What are Gamma Brainwave Frequencies

A gamma wave is a pattern of neural oscillation in humans with a frequency between 25 to 100 Hz though 40 Hz is typical.

Experiments on Tibetan Buddhist monks have shown a correlation between transcendental mental states and gamma waves.

A 2004 study took eight long-term Tibetan Buddhist practitioners of meditation and, using electrodes, monitored the patterns of electrical activity produced by their brains as they meditated. The researchers compared the brain activity of the monks to a group of novice meditators (the study had these subjects meditate an hour a day for one week prior to empirical observation). In a normal meditative state, both groups were shown to have similar brain activity. However, when the monks were told to generate an objective feeling of compassion during meditation, their brain activity began to fire in a rhythmic, coherent manner, suggesting neuronal structures were firing in harmony. This was observed at a frequency of 25–40 Hz, the rhythm of gamma waves. These gamma-band oscillations in the monk’s brain signals were the largest seen in humans. Conversely, these gamma-band oscillations were scant in novice meditators. Though, a number of rhythmic signals did appear to strengthen in beginner meditators with further experience in the exercise, implying that the aptitude for one to produce gamma-band rhythm is trainable.

Such evidence and research in gamma-band oscillations explains the heightened sense of consciousness, bliss, and intellectual acuity subsequent to meditation. Notably, meditation is known to have a number of health benefits: stress reduction, mood elevation, and increased life expectancy of the mind and its cognitive functions.

A number of experiments conducted by Dr. Rodolfo Llinás, MD, PhD, supports a hypothesis that the basis for consciousness in awake states and dreaming is 40-Hz oscillations throughout the cortical mantle in the form of thalamocortical iterative recurrent activity. In two papers entitled "Coherent 40-Hz oscillation characterizes dream state in humans” (Rodolfo Llinás and Urs Ribary, Proc Natl Acad Sci USA 90:2078-2081, 1993) and "Of dreaming and wakefulness” (Llinas & Pare, 1991), Llinás proposes that the conjunction into a single cognitive event could come about by the concurrent summation of specific and nonspecific 40-Hz activity along the radial dendritic axis of given cortical elements, and that the resonance is modulated by the brainstem and is given content by sensory input in the awake state and intrinsic activity during dreaming. According to Llinás’ hypothesis, known as the thalamocortical dialogue hypothesis for consciousness, the 40-Hz oscillation seen in wakefulness and in dreaming is proposed to be a correlate of cognition, resultant from coherent 40-Hz resonance between thalamocortical-specific and nonspecific loops. In Llinás & Ribary (1993), the authors propose that the specific loops give the content of cognition, and that a nonspecific loop gives the temporal binding required for the unity of cognitive experience.

Here are some of the Experimental Frequencies Tested in the Gamma Frequency range

30 – 60 Gamma Range little known but includes decision making in a fear situation, muscle tension
30 – 190 Lumbago
32 Desensitizer; enhanced vigour and alertness 35 – 150 Fractures
35 – 193 Arthralgy
35 Awakening of mid-chakras, balance of charkas
36 – 44 Learning frequencies, when [actively] studying or thinking. Helps to maintain alertness. Waking operating state
38 Release of endorphins
39 Dominant when problem solving in fearful situations; Gamma – associated with information-rich task processing; 40 – 60 Anxiolytic effects and stimulates release of beta-endorphines
43 – 193 Carcinomatosis
50 Dominant frequency of polyphasic muscle activity 50 Slower cerebral rhythyms
55 Tantric yoga; stimulates the kundalini
60 Used for speed learning and superlearning 63 Astral Projection
65.8 Associated with coccyx (small triangular bone at end of spinal column) 70 Mental and astral projection
72 Emotional spectrum

73.6 Associated with genitals
80 Awareness and control of right direction. Appears to be involved in stimulating 5-hydroxytryptamine production, with 160 Hz. Combine with 2.5 Hz.
82.3 Associated with bladder
83 Third eye opening for some people
85.5 Associated with intestines
90 Good feelings, security, well-being, balancing
90 – 111 Pleasure-producing beta-endorphins rise between these frequencies 95 Use for pain along with 3040 Hz
98.4 Associated with hara (3cm or 1.5 inch below navel, balance of pelvis) 100 Can help with pain (used with electrical stimulation)
105 Overall view of complete situation 108 Total knowing
110.0 Frequency associated with stomach. associated with ovaries (effects = vitality, life at every level)
111 Beta endorphins, cell regeneration
117.3 Frequency associated with Pancreas
120 PSI, moving of objects, changing matter, transmutation, psychokinesis 120 Helps with fatigue

What are the Different Types of Brainwave Entrainment

Binaural Beats
Binaural beats requires the use of headphones. The idea is that if you play a certain frequency in one ear (e.g. 300 Hz) and a slightly different frequency in the other ear (e.g. 310 Hz), the brain will entrain to match the difference between the two frequencies. This would result in a dominant brainwave frequency at 10Hz

Monaural Beats
Monaural beats again use two frequencies to create a single beat. The two tones are played through the same speaker. If you were to play a 310 Hz tone and 300 Hz tone through the same speaker, they would merge to create a perceived 10 Hz “monaural” beat.
Monaural beats also directly stimulate the basilar membrane, a different area of the cortex than binaural beats.

