherein the neurostimulation pattern is defined by at least one automated processor after receiving the presentation, and in selective dependence on at least one characteristic of the recipient.

61. The method according to claim 51, wherein the presentation comprises an audiovisual presentation.

62. The method according to claim 51, wherein the presentation comprises a virtual reality presentation.

63. The method according to claim 51, wherein the presentation comprises an audiovisual presentation, and the neurostimulation pattern is encoded as at least one of an audio and a visual stimulus within the audiovisual presentation.

64. The method according to claim 63, wherein the neurostimulation pattern is encoded as the at least one of the audio and the visual stimulus within the audiovisual presentation dependent on at least one characteristic of the recipient.

65. The method according to claim 51, wherein the neurostimulation pattern is dependent on automatically generated feedback from the recipient.

66. The method according to claim 51, wherein the neurostimulation pattern is dependent on manually generated feedback from the recipient.

67. A system for increasing emotional response to a presentation by neurostimulation concurrent with presentation of the presentation, comprising:

a memory configured to store a set of information associated with a target emotional state, derived from recorded neural correlates of at least one donor engaged in the respective target emotional state and being associated with predetermined portions of the presentation; and

at least one automated processor configured to define a neurostimulation pattern for a respective portion of the presentation based on the set of information.

68. The system according to claim 67, wherein the presentation defines a series of associations of respective target emotional states with respective portions of the presentation, further comprising a neurostimulator configured to emit a series of the defined neurostimulation patterns synchronized with the series of associations of the respective target emotional states with the respective portions of the presentation.

69. The system according to claim 67, wherein the set of information is stored in a relational database, having a first table of respective emotional states, and a second table of information relating to neural correlates of the respective emotional states, the first table and the second table being linked together and searchable based on respective emotional state.

70. The system according to claim 67, wherein the set of information is derived from recorded neural correlates of a plurality of different donors engaged in a common respective target emotional state.

71. The system according to claim 70, wherein the set of information comprises a consensus of the plurality of different donors.

72. The system according to claim 70, wherein the set of information comprises a plurality of subsets, each subset being derived from a distinct subpopulation of the plurality of different donors, a respective sub-record being selectable from the record based on the determined characteristic.

73. The system according to claim 67, wherein the neurostimulation pattern is configured for modulation of at least one of an electrical current stimulator, a magnetic field stimulator, a light signal stimulator, and an acoustic signal stimulator.

74. The system according to claim 67, wherein the neurostimulation pattern is encoded in the presentation.

75. The system according to claim 67, wherein the neurostimulation pattern is defined by the at least one automated processor dependent on the presentation, and in selective dependence on at least one characteristic of the recipient.

76. The system according to claim 67, wherein the presentation comprises an audiovisual presentation.

77. The system according to claim 67, wherein the presentation comprises a virtual reality presentation.

78. The system according to claim 67, wherein the presentation comprises an audiovisual presentation, and the defined neurostimulation pattern is encoded as at least one of an audio and a visual stimulus within the audiovisual presentation.

79. The system according to claim 67, wherein the defined neurostimulation pattern is dependent on feedback from the recipient.

80. A nontransitory computer readable instructions, storing therein instruction codes for a programmable processor, comprising:

program codes for defining respective neurostimulation pattern associated with achieving a respective target emotional state, derived from recorded neural correlates of donors engaged in the target emotional state;

program codes for associating a respective target emotional state with portions of a presentation; associated with the target emotional state; and

program codes for defining a series of neurostimulation patterns, each respective neurostimulation pattern being temporally synchronized with the portions of the presentation according to the associated respective target emotional state.

81. A method of creating an audiovisual presentation with enhanced emotional appeal, comprising:

identifying at least one emotional state corresponding to at least a portion of the audiovisual presentation;

selecting an appropriate neurostimulation pattern corresponding to said at least one emotional state; and

embedding the appropriate neurostimulation pattern into said at least a portion of the audiovisual presentation.

82. The method of claim 81, wherein the audiovisual presentation is at least one of a digital photograph, a movie, a video, a 3-D video, a holographic video, an audio, an Internet page, a virtual reality presentation, and a computer game.

83. The method of claim 81, wherein the neurostimulation pattern is obtained by:

recording brainwaves of at least one donor in an emotional state; and

extracting at least one of a temporal and a spatial pattern from the recorded brainwaves;

converting said at least one of a temporal and a spatial pattern into a neurostimulation pattern.

84. The method of claim 83, further comprising storing the neurostimulation pattern in a relational database comprising a neurostimulation pattern table linked to an emotional state table, the relational database being configured to retrieve the neurostimulation pattern corresponded to the emotional state.

85. The method of claim 83, wherein the recording is performed using one of an electroencephalogram and magnetoencephalogram.

86. The method of claim 83, wherein the extracting comprises at least one of filtering for noise, performing time-frequency analysis, and performing a statistical analysis.

87. The method of claim 81, wherein the embedded neurostimulation pattern modulates a video element of the audiovisual presentation.

88. The method of claim 81, wherein the embedded neurostimulation pattern modulates an audio element of the audiovisual presentation.

89. The method of claim 88, wherein the modulated element of the audio element of the audiovisual presentation generates binaural beats.

90. The method of claim 81, further comprising selectively modulating at least one of an electric current, a magnetic field, a light, a sound, selectively dependent on the embedded neurostimulation pattern.

91. The method of claim 90, where

the electric current is used for one of a TES, a tDCS, a tACS, an osc-tDCS, a rtDCS, and a tPCS;

the magnetic field is used of one of TMS and rTMS;

light is used for light sensory stimulation; and

the sound is used for auditory sensory stimulation, wherein the auditory sensory stimulation is one of binaural beats and isochronic tones.

92. A method of inducing an emotional state in a target subject, comprising:

determining a desired emotional state;

selecting a profile from a plurality of profiles stored in a memory, the plurality of profiles each corresponding to a brain activity pattern of a donor subject having a respective emotional state; and

exposing the target subject to at least one stimulus modulated according to the selected profile representing and being adapted to induce, in the target subject, the desired emotional state.

93. The method of claim 92, wherein the brain activity pattern is at least one of an electroencephalographic brainwave pattern and a magnetoencephalographic brainwave pattern.

94. The method of claim 92, wherein said at least one stimulus stimulates a cranial nerve of the target subject.

95. The method of claim 92, wherein said at least one stimulus comprises at least one of a visual stimulus, and an auditory stimulus.

96. The method of claim 95, wherein said at least one stimulus comprises a two-channel auditory stimulus adapted to induce binaural beats.

97. The method of claim 92, wherein the stimulus comprises at least one of a tactile stimulus and a proprioceptive stimulus.

98. The method of claim 92, wherein the stimulus comprises an at least one of a direct electrical current and an alternating electrical current.

99. The method of claim 92, wherein the stimulus comprises a magnetic field.

100. The method of claim 92, wherein the desired emotional state is one of happiness, joy, gladness, cheerfulness, bliss, delight, ecstasy, optimism, exuberance, merriment, joviality; vivaciousness, pleasure, excitement, sexual arousal, relaxation, harmony, and peace.

101. The method of claim 92, wherein the target subject is different from the donor subject.

102. The method of claim 92, wherein the target subject is identical with the donor subject and wherein the brain activity pattern of the donor subject was recorded prior to the exposing the target subject to at least one stimulus.

103. The method of claim 92, wherein said at least one stimulus comprises a dynamically changing electromagnetic field adapted to synchronize the target subject's brainwave pattern with a brainwave pattern of the donor subject having the desired emotional state.

104. The method of claim 92, wherein the selected profile is derived from recording of brainwave patterns of the donor subject selectively acquired during the desired emotional state.

105. The method of claim 104, wherein the selected profile comprises a model derived from at least one of a spatial, a frequency and a phase analysis of the recorded brainwave patterns.

106. The method of claim 104, wherein the stimulus comprises at least one of an auditory stimulus and a visual stimulus with a frequency corresponding to at least a frequency pattern in a brainwave pattern of the donor subject.

107. The method of claim 92, further comprising:

recording EEG signals of the donor subject in the desired emotional state;

decoding at least one of a temporal and a spatial pattern from the recorded EEG signals; and

storing the decoded at least one of temporal and spatial pattern in a non-volatile memory as at least one profile.

108. The method of claim 92, further comprising selectively modifying stimulus based on differences between the donor subject, from which the profile is derived, and the target subject.

109. The method of claim 92, wherein the stimulus comprises applying at least one of a temporal and a spatial electrical stimulation pattern to the target subject via transcranial electrical stimulation (TES) to induce the desired emotional state.

110. The method of claim 109, wherein the transcranial electrical stimulation (TES) is at least one of a transcranial direct current stimulation (tDCS), an oscillating transcranial direct current stimulation (osc-tDCS), a transcranial alternating current stimulation (tACS), a transcranial pulsed current stimulation (tPCS), and a transcranial random noise stimulation (tRNS).

111. The method of claim 92, wherein the profile is derived from brain activity pattern of the donor subject comprising a magnetoencephalogram (MEG), and the stimulus comprises applying a spatial magnetic stimulation pattern to the target subject via transcranial magnetic stimulation (TMS) to induce the desired emotional state.

112. The method of claim 92, wherein the stimulus achieves brain entrainment in the target subject.

113. The method of claim 92, further comprising

determining a second desired emotional state;

selecting a second profile from the plurality of profiles stored in a memory; and

exposing the target subject to a stimulus modulated according to the selected second profile, representing and being adapted to induce, in the target subject, the second desired emotional state, the second emotional state being different from the emotional state and being induced in succession after the emotional state.

114. The method of claim 92, wherein at least one profile corresponds to consensus brain activity pattern of a plurality of donor subjects, each of the plurality of donor subjects having the respective emotional state.

115. A method of brainwave entrainment with a brainwave pattern stored in a memory, the brainwave pattern representing at least one of a temporal and spatial decoded pattern from brainwaves of a first subject while in a desired emotional state, comprising:

retrieving said pattern from the memory;

modulating the decoded at least one of the temporal and the spatial pattern on at least one stimulus signal; and

applying said at least one stimulus signal to a second subject, to induce the second subject to assume the emotional state.

116. The method of claim 115, wherein the step of recording brainwaves comprise recording of at least one of electroencephalogram and magnetoencephalogram of the brainwaves.

117. The method of claim 115, wherein the stimulus signal is at least one of a direct current and an alternating current, and said applying comprises applying said at least one of a direct current and an alternating current to the second subject via respectively a transcranial direct current stimulation (tDCS) or transcranial alternating current stimulation (tACS) to induce the desired emotional state.

118. The method of claim 115, wherein said modulating comprises modulating the at least one of the temporal and spatial pattern on at least one of a current, a magnetic field, a light signal, and an acoustic signal.

119. A system for brainwave entrainment, comprising:

a memory, configured to store a brainwave pattern representing at least one of a temporal and spatial decoded pattern from brainwaves of a first subject while in a desired emotional state;

at least one processor configured to modulate the decoded at least one of the temporal and the spatial pattern on at least one stimulus signal; and

a stimulator configured to apply the at least one stimulus signal to a second subject, to induce the second subject to assume the emotional state.

120. The method of claim 119, wherein the stimulator comprises at least one of a current stimulator, a magnetic stimulator, a light signal stimulator, and an acoustic stimulator.

121. A method of recording neural correlates of a desired emotional state from a donor, comprising:

determining an emotional state of the donor;

recording neural correlates of the desired emotional state of the donor when the donor is in the desired emotional state;

analyzing neural correlates of the desired emotional state of the donor to decode at least one of a temporal and a spatial pattern corresponding to the desired emotional state;

converting said at least one of a temporal and a spatial pattern corresponding to the desired emotional state into a neurostimulation pattern; and

storing the neurostimulation pattern in the nonvolatile memory.

122. The method of claim 121, wherein the neural correlates are brainwaves of the donor.

123. The method of claim 122, wherein the step of analyzing neural correlates comprises identifying principal components of the brainwaves.

124. The method of claim 123, wherein the identifying principal components comprises performing one of a principal component analysis (PCA), a curvilinear principal component analysis, an independent component analysis (ICA), a Karhunen–Loève transform (KLT), a singular value decomposition (SVD), and a Factor analysis.

125. The method of claim 123, wherein the step of analyzing neural correlates comprises performing a frequency domain analysis.

126. The method of claim 125, wherein the step of performing the frequency analysis comprises performing one of a Fourier Transform, a Laplace Transform, a Fourier–Stieltjes transform, a Gelfand transform, time-frequency analysis, a short-time Fourier transform, and a fractional Fourier transform.

127. The method of claim 121, wherein the desired emotional state is one of happiness, joy, gladness, cheerfulness, bliss, delight, ecstasy, optimism, exuberance, merriment, joviality; vivaciousness, pleasure, excitement, sexual arousal, relaxation, harmony, and peace.

128. The method of claim 121, further comprising:

retrieving the neurostimulation pattern from the nonvolatile memory; and

stimulating the recipient's brain with at least one stimulus modulated with the neurostimulation pattern to induce the desired emotional state in the recipient.

129. The method of claim 128, wherein said at least one stimulus is one of a direct current, an alternating current, a magnetic field, a light, a sound, a tactile signal and an olfactory signal.

130. The method of claim 128, wherein the recipient is the donor at a point in time subsequent to the time of recording the neural correlates of the emotional state of the donor.

131. The method of claim 128, further comprising determining an emotional state of the recipient to confirm that the recipient is in the desired emotional state.

132. The method of claim 128, further comprising:

developing a brain model of the recipient; and

adjusting said at least one stimulus in accordance with the model to adjust for the differences between the recipient's brain and the donor's brain.