Isochronic Tones
These tones are normal beats of a single tone (tremelo effect) or a tone that is pulsed or phased. The result is a tone pulsation that entrains your brain to the specific frequency of the tone.

Speaker Panning:
You can create a similar effect by alternating the volume of the music to each ear independently. This must be done at the correct frequency. Obviously headphones are required for this technique

Combinations:
It is possible to combine multiple techniques to increase the efficacy of the entrainment or to create complex brainwave patterns

Photic Stimulation:
The use of flashing lights to change brainwave activity. There are many mind machines on the amrket that will create these effects. They have been known to induce photo epilepsy in susceptible individuals

Electromagnetic Entrainment:
Uses electrodes on the scalp to induce localized electrical fields. These in turn provoke brainwave entrainment to the desired frequency. The Koren Helmet is a good example of this type of device

How Can We Induce Gamma Frequency Activity in the Brain Ourselves

We have done all the hard work and incorporated some of the above frequencies as isochronic tones into easy to use programs. Accurately calibrated music synthesis software has been used to create the exact frequencies required to induce different Gamma states.

Experimenting through the whole range of gamma waves (from 25 - 100 Hz) it was found that certain combinations of

frequencies consistently caused a complete shift in brainwave activity.
This phenomenon allows you to repeat the many benefits of gamma entrainment at will; and with minimal practice. All you need to do is play the specially coded music on your mp3 player or other music device and listen... that's it... it really is that simple. You could be getting the benefits in minutes. Click Here to listen to a sample of Gamma Max

Here are some of applications available for gamma frequency entrainment

Astral Travel
The gamma max frequencies induce astral travel states in a totally new and novel way.This is not the same as the many low frequency binaural and isochronic entrainment products on the market.Gamma entrainment creates more consistent and intense astral travel experiences than any other technique
Click Here

Cell Regeneration
Use the special frequencies in the music to stimulate at a cellular level.Look and feel younger. Have better health an energy
Click Here

Control Anger
Increase your ability to control anger states. Prolonged use will help to eliminate anger states completely
Click Here

Fat Blaster
Use the special frequencies in the music to stimulate the pancreas. Lose weight and get rid of fat naturally. Stay lean and healthy. If you want to help overcome obesity. If you want to help to deal with insulin resistance
Click Here

Fixing Lower Back
Use the special frequencies in the music to stimulate the lower back and help it to heal. Eliminate back pain quickly and effectively
Click Here

Hara
The hara is the centre of energy of the body. In many martial arts, extension from this centre has become a common concept. Aikido in particular emphasises moving from the hara.There are several breathing exercises in traditional Japanese martial arts where attention is always kept on hara. The hara centre is below the stomach in the lower abdomen. Using gamma entrainment will help to strengthen the hara and enhance your awareness of this energy centre. To develop the hara is to develop great balance and composure. Once developed you will experience a great sense of peace.
Click Here

HGH Endorphin
Use the special frequencies in the music to stimulate the pituitary to release more HGH
The special frequencies in the music will also stimulate the release of more natural beta endorphins Both stimulations can be used for natural pain relief
Click Here

Impotence Cure
It has never been easier to cure impotence (erectile dysfunction). The program works in all cases of non- physiological impotence (erectile dysfunction).Never again be embarrassed by an inability to perform.
Click Here

Increase Fertility
Use the special frequencies in the music to stimulate the ovaries or testicles. Supercharge your fertility Click Here

Increase Sensitivity

Increase your sensitivity and your ability to love. Increase the power of all of your senses
Heighten pleasure and excitement. If you want to develop the ability to open up more to other people If you want to learn how to enjoy being in the now more
Click Here

Kundalini
Unique Musical Composition incorporating Potent kundalini stimulating frequencies.Increased kundalini has been shown to strengthen the immune system.Stimulating Kundalini is said to increase psychic ability.If you want to heighten all of your senses. If you want to get rid of bad habits
If you want to develop a strong sense of inner peace. No need for meditation, headphones or mantras. You can even play this while sleeping or watching TV
Click Here

Legal High
Its trippy... its legal ...and it WILL get you high. Accurately calibrated music synthesis software has been used to create the exact frequencies required to induce different Gamma states
Experimenting through the whole range of gamma waves (from 25 - 100 Hz) it was found that certain combinations of frequencies consistently caused a complete shift in brainwave activity.
Click Here

Mega Intelligence
Increase your intelligence.Improve your performance in exams and tests. Increase the respect you get from friends and colleagues
Click Here

Mental Projection
It is clear that the ability to make things happen or manifest has a reproducible and re-creatable brain pattern. We have been able to recreate this pattern using gamma max technology. This program will help you to clearly visualize and manifest everything that you desire.
Click Here

Problem Solver
Increase your ability to solve problems by a factor of 10. Develop the ability to solve more and more complex problems. Think your way out of any situation
Click Here

Psi Power
Increase your psychic power and ability.Develop stronger senses and intuition. Everybody has the power to be psychic. Develop psychic skills quickly and safely. Established psychics and clairvoyants can improve their abilities. The Gamma Max Psi Booster will achieve all of these goals and more
Click Here

Relieve Depression
Use the special frequencies in the music to balance the levels of serotonin
In clinical trials increased Serotonin has been shown to : moderate and control depression, moderate and control eating disorders, Relieve Pain & migraines, Ease stress and tension, Improve immune function, Improve blood vessel tone, Improve sleep
Click Here

Sinus Treatment
Use the special frequencies in the music to help calm the sinuses.Help to reduce swelling in the sinus cavities and allow them to drain naturally.Help to eliminate the pain and discomfort of swollen sinuses
Click Here

Speed Learning
Stimulate your mind to learn faster
You will be able to study for longer and retain more of the information you study
You will improve your ability to remember the information accurately when it is required Click Here

Stomach repair
Use the special frequencies in the music to stimulate the stomach to help digestion and healing Can be used as a treatment for irritable bowel syndrome (IBS). Can be used as a treatment for colic Click Here

Super Energy
Energy Increased in Minutes .
Enhance your creativity or confidence in 20 minutes .Energize and revitalize easily. Stimulate your brain with scientifically generated frequencies. The chosen frequencies will ;
instantly increase your energy. Create a measurable increase in alertness that can last for up to 2 hours. Click Here

Super Focus
Increase your ability to concentrate by a factor of 10. Stay focused on any task until you finish
Eliminate distractions completely. If you want to develop the ability to concentrate absolutely for hours. If you want to learn how to stay focused on any task until you are finished
If you want to eliminate distractions completely.Massively improve your ability to concentrate. Click Here

Super Influence
Increase your ability to influence others. People will begin to act just by the power of your thoughts
Develop the powers of "Silent Command". If you want to develop the ability change the behaviour of others. If you want to learn how to develop a magnetic personality and draw people to you
The Gamma Max Super Influencer will achieve all of these goals Click Here

Tinnitus Treatment
Use the special frequencies in the music to stimulate the sensory apparatus of the ears
Certain types of tinnitus can be cured by audio habituation alone. It can certainly give temporary relief in most cases.The use of full spectrum low impact noise has been scientifically proven to provide audio habituation for the tinnitus sufferer.Our specially developed Gamma Max Tinnitus Treatment will reduce your symptoms quickly .Over time your tinnitus could be eliminated completely.
Click Here

What are the brain frequencies?
Electrical instruments (electroencephalographs) are commonly used by medical people to evaluate mental states. These instruments measure the neuron firing rates of groups of brain cells. These firing rates are commonly thought to control mental
states. Gamma, beta, alpha, theta and delta are terms that medicine uses to indicate the rates of
brain cell firing and the corresponding mental states associated with them. We have already dscussed the gamma frequency state and here are the others

The Beta State
The beta state is that state of mind that you experience when awake and active during the day. It includes any brain wave with a frequency greater than or equal to 13 Hz (faster repetition than 13 times per second). Beta states above 20 Hz are generally classed as higher beta or gamma.
The higher beta state, often referred to as the gamma state, is experienced while wide- awake and highly aroused. The higher beta state is very stimulating and can be associated with anxiety. This anxiety could be related to subconscious resistance to these states. The brain wave amplitudes tend to be very small.
The lower beta state is that state of mind commonly experienced while awake and busy during the day. This is the state of mind in which you commonly deal with your daily routines. You can experience anxiety with some of the lower beta frequencies.
The low beta state involves frequencies from 13Hz to 20Hz. The am
plitudes are generally quite small. This type of frequency has been used successfully as a harmonic of lower frequencies

to create unusual effects.