133. The method of claim 128, further comprising the step of administering a pharmacological agent to the recipient to facilitate response of the recipient to said at least one stimulus to induce the desired emotional state.

134. The method of claim 128, further comprising performing, by the recipient, a physical exercise in conjunction with the at least one stimulus.

135. A system for recording neural correlates of a desired emotional state from a donor, comprising:

a first input configured to receive information reflecting an emotional state of the donor;

a second input configured to receive an informational representation of neural correlates of the desired emotional state of the donor when the donor is in the desired emotional state;

at least one processor configured to

analyze neural correlates of the desired emotional state of the donor to decode at least one of a temporal and a spatial pattern corresponding to the desired emotional state; and

convert the at least one of a temporal and a spatial pattern corresponding to the desired emotional state into a neurostimulation pattern; and

a non-volatile memory configured to store the neurostimulation pattern.

136. The system of claim 135, wherein the neural correlates are brainwaves of the donor.

137. The system of claim 135, wherein the neurostimulation pattern is one of an electrical and a magnetic brain stimulation pattern.

138. The system of claim 135, wherein the neurostimulation pattern is one of an audio and visual stimulation pattern.

139. The system of claim 135, wherein the at least one processor comprises at least one single-instruction multiple-data processor.

140. A relational database of neural correlates of emotional states, comprising a first table storing a plurality of respective emotional states, linked with a second table storing information associated with respective emotional states obtained by:

recording neural correlates of the respective emotional state of each of a plurality of donors while in the respective emotional state;

decoding from the recorded neural correlates at least one of a temporal and a spatial pattern corresponding to the plurality of respective emotional states; and

storing information selectively derived from said at least one of the temporal and the spatial pattern corresponding to the plurality of respective emotional states in the second table

141. The relational database of claim 140, wherein the neural correlates of each respective emotional state are brainwaves.

142. The relational database of claim 140, wherein the recording of neural correlates is done by using one of an electroencephalogram and a magnetoencephalogram.

143. The relational database of claim 140, which is accessible by receipt of a respective emotional state and responsive by providing information linked to the respective emotional state.

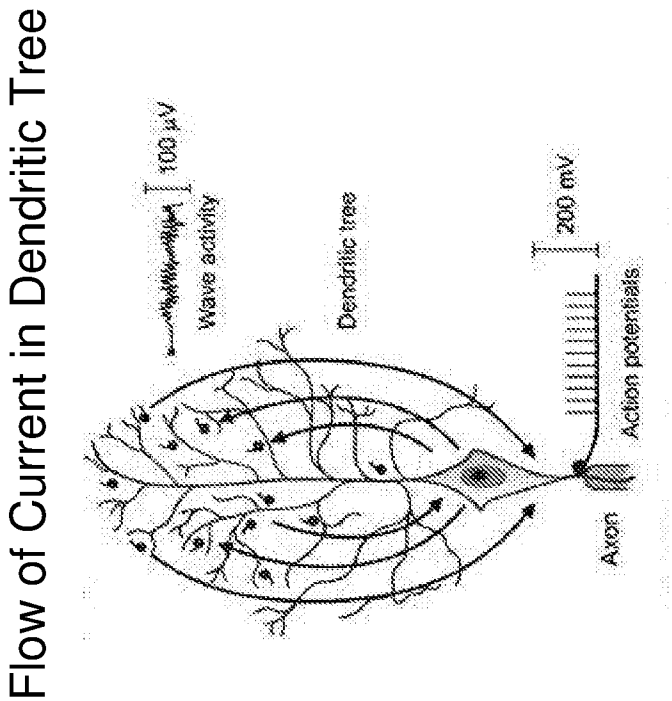


Fig. 1

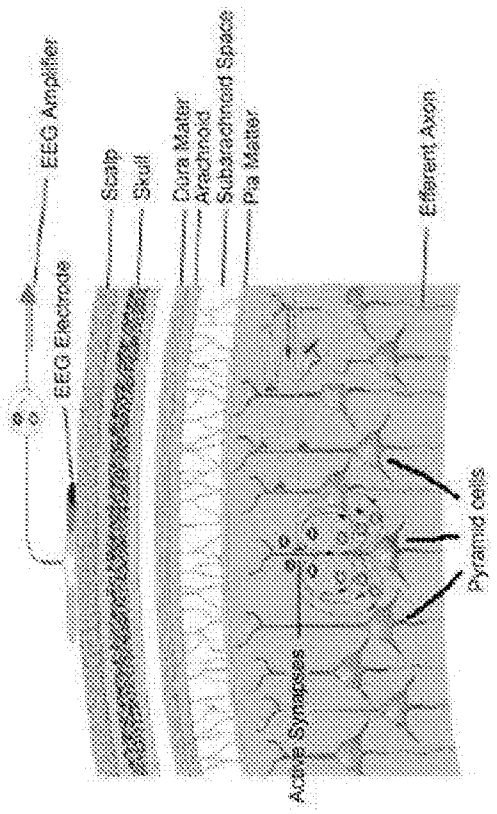


Fig. 2

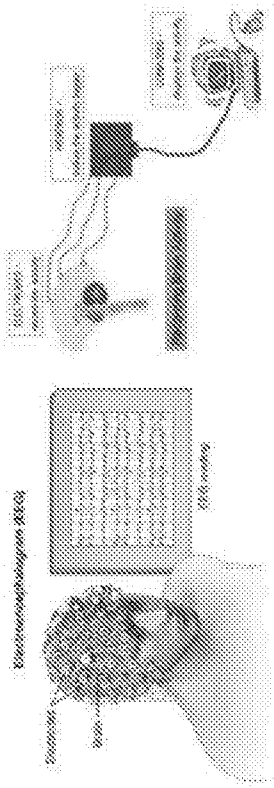


Fig. 3
EEG Reading

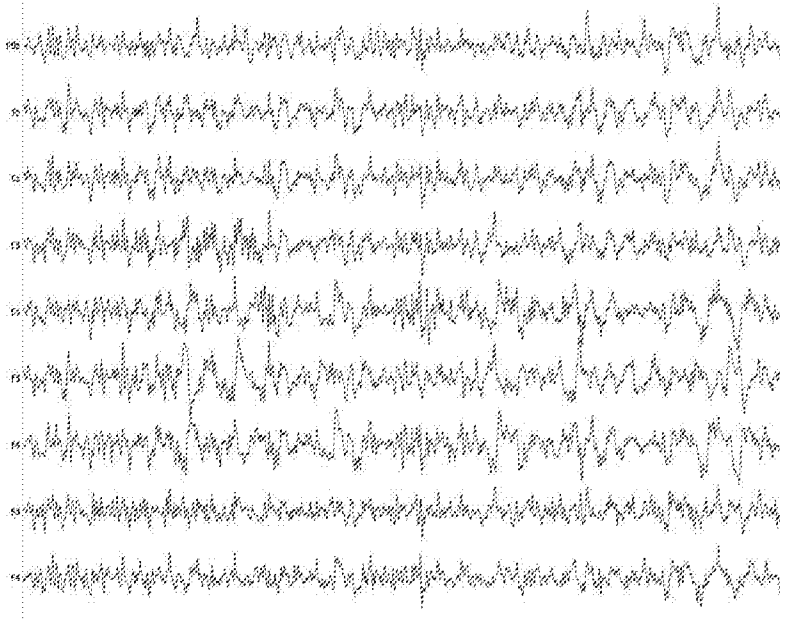


Fig. 4

One second of EEG signal

Fig. 5

Brain Wave Patterns

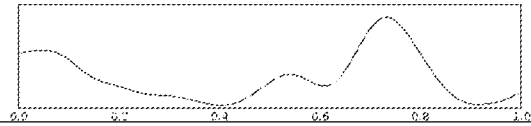
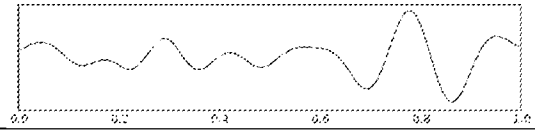
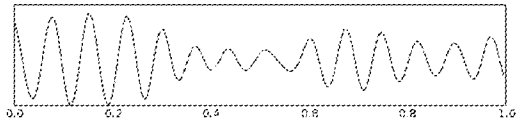
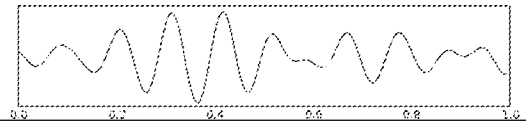
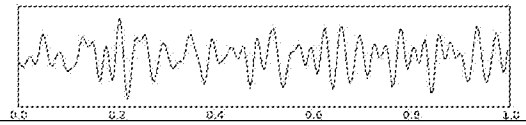
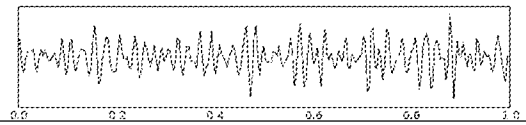
Delta waves 0.1 - 4 Hz	
Theta waves 4 - 8 Hz	
Mu rhythm 8 - 12 Hz Sensorimotor rhythm 12.5 - 15.5 Hz	
Alpha waves 8-14 Hz	
Beta waves 14-30 Hz	
Gamma waves 30-50 Hz	

Fig. 6

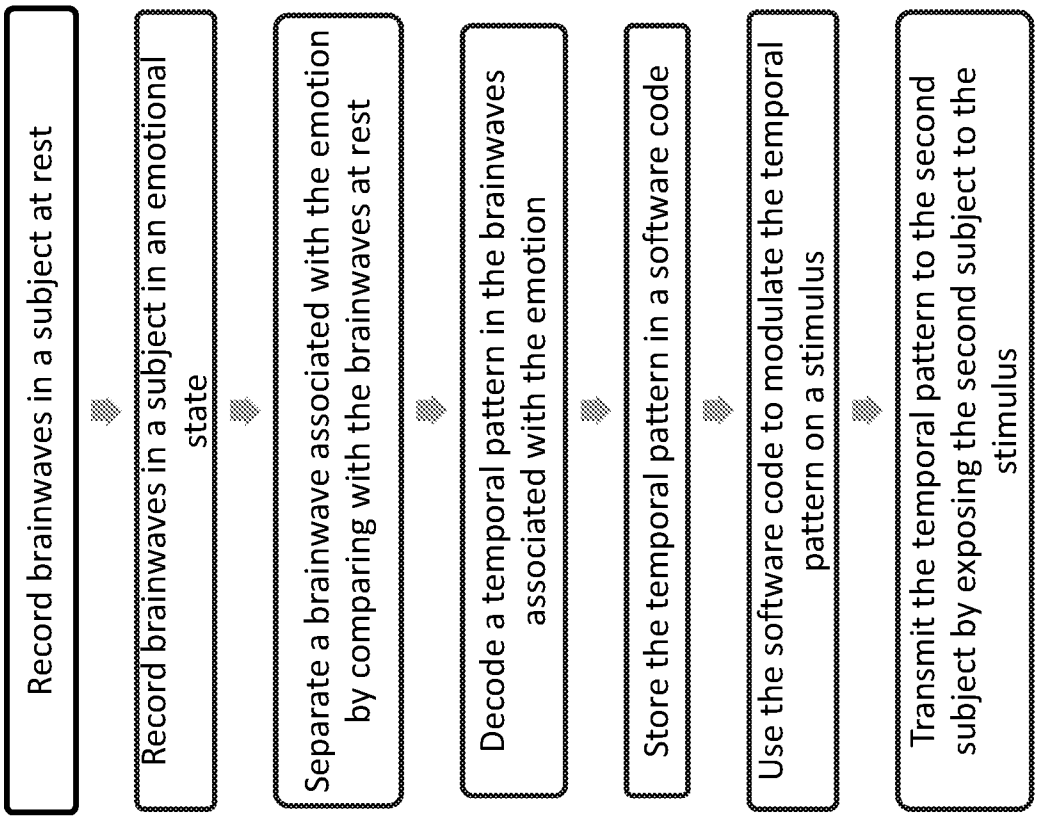

Record brainwaves in a subject at rest
Record brainwaves in a subject in an emotional state
Separate a brainwave associated with the emotion by comparing with the brainwaves at rest
Decode a temporal pattern in the brainwaves associated with the emotion
Store the temporal pattern in a software code
Use the software code to modulate the temporal pattern on a stimulus
Transmit the temporal pattern to the second subject by exposing the second subject to the stimulus

Fig. 7

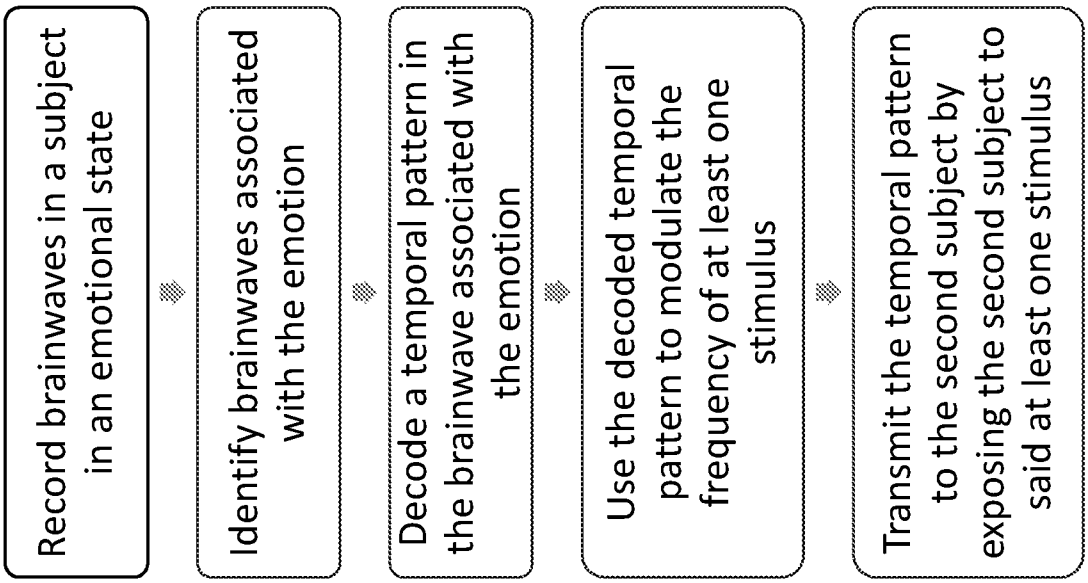

Record brainwaves in a subject in an emotional state
Identify brainwaves associated with the emotion
Decode a temporal pattern in the brainwave associated with the emotion
Use the decoded temporal pattern to modulate the frequency of at least one stimulus
Transmit the temporal pattern to the second subject by exposing the second subject to said at least one stimulus