The Alpha State

The alpha mind state is that state commonly experienced while the body is resting and the mind is calm. The alpha state is the one you experience whilst doing a mundane repetitative task with nothing particular on your mind. A typical exam ple would be driving a car (how many times have you driven from work and barely remembered the journey?). The alpha state of mind involves frequencies from 8.0 to 12.9Hz. The natural amplitudes tend to be larger than beta. The alpha state is also characteristic of mild meditation and programmes such as Silva mind control

Note: You can quickly induce alpha state by closing your eyes and generally looking upwards, allowing your eyes to roll backwards.

The Theta State

The theta state is commonly experienced in deepened states of meditation, at the onset and in lighter parts of sleep. It seems to present in hypnogogic and hypnopompic hallucination. It is characterised by frequencies from 4.0Hz to 7.9Hz. It is believed by some scientists that high amplitude Theta frequencies accompany most (if not all) psychic activity.

The Delta State

The Delta mind state is commonly experienced at night during deep sleep or possibly during the day by people experiencing depression or mental fatigue. The Delta state of mind involves frequencies from approximately 0.1Hz to 4Hz. The natural am plitudes are large in size. These frequencies are the least researched and are common in very deep trance states

What is brainwave entrainment?

If binaural, isochronic or monochronic frequencies are applied to the brain, it becomes possible to entrain the brain frequency from one stage to another. For example, if a person is in beta state and a frequency of 12Hz is applied to their brain for some time, the brain frequency is likely to change towards the applied frequency. The effect will be relaxing to the person. This phenomenon is also called frequency following response. When the brain's dominant frequency is close to the applied frequency, entrainment works more efficiently. Thus, when doing a sweep from one frequency to another, the starting frequency should be as close to your current brain state as possible. The sweep speed should be such that your brain's state changes steadily with it, so that the difference never gets very large.

You could liken the effect to a tuning fork or the harmonic vibration of a glass.

Here is a Quote from Scientific American Magazine - credit to Peter B Reiner 2009 New research reveals how meditation changes the brain

In the fall of 2005, the Dalai Lama gave the inaugural Dialogues between Neuroscience and Society lecture at the Annual Meeting of the Society for Neuroscience in Washington, DC. There were over 30,000 neuroscientists registered for the meeting, and it seemed as if most of them attended the talk. The Dalai Lama's address was designed to highlight the areas of convergence between neuroscience and Buddhist thought about the mind, and to many in the audience he clearly achieved his objective. There was some controversy over his being invited to deliver this lecture insofar as he is both a head of state and a religious leader, and for that reason he largely stuck to his prepared text. But he strayed from the text at least once, reminding the audience that not only was he a Buddhist monk but also an enthusiastic proponent of modern technology.

Elaborating, he shared a confidence with the audience, telling the audience of scientists that meditating was hard work for him (even though he meditates for 4 hours every morning), and that if neuroscientists were able to find a way to put electrodes in his brain and provide him with the same outcome as he gets from meditating, he would be an enthusiastic volunteer. It turns out that a recent set of experiments, from researchers at MIT and Stanford, moves us a step closer to making his wish a reality.

The Dalai Lama's interest in neuroscience has been reciprocated by at least some members of the neuroscience community. Reasoning that studying the brains of people who meditate might lead to novel insights about the human brain, investigations of long-term meditators has been fertile ground for scientific investigation, with some of the more rigorous work emerging from Richard Davidson's laboratory at the University of Wisconsin. From the perspective of neuroscience, meditation can be characterized as a series of mental exercises by which one strengthens one's control over the workings of their own brain. The simplest of these meditation practices is 'focused attention' where one concentrates on a single object, for example one's breath. When expert meditators practiced focused attention meditation, demonstrable changes were seen using fMRI in the networks of the brain that are known to modulate attention. A second set of experiments studied long-term meditators practicing 'open monitoring meditation', a more advanced meditation practice which in many ways is a form of metacognition: the objective is not to focus one's attention but rather to use one's brain to monitor the universe of mental experience without directing attention to any one task. The unexpected result of this experiment was that the EEG of long-term meditators exhibited much more gamma-synchrony than that of naive meditators. Moreover, normally human brains produce only short bursts of gamma-synchrony. What was most remarkable about this study was that long-term meditators were able to produce sustained gamma-activity in a manner that had never previously been observed in any other human. As such, sustained gamma activity has emerged as a proxy for at least some aspects of the meditative state.

Gamma Waves

But what causes gamma rhythm? And are there any potential benefits of sustained gamma-activity? The strongest hypothesis for the cellular mechanisms underlying generation of the gamma rhythm is that it is due to the activation of fast-spiking interneurons in the cerebral cortex. In two new papers to be published in Nature, the laboratories of Christopher Moore and Li-Huei Tsai at MIT and Karl Deisseroth at Stanford tested this hypothesis directly. The experimenters utilized optogenetics, developing custom-designed viruses to infect only the fast-spiking interneurons of either the prefrontal or barrel cortex in mice with genetically engineered, light-sensitive cation channels. Then, they inserted fine optical fibers into the relevant region of the cortex, allowing light to be delivered to the infected neurons and thereby activating only the fast-spiking interneurons. (In essence, this allowed them to switch particular brain cells on and off.) In both experiments, selectively stimulating the fast-spiking interneurons evoked gamma oscillations, thereby confirming the hypothesis that these neurons drive the gamma rhythm.

It is hard to ignore the fact that the sustained gamma activity evoked in these mice was highly reminiscent of the type of electrical activity recorded from the long-time meditators practicing the elusive phenomenon known as open monitoring meditation. That being said, despite the elegant experimental design utilized by the investigators, sustained gamma-activity is not identical to meditation. For these reasons and more, it is doubtful that anyone would accept this experiment as satisfying the Dalai Lama's call to the neuroscience community to develop a technological replacement for the many hours spent immersed in contemplative thought. But given the growing body of evidence which suggests that even short-term meditation improves measures of attention, these new experiments provide an interesting twist to the growing field of cognitive enhancement.

How long will it be before a new version of this technology is available for human consumption? It is hard to imagine anyone but the most ardent transhumanist signing up to have genetically engineered viruses and optical probes inserted into their brains. But it is worth remembering that both deep brain stimulation and transcranial magnetic stimulation are rapidly moving from the laboratory to the clinic, and these represent relatively crude forms of brain stimulation. The field of optogenetics is advancing very quickly; one recent paper in Neuron demonstrated that neurons can be infected and optical fibers implanted safely in non-human primates. At the very least, it is safe to say that the prospect of using advanced technology to mimic at least some of the brain activity present during meditation states has moved from the realm of science fiction to that of scientific possibility.

Here is the full study into gamma frequencies conducted by Antoine Lutz,*† Lawrence L. Greischar,* Nancy B. Rawlings,* Matthieu Ricard,‡ and Richard J. Davidson*† as published in the Proceedings of the National Academy of Sciences of the United States of America in 2004

Long-term meditators self-induce high-amplitude gamma synchrony during mental practice

Practitioners understand "meditation," or mental training, to be a process of familiarization with one's own mental life leading to long-lasting changes in cognition and emotion. Little is known about this process and its impact on the brain.

Here we find that long-term Buddhist practitioners self-induce sustained electroencephalographic high-amplitude gamma-band oscillations and phase-synchrony during meditation. These electroencephalogram patterns differ from those of controls, in particular over lateral frontoparietal electrodes. In addition, the ratio of gamma-band activity (25-42 Hz) to slow oscillatory activity (4-13 Hz) is initially higher in the resting baseline before meditation for the practitioners than the controls over medial frontoparietal electrodes. This difference increases sharply during meditation over most of the scalp electrodes and remains higher than the initial baseline in the postmeditation baseline. These data suggest that mental training involves temporal integrative mechanisms and may induce short-term and long-term neural changes.
Keywords: electroencephalogram synchrony, gamma activity, meditation

Little is known about the process of meditation and its impact on the brain (1, 2). Previous studies show the general role of neural synchrony, in particular in the gamma-band frequencies (25-70Hz), in mental processes such as attention, working-memory, learning, or conscious perception (3-7). Such synchronizations of oscillatory neural discharges are thought to play a crucial role in the constitution of transient networks that integrate distributed neural processes into highly ordered cognitive and affective functions (8, 9) and could induce synaptic changes (10, 11). Neural synchrony thus appears as a promising mechanism for the study of brain processes underlining mental training.

Go to:

Methods

The subjects were eight long-term Buddhist practitioners (mean age, 49 ± 15 years) and 10 healthy student volunteers (mean age, 21 ± 1.5 years). Buddhist practitioners underwent mental training in the same Tibetan Nyingmapa and Kagyupa traditions for 10,000 to 50,000 h over time periods ranging from 15 to 40 years. The length of their training was estimated based on their daily practice and the time they spent in meditative retreats. Eight hours of sitting meditation was counted per day of retreat. Control subjects had no previous meditative experience but had declared an interest in meditation. Controls underwent meditative training for 1 week before the collection of the data.

We first collected an initial electroencephalogram (EEG) baseline consisting of four 60-s blocks of ongoing activity with a balanced random ordering of eyes open or closed for each block. Then, subjects generated three meditative states, only one of which will be described in this report. During each meditative session, a 30-s block of resting activity and a 60-s block of meditation were collected four times sequentially. The subjects were verbally instructed to begin the meditation and meditated at least 20 s before the start of the meditation block. We focus here on the last objectless meditative practice during which both the controls and Buddhist practitioners generated a state of “unconditional loving- kindness and compassion.”