Fig. 8

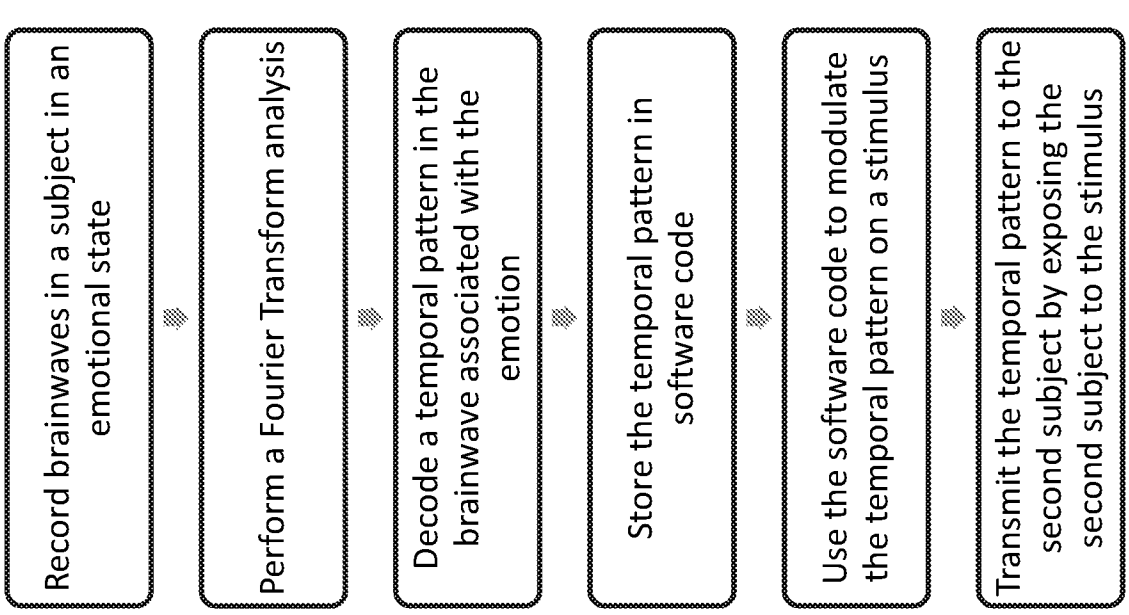

Record brainwaves in a subject in an emotional state
Perform a Fourier Transform analysis
Decode a temporal pattern in the brainwave associated with the emotion
Store the temporal pattern in software code
Use the software code to modulate the temporal pattern on a stimulus
Transmit the temporal pattern to the second subject by exposing the second subject to the stimulus

Fig. 9

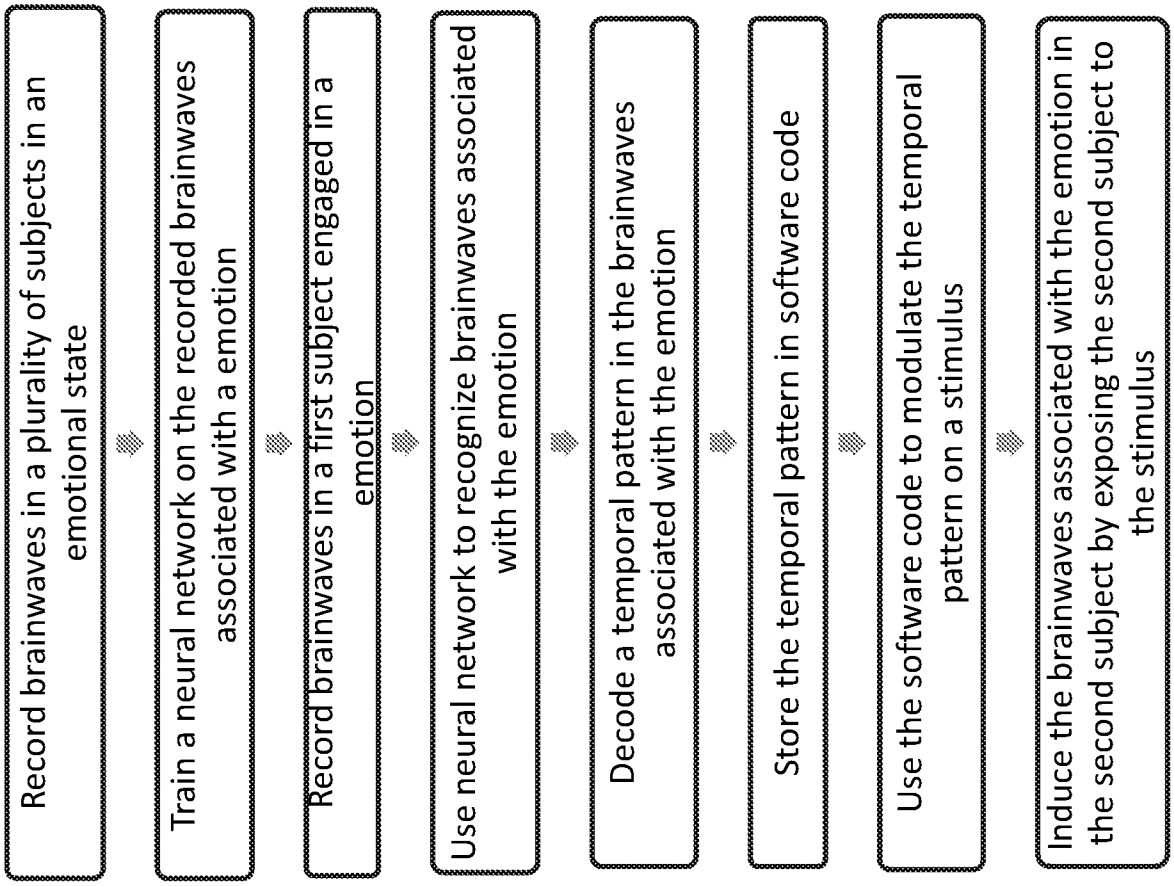

Record brainwaves in a plurality of subjects in an emotional state
Train a neural network on the recorded brainwaves associated with a emotion
Record brainwaves in a first subject engaged in a emotion
Use neural network to recognize brainwaves associated with the emotion
Decode a temporal pattern in the brainwaves associated with the emotion
Store the temporal pattern in software code
Use the software code to modulate the temporal pattern on a stimulus
Induce the brainwaves associated with the emotion in the second subject by exposing the second subject to the stimulus

Fig. 10

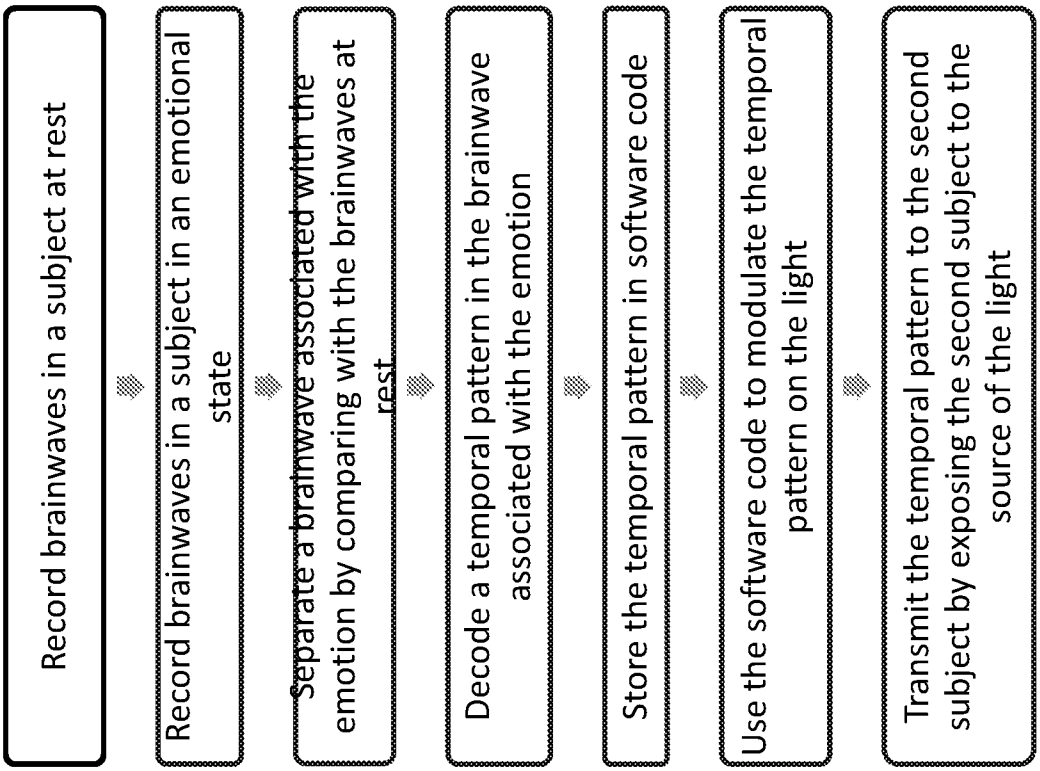

Record brainwaves in a subject at rest
Record brainwaves in a subject in an emotional state
Separate a brainwave associated with the emotion by comparing with the brainwaves at rest
Decode a temporal pattern in the brainwave associated with the emotion
Store the temporal pattern in software code
Use the software code to modulate the temporal pattern on the light
Transmit the temporal pattern to the second subject by exposing the second subject to the source of the light

Fig. 11

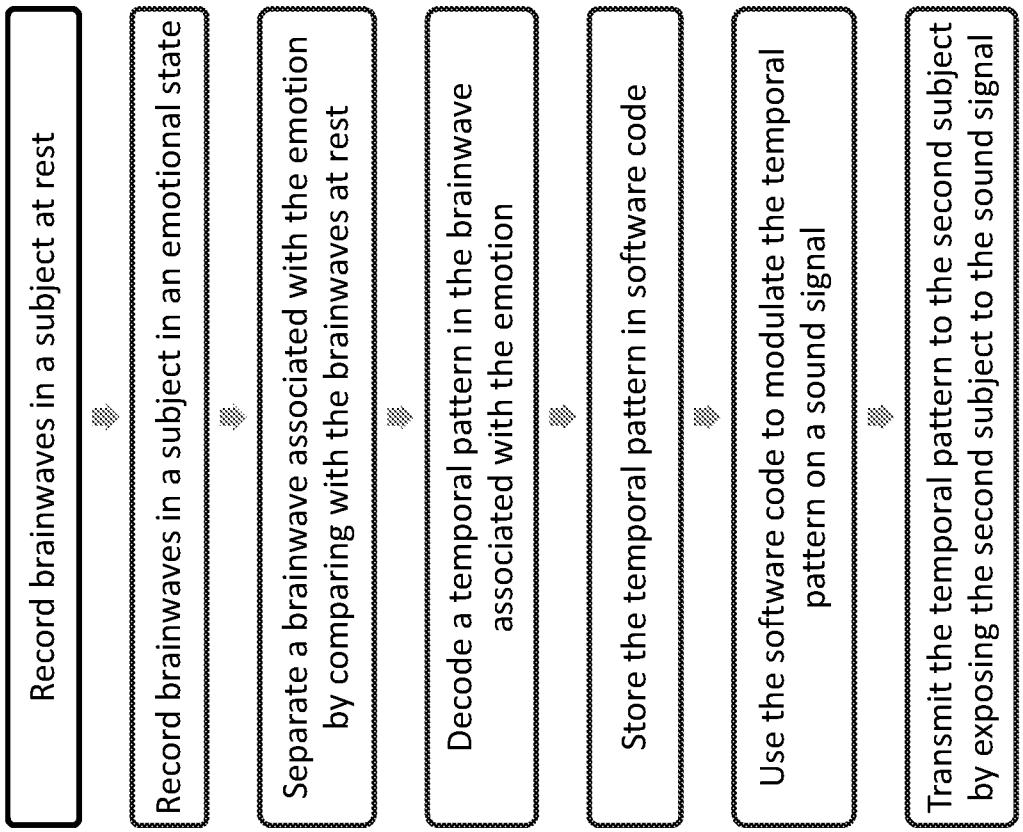

Record brainwaves in a subject at rest
Record brainwaves in a subject in an emotional state
Separate a brainwave associated with the emotion by comparing with the brainwaves at rest
Decode a temporal pattern in the brainwave associated with the emotion
Store the temporal pattern in software code
Use the software code to modulate the temporal pattern on a sound signal
Transmit the temporal pattern to the second subject by exposing the second subject to the sound signal