Meditative Instruction. The state of unconditional loving-kindness and compassion is described as an “unrestricted readiness and availability to help living beings.” This practice does not require concentration on particular objects, memories, or images, although in other meditations that are also part of their long-term training, practitioners focus on particular persons or groups of beings. Because “benevolence and compassion pervades the mind as a way of being,” this state is called “pure compassion” or “nonreferential compassion” (dmigs med snying rje in Tibetan). A week before the collection of the data, meditative instructions were given to the control subjects, who were asked to practice daily for 1 h. The quality of their training was verbally assessed before EEG collection. During the training session, the control subjects were asked to think of someone they care about, such as their parents or beloved, and to let their mind be invaded by a feeling of love or compassion (by imagining a sad situation and wishing freedom from suffering and well being for those involved) toward these persons. After some training, the subjects were asked to generate such feeling toward all sentient beings without thinking specifically about anyone in particular. During the EEG data collection period, both controls and long-term practitioners tried to generate this nonreferential state of loving-kindness and compassion. During the neutral states, all of the subjects were asked to be in a nonmeditative, relaxed state.

EEG Recordings and Protocol. EEG data were recorded at standard extended 10/20 positions with a 128-channel Geodesic Sensor Net (Electrical Geodesics, Eugene, OR), sampled at 500 Hz, and referenced to the vertex (Cz) with analog band-pass filtering between 0.1 and 200 Hz. EEG signals showing eye movements or muscular artifacts were manually excluded from the study. A digital notch filter was applied to the data at 60 Hz to remove any artifacts caused by alternating current line noise.

Bad channels were replaced by using spherical spline interpolation (12). Two-second epochs without artifact were extracted after the digital rereferencing to the average reference.

Spectral Analysis. For each electrode and for each 2-s epoch, the power spectral distribution was computed by using Welch's method (13), which averages power values across sliding and overlapping 512-ms time windows. To compute the relative gamma activity, the power spectral distribution was computed on the z-transformed EEG by using the mean and SD of the signal in each 2-s window. This distribution was averaged through all electrodes, and the ratio between gamma and slow rhythms was computed. Intraindividual analyses were run on this measure and a group analysis was run on the average ratio across 2-s windows. The group analysis of the topography was performed by averaging the power spectral distribution for each electrode in each block and then computing the ratio of gamma to slow rhythms before averaging across blocks.

Despite careful visual examination, the electroencephalographic spectral analysis was hampered by the possible contamination of brain signals by muscle activity. Here we assume that the spectral emission between 80 and 120 Hz provided an adequate measure of the muscle activity (14, 15). The muscle EEG signature is characterized by a broad-band spectrum profile (8-150 Hz) peaking at 70-80 Hz (16). Thus, the variation through time of the average spectral power in the 80-120 Hz frequency band provided a way to quantify the variations of the muscle contribution to the EEG gamma activity through time. To estimate the gamma activity, adjusted for the very high frequencies, we performed a covariance analysis for each region of interest (ROI) for each subject. The dependent variable was the average gamma activity (25-42 Hz) in each ROI. The continuous predictor was the electromyogram activity (80-120 Hz power). The categorical predictors were the blocks (initial baseline with eyes open and neutral blocks from 2 to 4) and the mental states (ongoing neutral versus meditation).

For the group analysis, separate repeated ANOVAs were then performed on the relative gamma and adjusted gamma variation between states, with the blocks as the within factor and the group (practitioners versus controls) as the categorical predictor. For the intrasubject analysis, we compared separately the relative gamma and the raw gamma activity averaged within the ROIs in the initial baseline state versus the meditative state.

Phase-Synchrony Detection. Electrodes of interest were referenced to a local average potential defined as the average potential of its six surrounding neighbors. This referencing montage restricted the electrical measurement to local sources only and prevented spurious long-range synchrony from being detected if the muscle activity over one electrode propagated to another distant electrode. The methods used to measure long-range synchronization are described in detail in Supporting Methods, which is published as supporting information on the PNAS web site. In summary, for each epoch and electrode, the instantaneous phase of the signal was extracted at each frequency band between 25 and 42 Hz in 2-Hz steps by using a convolution with Morlet wavelets. The stability through time of their phase difference was quantified in comparison with white-noise signals as independent surrogates. A measure of synchronous activity was defined as the number of electrode pairs among the 294 studied combinations that had higher synchrony density on average across frequencies than would be expected to occur between independent signals. The electrode pairs were taken between the ROIs when we measured the scalp distribution of gamma activity (see Fig. 3a). A repeated-measures ANOVA was performed on the average size of the synchrony pattern across all frequency bands and epochs in each block with the original resting state and the meditative state as the within factors and the group (practitioners versus controls) as the between-groups factor.
Fig. 3.
Fig. 3.
Absolute gamma power and long-distance synchrony during mental training. (a) Scalp distribution of gamma activity during meditation. The color scale indicates the percentage of subjects in each group that had an increase of gamma activity during the mental ... Go to:

Results

We first computed the power spectrum density over each electrode in the EEG signals visually free from artifacts. This procedure was adapted to detect change in local synchronization (6, 9). Local synchronization occurs when neurons recorded by a single electrode transiently oscillate at the same frequency with a common phase: Their local electric field adds up to produce a burst of oscillatory power in the signal reaching the electrode. Thus, the power spectral density provides an estimation of the average of these peaks of energy in a time window. During meditation, we found high-amplitude gamma oscillations in the EEGs of long-time practitioners (subjects S1-S8) that were not present in the initial baseline. Fig. 1a provides a representative example of the raw EEG signal (25-42 Hz) for subject S4. An essential aspect of these gamma oscillations is that their amplitude monotonically increased over the time of the practice (Fig. 1b).

Fig. 1.

Fig. 1.

High-amplitude gamma activity during mental training. (a) Raw electroencephalographic signals. At t = 45 s, practitioner S4 started generating a state of nonreferential compassion, block 1. (b) Time course of gamma activity power over the electrodes displayed ...

Relative Gamma Power. We characterized these changes in gamma oscillations in relation to the slow rhythms (4-13 Hz) that are thought to play a complementary function to fast rhythms (3). Fig. 2a shows the intraindividual analysis of this ratio averaged through all electrodes. This ratio, which was averaged across all electrodes, presented an increase compared with the initial baseline, which was greater than twice the baseline SD for two controls and all of the practitioners. The ratio of gamma-band activity (25-42 Hz) compared to slow rhythms was initially higher in the baseline before meditation for the practitioners compared with the controls ($t = 4.0$, $df = 16$, $P < 0.001$; t test) (Fig. 2b). This effect remained when we compared the three youngest practitioners with the controls (25, 34, and 36 years old, respectively) ($t = 2.2$, $df = 11$, $P < 0.05$; t test). This result suggests that the mean age difference between groups does not fully account for this baseline difference (17).

Fig. 2.

Fig. 2.

Relative gamma power during mental training. (a and b) Intraindividual analysis on the ratio of gamma (25-42 Hz) to slow (4-13 Hz) oscillations averaged through all electrodes. (a) The abscissa represents the subject numbers, the ordinate represents the ...

This baseline difference increased sharply during meditation, as revealed by an interaction between the state and group factors [$F(2, 48) = 3.7$, $P < 0.05$; ANOVA] (Fig. 2b). This difference was still found in comparisons between gamma activity and both theta (4-8 Hz) and alpha activity. To localize these differences on the scalp, similar analyses were performed on each individual electrode. Fig. 2c shows a higher ratio of fast versus slow oscillations for the long-term practitioners versus the controls in the initial baseline over medial frontoparietal electrodes ($t > 2.59$, $P = 0.01$; t test). Similarly, Fig. 2d shows a group difference between the ongoing baseline states and the meditative state, in particular over the frontolateral and posterior electrodes. Interestingly, the postmeditative baseline (neutral states in blocks 2, 3, and 4) also revealed a significant increase in this ratio compared with the premeditation baseline over mainly anterior electrodes (Fig. 2e).

These data suggest that the two groups had different electrophysiological spectral profiles in the baseline, which are characterized by a higher ratio of gamma-band oscillatory rhythm to slow oscillatory rhythms for the long-term practitioners than for the controls. This group difference is enhanced during the meditative practice and continues into the postmeditative resting blocks.

Absolute Gamma Power. We then studied the variation through time of the ongoing gamma-band activity itself. The gamma-band activity (25-42 Hz) was first z-transformed in each block and compared over each electrode with the mean and SD of their respective neutral block (ongoing baseline). The normalized gamma activity was then averaged across the blocks. Fig. 3a shows the percentage of subjects presenting an increase of at least 1 SD during meditation compared with neutral state. A common topographical pattern of gamma activity emerged across the long-term practitioners but not across the control subjects. This pattern was located bilaterally over the parieto-temporal and midfrontal electrodes. Fig. 3a shows four ROIs containing seven electrodes each and located around F3-8, Fc3-6, T7-8, Tp7-10, and P7-10. Hereafter, we focus on the electrodes activated in these ROIs.