Fig. 12

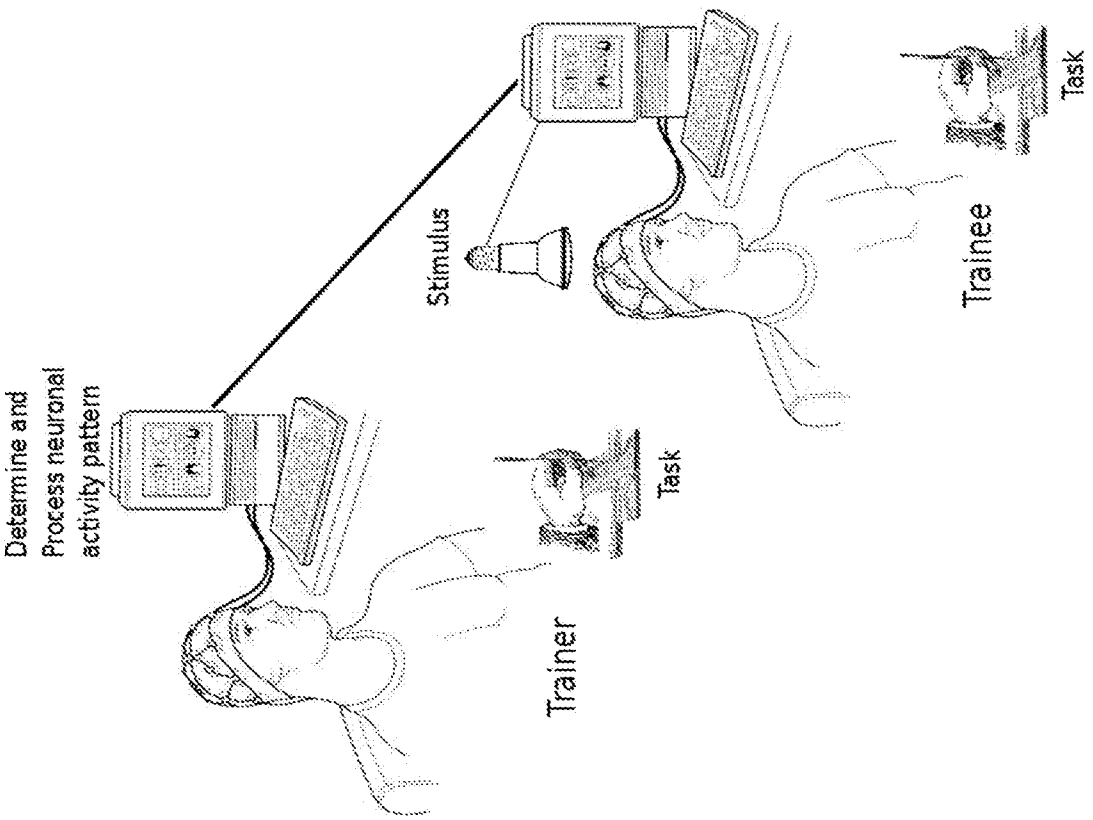

Determine and Process neuronal activity pattern
Stimulus
Trainer
Task
Trainee
Task

Fig. 14

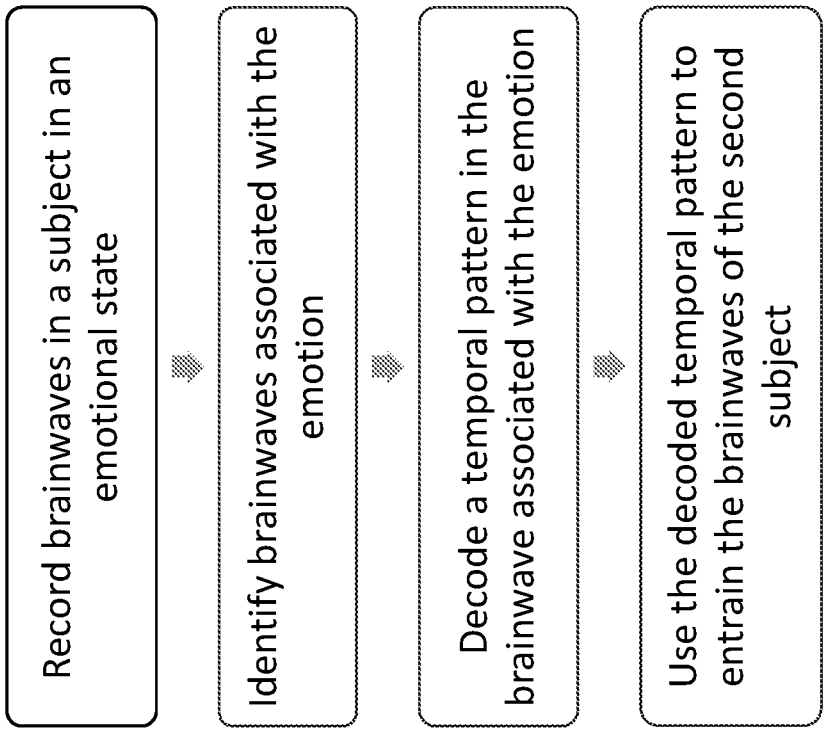

Record brainwaves in a subject in an emotional state
Identify brainwaves associated with the emotion
Decode a temporal pattern in the brainwave associated with the emotion
Use the decoded temporal pattern to entrain the brainwaves of the second subject

Fig. 13

Brainwave RT BOLD (Blood Oxygen Level Dependent) fMRI studies acquired with synchronized stimuli

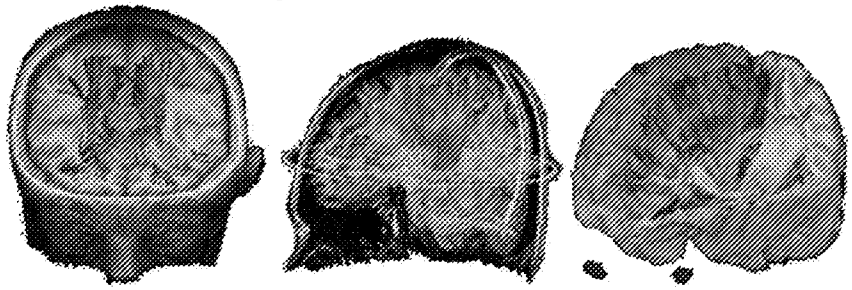


Fig. 15

Brain Entrainment Frequency Following Response (or FFR) Brain Response to 10 Hz Entrainment

Brainwaves (Before) Brainwaves (After)

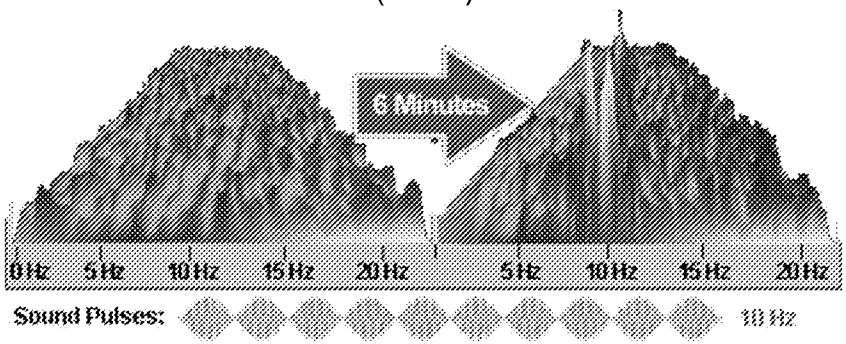


Fig. 16

Brainwave Entrainment

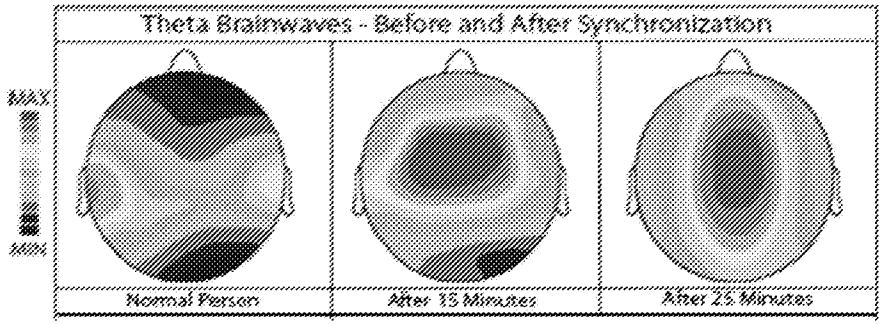
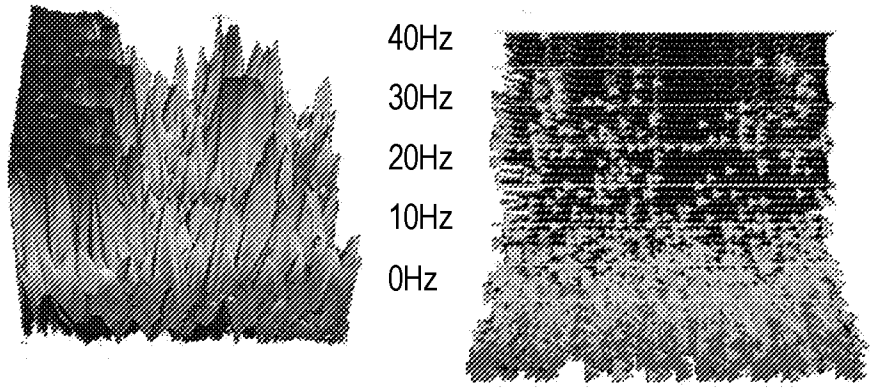


Fig. 17

Brainwaves during inefficient problem solving and stress

3D Rendering Peak Indicators



0Hz 10Hz 20Hz 30Hz 40Hz

Fig. 18

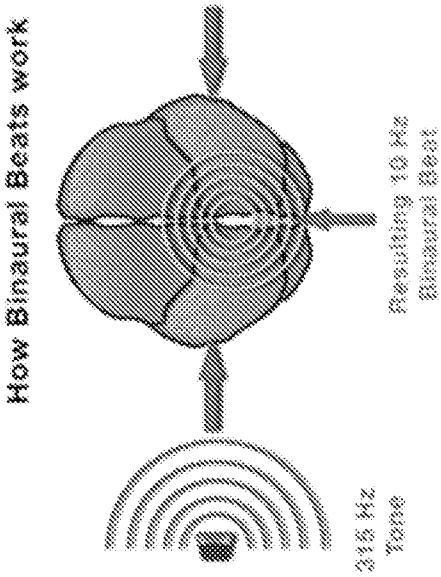


Fig. 19

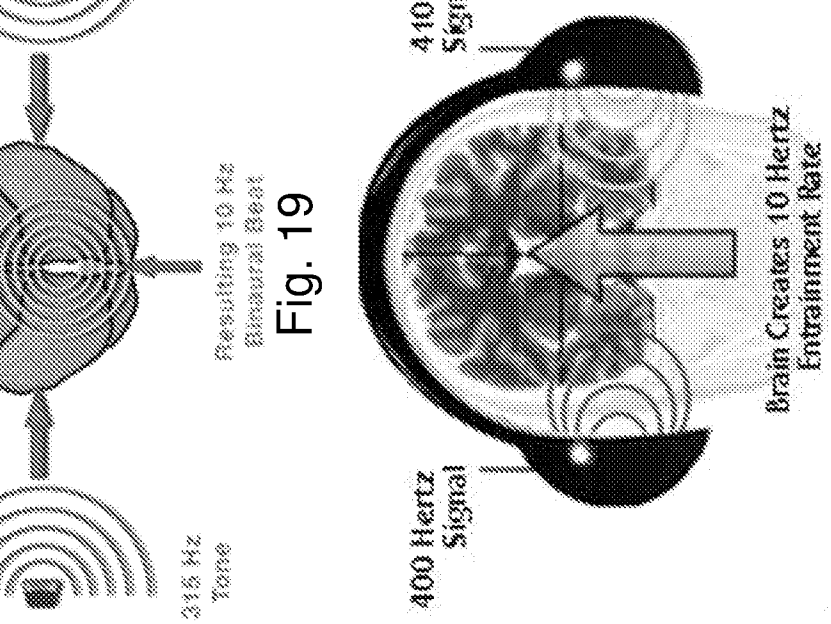


Fig. 20

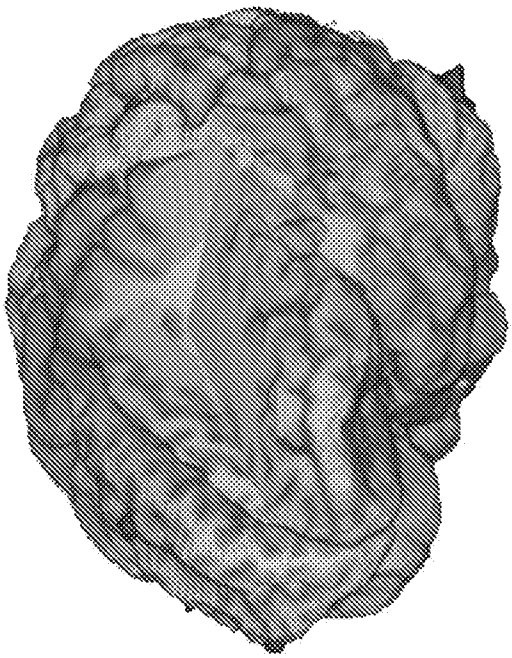


Fig. 21

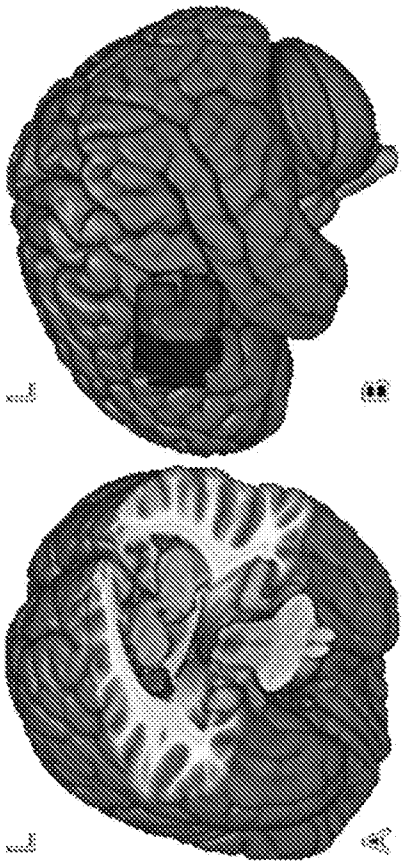


Fig. 22

Fig. 23

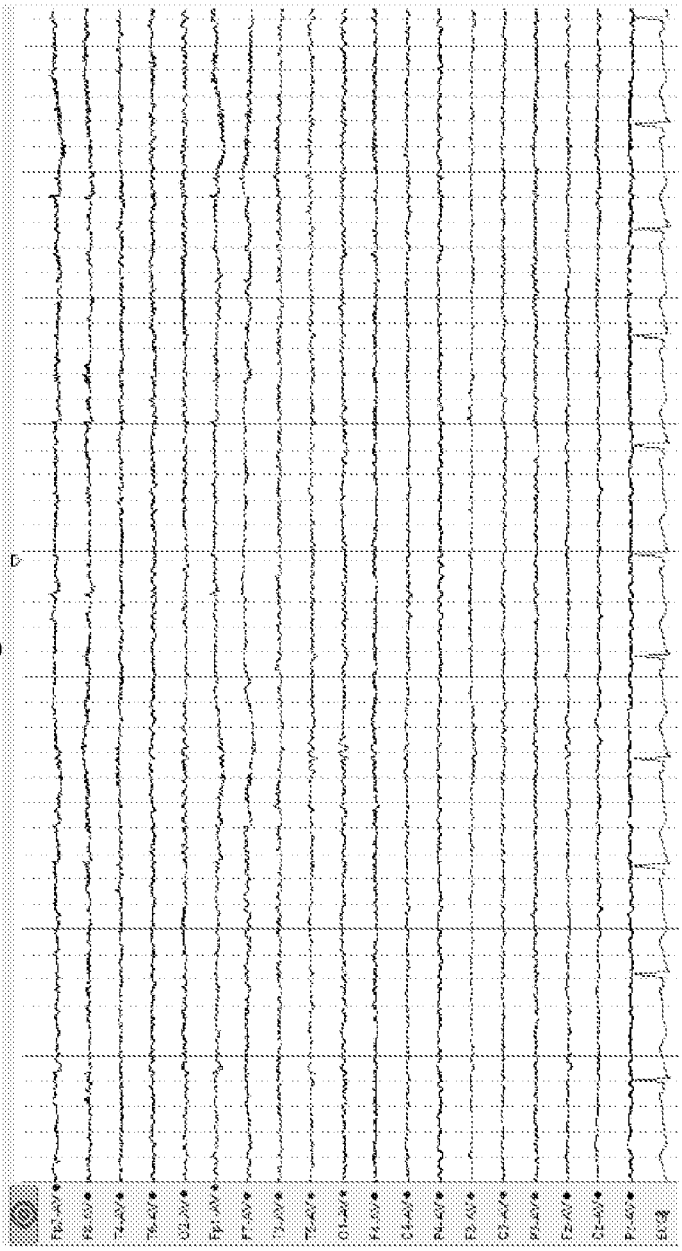


Fig. 24

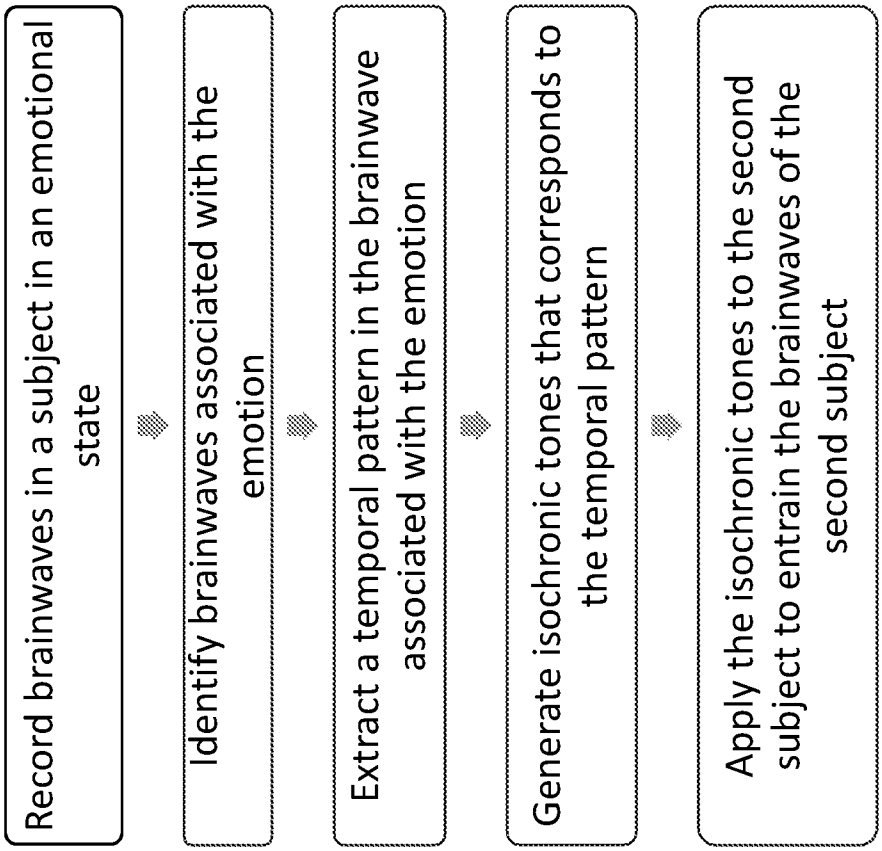

Record brainwaves in a subject in an emotional state
Identify brainwaves associated with the emotion
Extract a temporal pattern in the brainwave associated with the emotion
Generate isochronic tones that corresponds to the temporal pattern
Apply the isochronic tones to the second subject to entrain the brainwaves of the second subject

Fig. 26

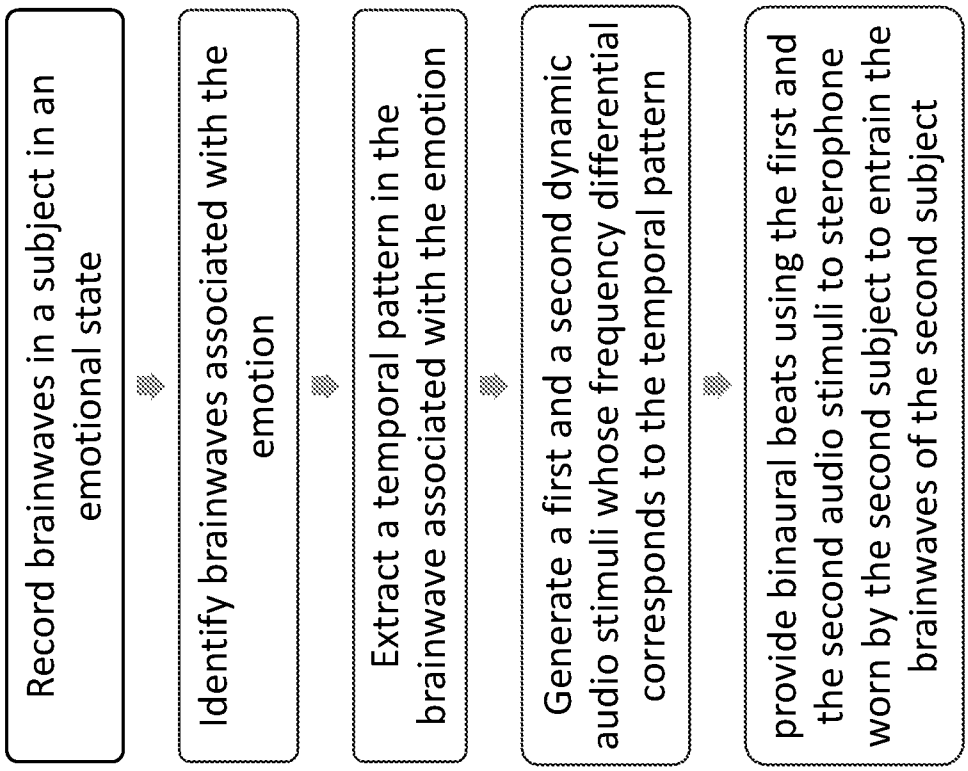

Record brainwaves in a subject in an emotional state
Identify brainwaves associated with the emotion
Extract a temporal pattern in the brainwave associated with the emotion
Generate a first and a second dynamic audio stimuli whose frequency differential corresponds to the temporal pattern
provide binaural beats using the first and the second audio stimuli to sterophone worn by the second subject to entrain the brainwaves of the second subject

Fig. 25

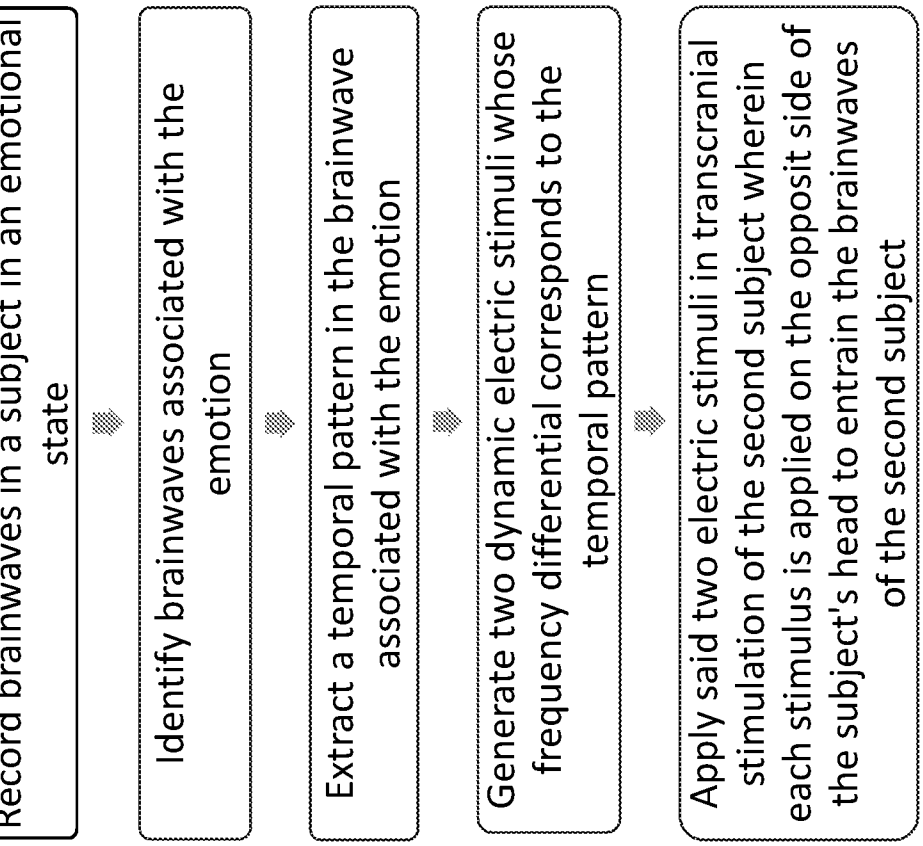

Record brainwaves in a subject in an emotional state
Identify brainwaves associated with the emotion
Extract a temporal pattern in the brainwave associated with the emotion
Generate two dynamic electric stimuli whose frequency differential corresponds to the temporal pattern
Apply said two electric stimuli in transcranial stimulation of the second subject wherein each stimulus is applied on the opposit side of the subject's head to entrain the brainwaves of the second subject

Fig. 28

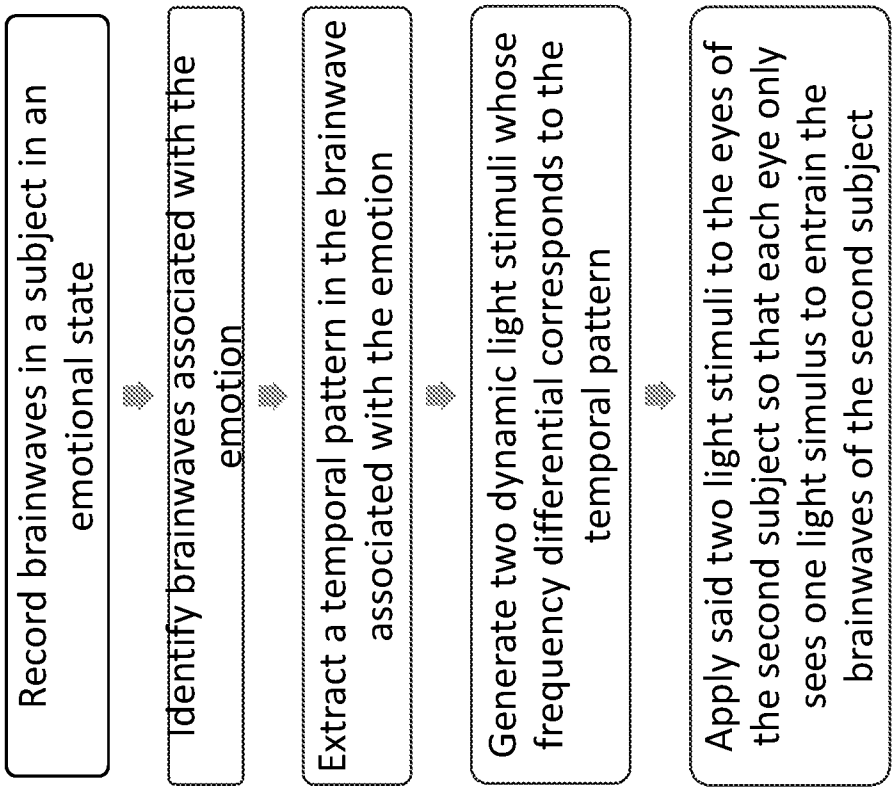

Record brainwaves in a subject in an emotional state
Identify brainwaves associated with the emotion
Extract a temporal pattern in the brainwave associated with the emotion
Generate two dynamic light stimuli whose frequency differential corresponds to the temporal pattern
Apply said two light stimuli to the eyes of the second subject so that each eye only sees one light simulus to entrain the brainwaves of the second subject

Fig. 27

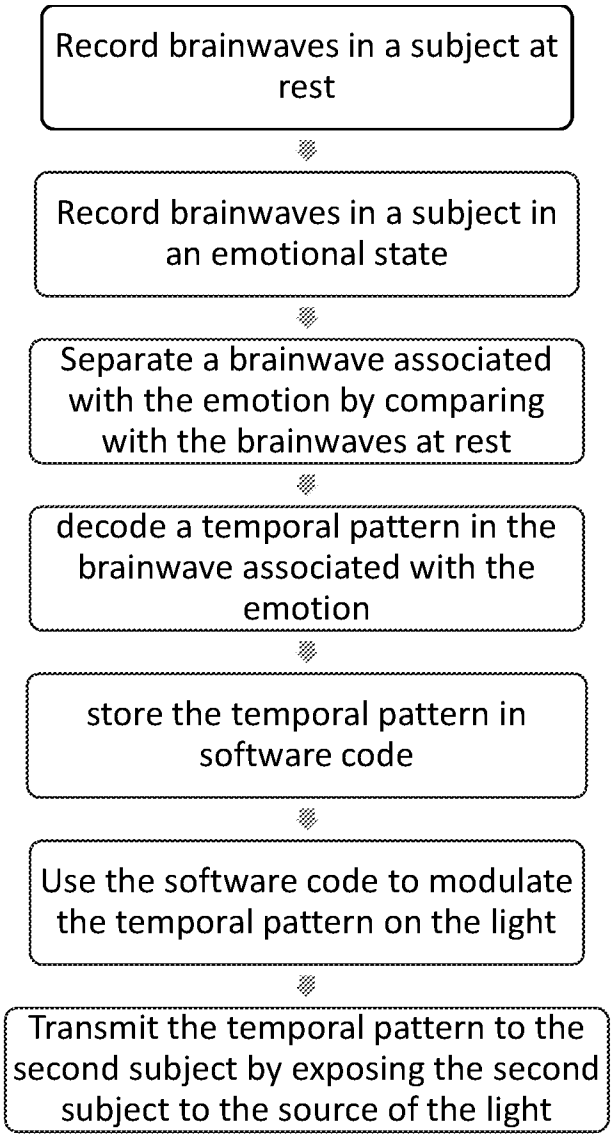
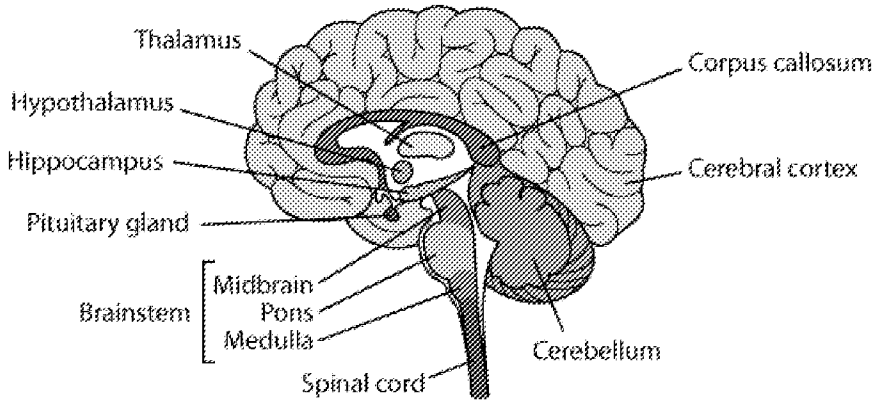
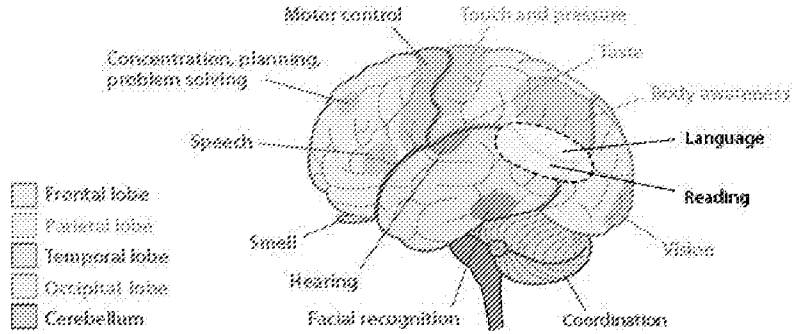


Fig. 29



Brain Anatomy

Fig. 30



Brain Map

Fig. 31

Neuron Anatomy

Fig. 32

Dimensional View of Emotions

Fig. 33

Fig. 34

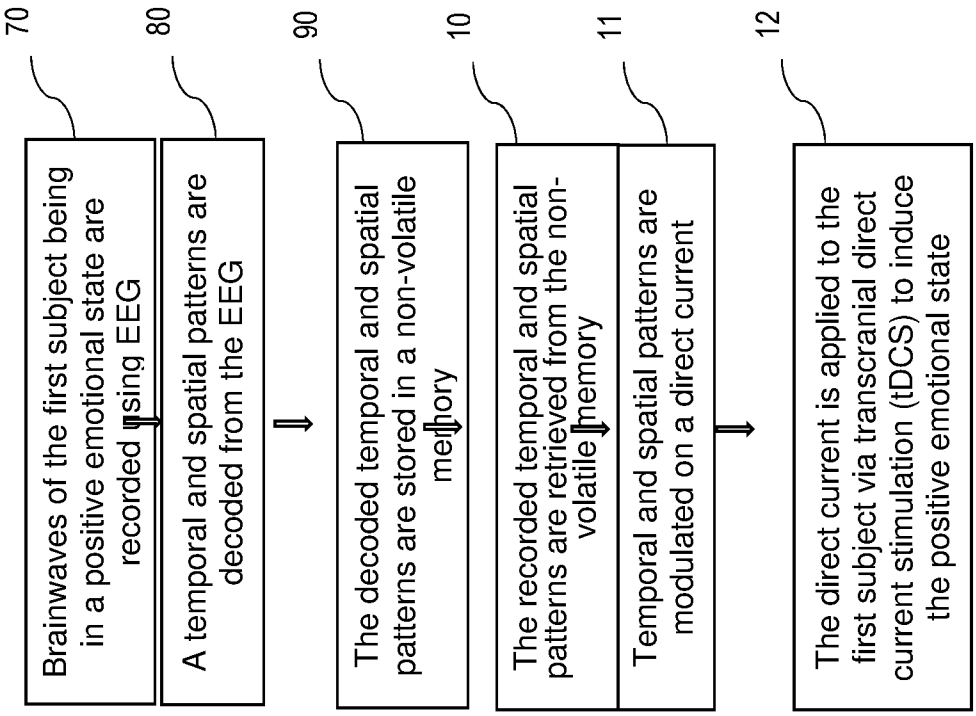

70
Brainwaves of the first subject being in a positive emotional state are recorded using EEG
80
A temporal and spatial patterns are decoded from the EEG
90
The decoded temporal and spatial patterns are stored in a non-volatile memory
10
The recorded temporal and spatial patterns are retrieved from the non-volatile memory
11
Temporal and spatial patterns are modulated on a direct current
12
The direct current is applied to the first subject via transcranial direct current stimulation (tDCS) to induce the positive emotional state

Fig. 36

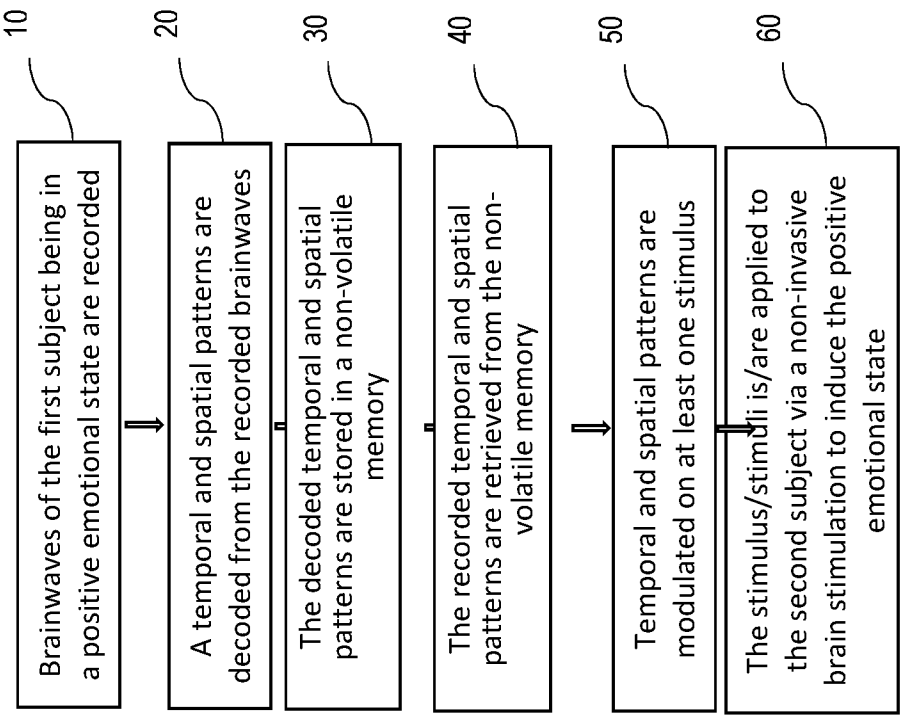

10
Brainwaves of the first subject being in a positive emotional state are recorded
20
A temporal and spatial patterns are decoded from the recorded brainwaves
30
The decoded temporal and spatial patterns are stored in a non-volatile memory
40
The recorded temporal and spatial patterns are retrieved from the non-volatile memory
50
Temporal and spatial patterns are modulated on at least one stimulus
60
The stimulus/stimuli is/are applied to the second subject via a non-invasive brain stimulation to induce the positive emotional state

Fig. 35

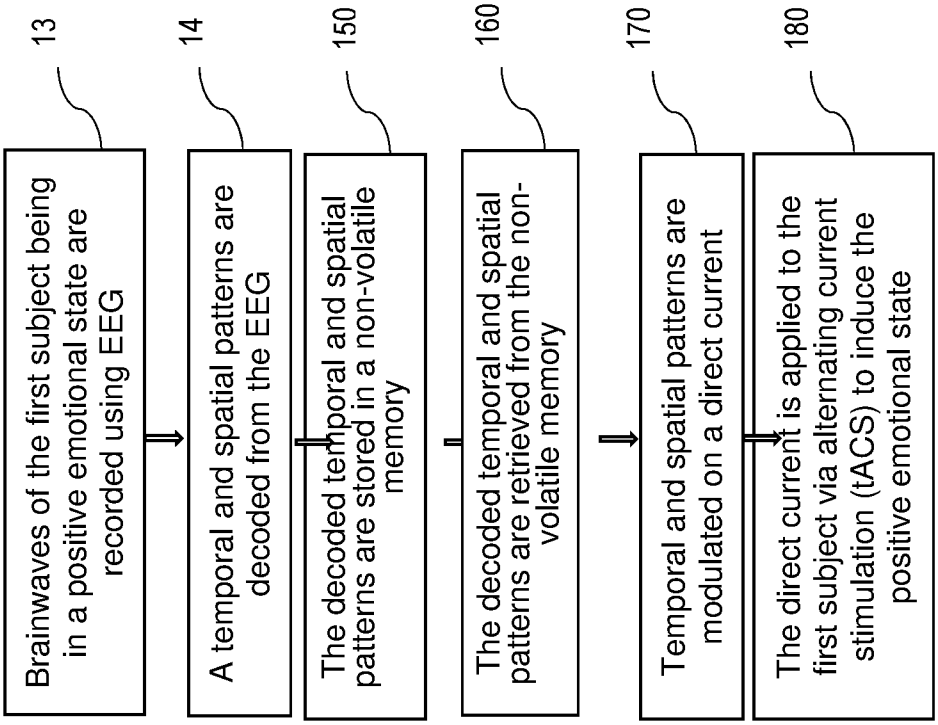

13
Brainwaves of the first subject being in a positive emotional state are recorded using EEG
14
A temporal and spatial patterns are decoded from the EEG
150
The decoded temporal and spatial patterns are stored in a non-volatile memory
160
The decoded temporal and spatial patterns are retrieved from the non-volatile memory
170
Temporal and spatial patterns are modulated on a direct current
180
The direct current is applied to the first subject via alternating current stimulation (tACS) to induce the positive emotional state

Fig. 37

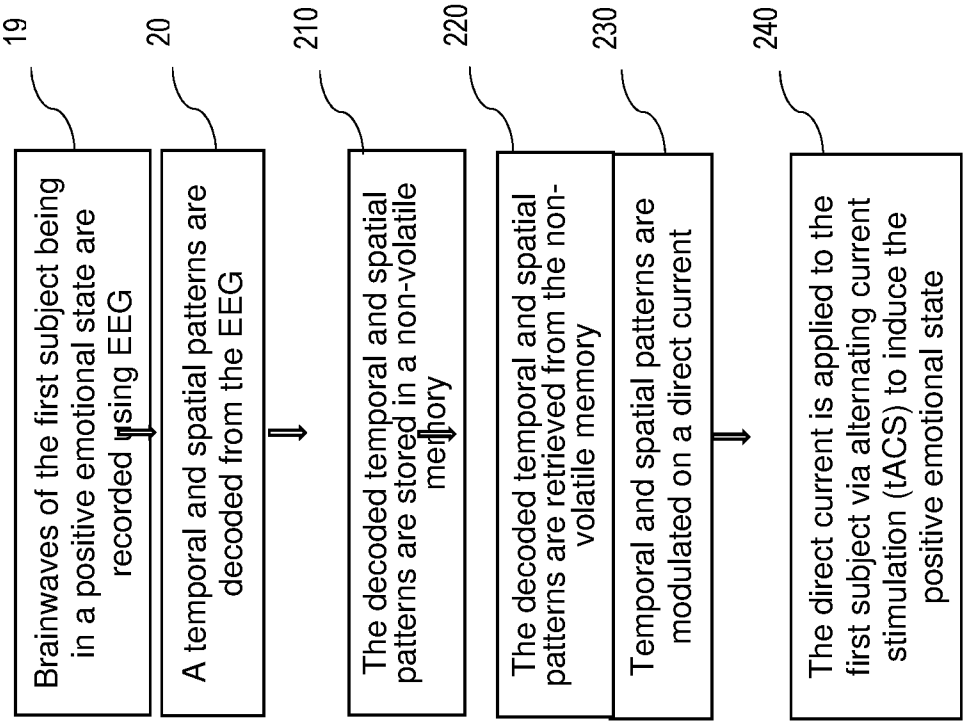

19
Brainwaves of the first subject being in a positive emotional state are recorded using EEG
20
A temporal and spatial patterns are decoded from the EEG
210
The decoded temporal and spatial patterns are stored in a non-volatile memory
220
The decoded temporal and spatial patterns are retrieved from the non-volatile memory
230
Temporal and spatial patterns are modulated on a direct current
240
The direct current is applied to the first subject via alternating current stimulation (tACS) to induce the positive emotional state

Fig. 38

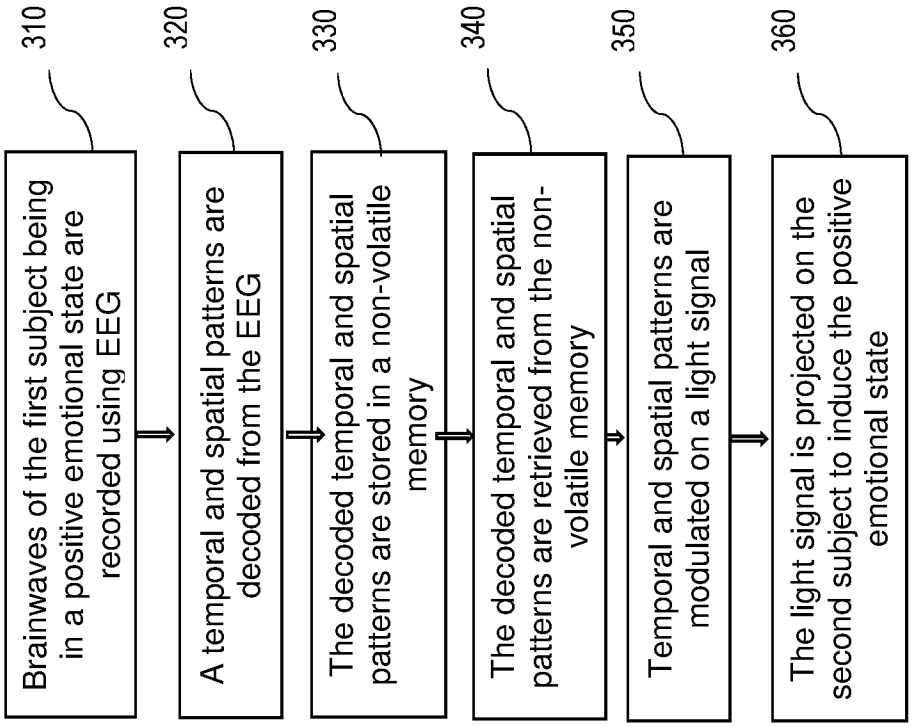

310
Brainwaves of the first subject being in a positive emotional state are recorded using EEG
320
A temporal and spatial patterns are decoded from the EEG
330
The decoded temporal and spatial patterns are stored in a non-volatile memory
340
The decoded temporal and spatial patterns are retrieved from the non-volatile memory
350
Temporal and spatial patterns are modulated on a light signal
360
The light signal is projected on the second subject to induce the positive emotional state

Fig 40

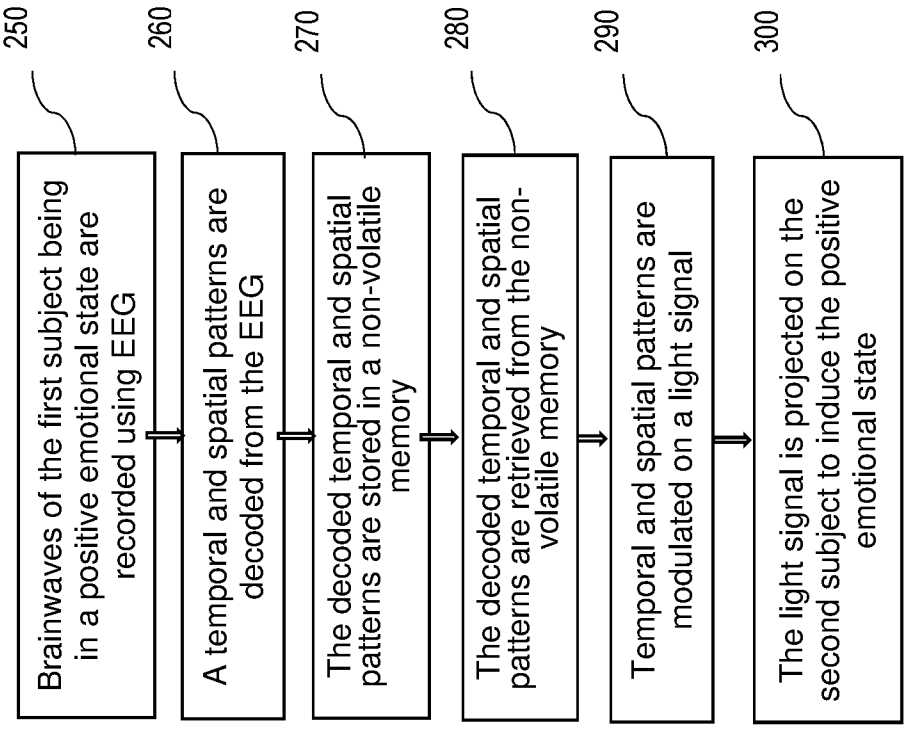

250
Brainwaves of the first subject being in a positive emotional state are recorded using EEG
260
A temporal and spatial patterns are decoded from the EEG
270
The decoded temporal and spatial patterns are stored in a non-volatile memory
280
The decoded temporal and spatial patterns are retrieved from the non-volatile memory
290
Temporal and spatial patterns are modulated on a light signal
300
The light signal is projected on the second subject to induce the positive emotional state

Fig 39

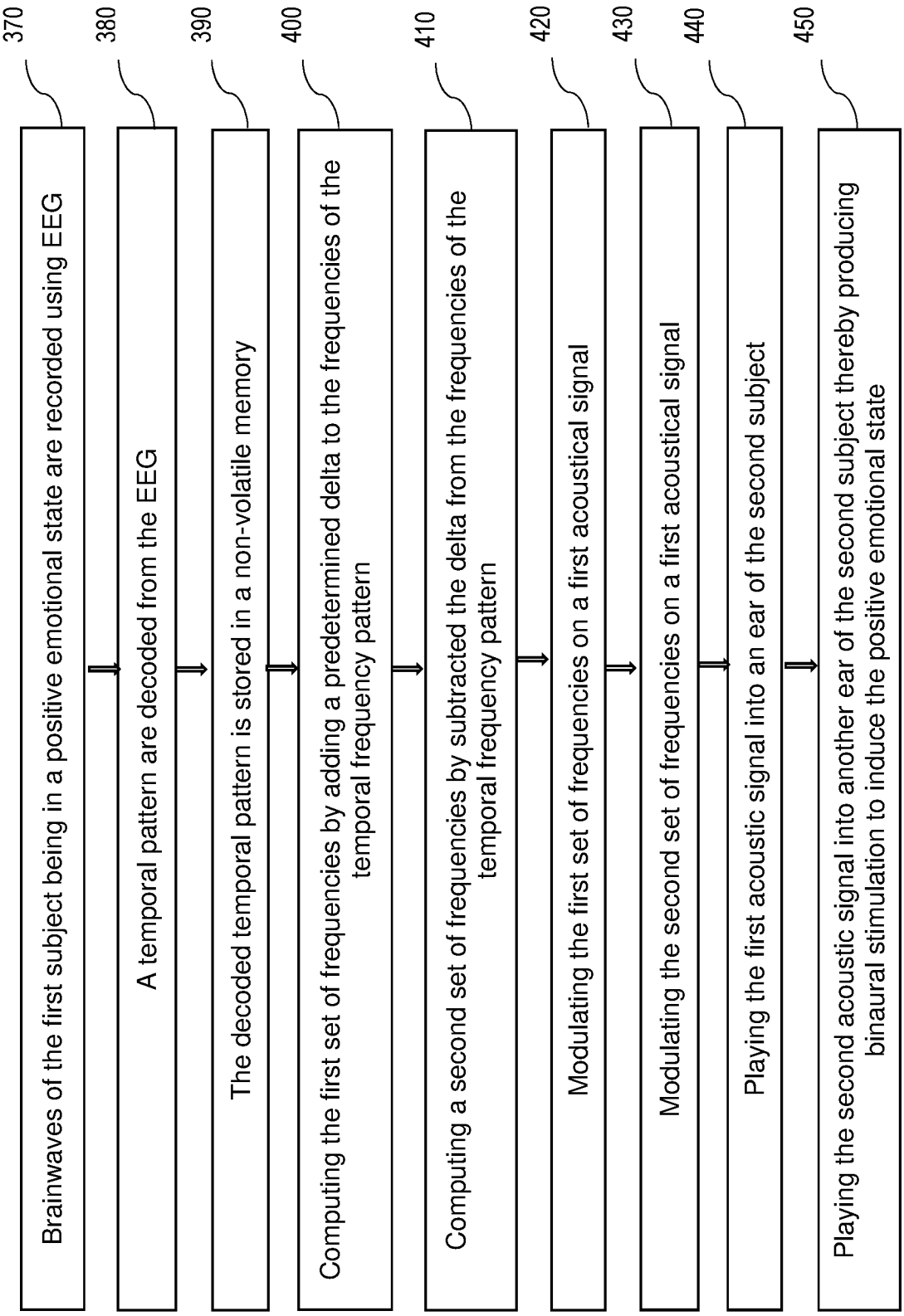

370
Brainwaves of the first subject being in a positive emotional state are recorded using EEG
380
A temporal pattern are decoded from the EEG
390
The decoded temporal pattern is stored in a non-volatile memory
400
Computing the first set of frequencies by adding a predetermined delta to the frequencies of the temporal frequency pattern
410
Computing a second set of frequencies by subtracted the delta from the frequencies of the temporal frequency pattern
420
Modulating the first set of frequencies on a first acoustical signal
430
Modulating the second set of frequencies on a first acoustical signal
440
Playing the first acoustic signal into an ear of the second subject
450
Playing the second acoustic signal into another ear of the second subject thereby producing binaural stimulation to induce the positive emotional state

Fig. 41

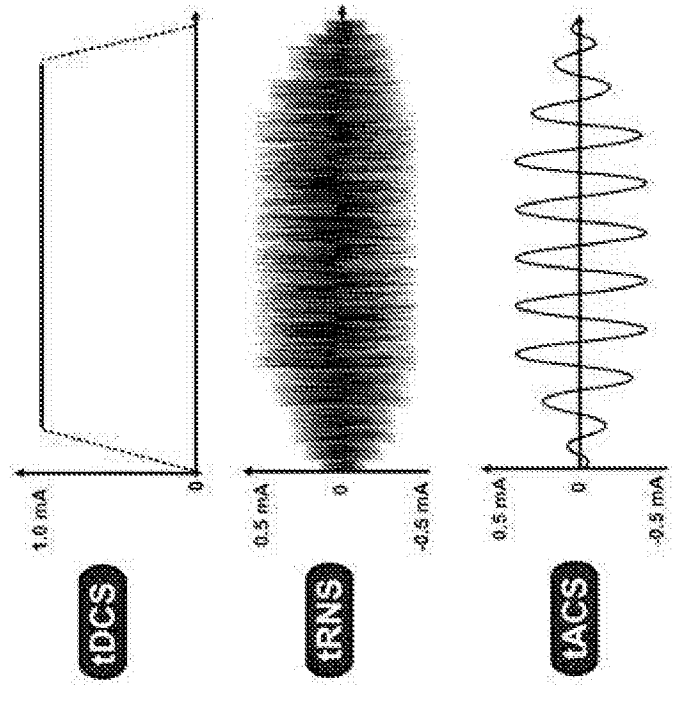


Fig. 42

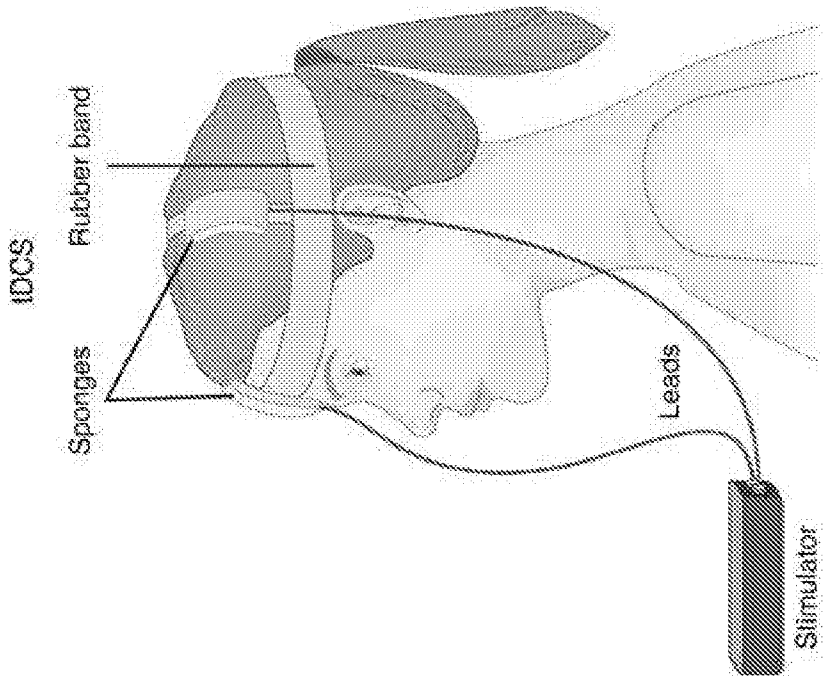


Fig. 44

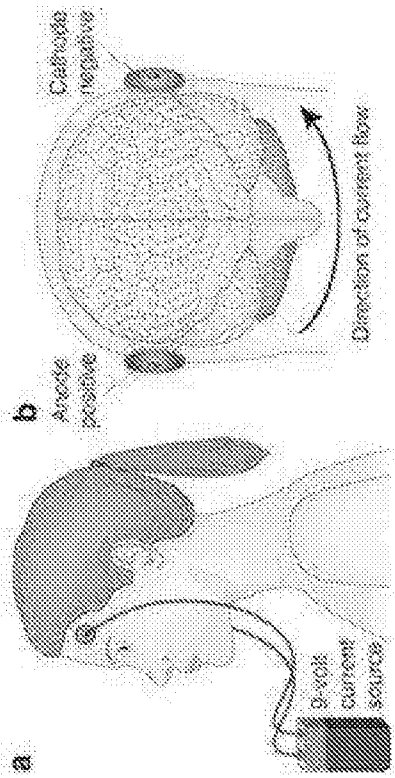


Fig. 43

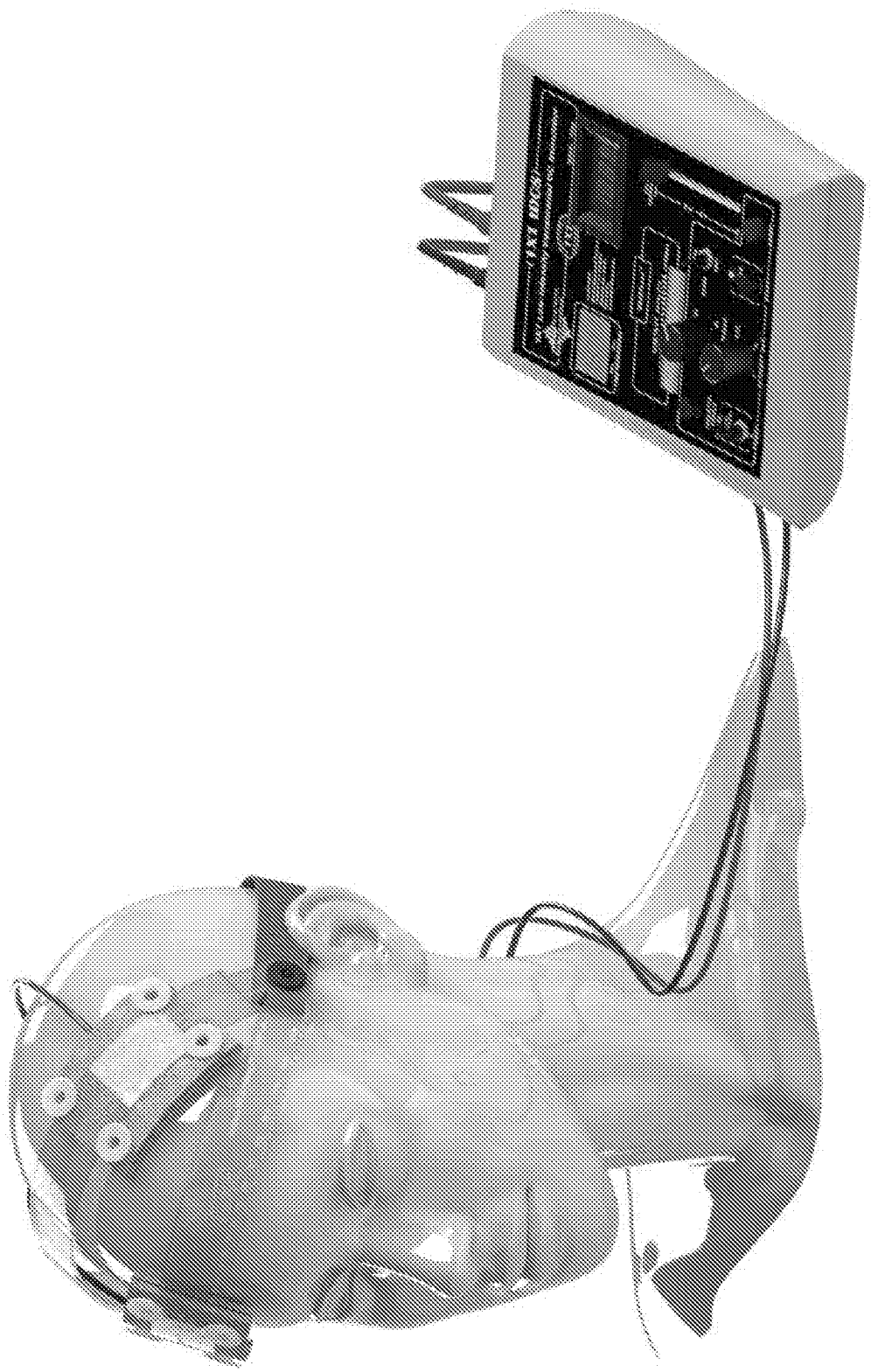


Fig. 45

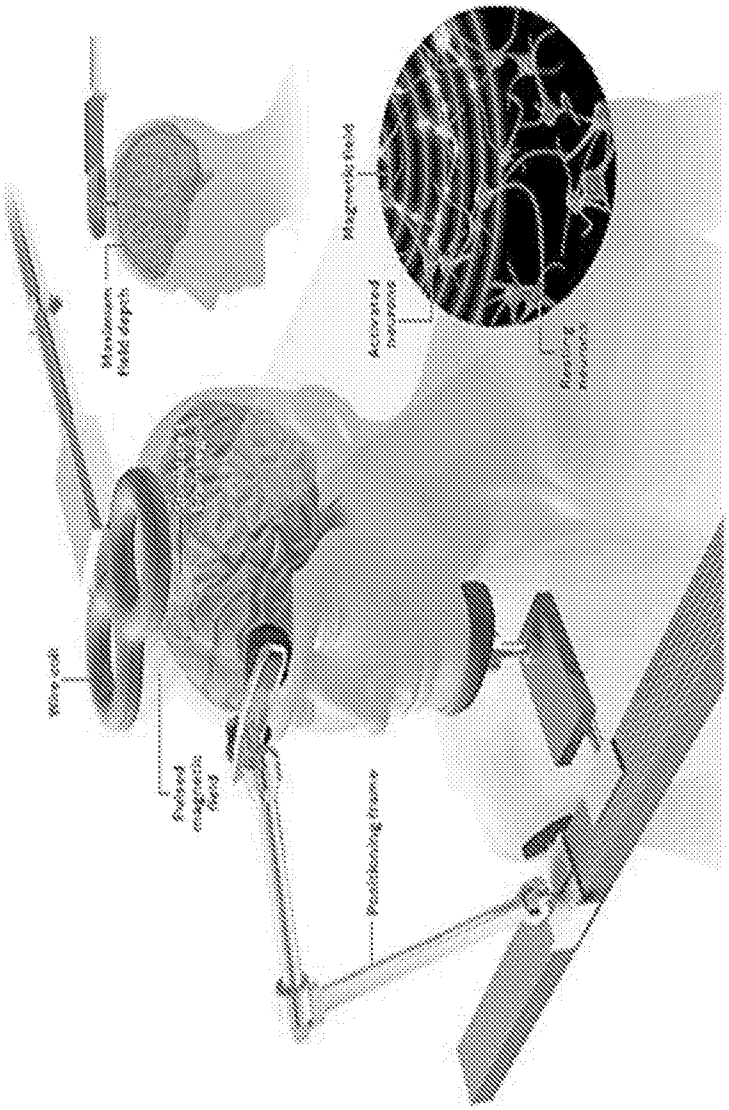

Wire coil
Paired magnetic field
Positioning frame
Maximum field depth
Magnetic field
Activated neurons
Resting neurons

Fig. 46

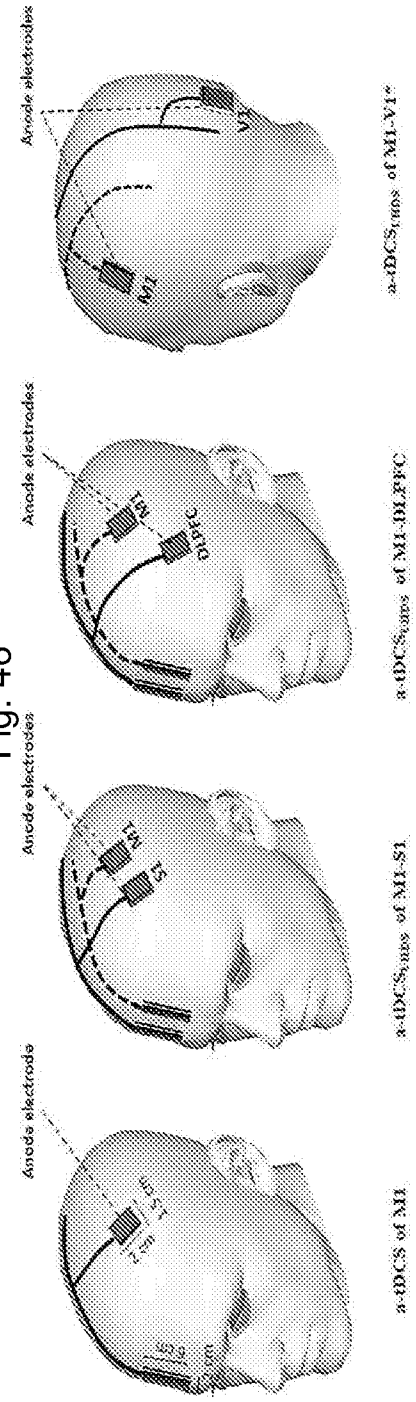

Anode electrode
M1
S1
Anode electrodes
M1
DLPFC
Anode electrodes
M1
V1
a-tDCS of M1
a-tDCS$_{LIDS}$ of M1-S1
a-tDCS$_{LIDS}$ of M1-DLPFC
a-tDCS$_{LIDS}$ of M1-V1*

Fig. 47

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 2018/068220

A. CLASSIFICATION OF SUBJECT MATTER

A61B 5/0484 *(2006.01)*
A61B 5/16 *(2006.01)*

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A61N 1/00, 2/00, A61B 5/0476, 5/05, 5/16, 5/0484

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PatSearch (RUPTO Internal), USPTO, PAJ, Espacenet, Information Retrieval System of FIPS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2015/0105837 A1 (NEUROMETRICS, S.L.) 16.04.2015, paragraphs [0005], [0011], [0014], [0034], [0036], [0052], [0053], [0062], [0066], [0067], [0069] - [0071], [0073] - [0085], [0087], [0093], [0098], claims 1, 9, 11-20	1, 2, 4, 14-16, 18-21, 23-25, 30-33, 39, 40, 43, 44, 92, 93, 101-109, 112-117, 119, 121-126, 128, 130-133, 135, 136, 139
Y		3, 5-13, 17, 22, 26-29, 34-38, 41, 42, 45-91, 94-99, 100, 110, 111, 118, 120, 127, 129, 134, 137, 138, 140-143
Y	US 2016/0346545 A1 (SUMON K. PAL et al.) 01.12.2016, paragraphs [0089], [0091] - [0093], [0104], [0105], [0116], [0118], [0134], [0157], [0175], claim 21	3, 5-13, 17, 22, 26-29, 34-38, 41, 42, 45-91, 94-99, 100, 110, 111, 118, 120, 127, 129, 134, 137, 138
Y	US 2017/0061034 A1 (KURTIS JOHN RITCHEY et al.) 02.03.2017, paragraphs [0051], [0175]	3, 54, 69, 84, 140-143

☐ Further documents are listed in the continuation of Box C.

☐ See patent family annex.

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"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20 March 2019 (20.03.2019)	18 April 2019 (18.04.2019)

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