Intraindividual analyses similar to those for relative gamma activity were run on the average gamma power across these ROIs and exhibited the same pattern as that found for relative gamma. It is possible that these high-amplitude oscillations are partially contaminated by muscle activity (18). Because we found increases in gamma activity during the postmeditative resting baseline compared with the initial resting baseline, it is unlikely that the changes we reported could be solely caused by muscle activity, because there was little evidence of any muscle activity during these baseline periods. (Fig. 2e). Secondly, we showed that the meditative state and nonmeditative state that mimicked and exaggerated the possible muscle activity during meditation exhibit significantly different spectral profiles (Fig. 4, which is published as supporting information on the PNAS web site). Furthermore, for the two subjects showing the highest gamma activity, we showed that amplitude of the gamma-band activity before external stimulation predicts the amplitude of high fast-frequency oscillations (20-45 Hz) evoked by auditory stimuli (Fig. 5, which is published as supporting information on the PNAS web site). Because the evoked activity is relatively independent of muscle activity, the relationship between the pre-stimulation fast-frequency oscillation and the evoked activity suggests that these high- amplitude gamma rhythms are not muscle artifacts (Fig. 5 and Fig. 6, which is published as supporting information on the PNAS web site). This claim is further supported by the localization within the brain of the dipole sources of these fast-frequency-evoked oscillations (Figs. 7-9, which are published as supporting information on the PNAS web site).

Yet we still chose to cautiously interpret the raw values of these gamma oscillations because of the concomitant increase of spectral power >80 Hz during meditation. This increase could also reflect a change in muscle activity rather than high-frequency, gamma-band oscillations [70-105 Hz (19)], which are mostly low-pass filtered by the skull at >80 Hz. Thus, we chose to conservatively interpret the activity at >80 Hz as indicating muscle activity.

To remove the contribution of putative muscle activity, we quantified the increase in the average amplitude of gamma oscillation (25-42 Hz) adjusted for the effect of the very high-frequency variation (80-120 Hz) (see Methods and ref. 20). The adjusted average variation in gamma activity was >30-fold greater among practitioners compared with controls (Fig. 3b). Group analysis was run on the average adjusted gamma activity over these ROIs. Gamma activity increased for both the long-term practitioners and controls from neutral to meditation states [$F(1, 16) = 5.2$, $P < 0.05$; ANOVA], yet this increase was higher for the long-time practitioners than for the controls [$F(1, 16) = 4.6$, $P < 0.05$; interaction between the state and group factors ANOVA] (Fig. 3b). In summary, the generation of this meditative state was associated with gamma oscillations that were significantly higher in amplitude for the group of practitioners than for the group of control subjects.

Long-Distance Gamma Synchrony. Finally, a long-distance synchrony analysis was conducted between electrodes from the ROIs found in Fig. 3a. Long-distance synchrony is thought to reflect large-scale neural coordination (9) and can occur when two neural populations recorded by two distant electrodes oscillate with a precise phase relationship that remains constant during a certain number of oscillation cycles. This approach is illustrated in Fig. 1c for selected electrodes (F3/4, Fc5/6, and Cp5/6). For subject S4, the density of cross-hemisphere, long-distance synchrony increases by ˜30% on average during meditation and follows a pattern similar to the oscillatory gamma activity.

For all subjects, locally referenced, long-distance synchronies were computed for each 2-s epoch during the neutral and meditative states between all electrode pairs and across eight frequencies ranging from 25 to 42 Hz. In each meditative or neutral block, we counted the number of electrode pairs (294 electrode pairs maximum) that had an average density of synchrony higher than those derived from noise surrogates (see Methods). We ran a group analysis on the size of the synchronous pattern and found that its size was greater for long-time practitioners than for controls [$F(1, 16) = 10.3$, $P < 0.01$; ANOVA] and increased from neutral to meditation states [$F(1, 16) = 8.2$, $P < 0.02$; ANOVA]. Fig. 3c shows that the group and state factors interacted on long-distance synchrony [$F(1, 16) = 6.5$, $P < 0.05$; ANOVA]: The size of synchrony patterns increased more for the long-time practitioners than for the controls from neutral to meditation states. These data suggest that large-scale brain coordination increases during mental practice.

Finally, we investigated whether there was a correlation between the hours of formal sitting meditation (for subjects S1-S8, 9,855-52,925 h) and these electrophysiological measures for the long-term practitioners, in either the initial or meditative states (same values as in Figs. ?Figs.22 and ?and3).3). The correlation coefficients for the relative, absolute, and phase-synchrony gamma measures were positive: $r = 0.79$, 0.63, and 0.64, respectively, in the initial state, and $r = 0.66$, 0.62, and 0.43, respectively, in the meditative state. A significant positive correlation was found only in the initial baseline for the relative gamma ($r = 0.79$, $P < 0.02$) (Fig. 3d). These data suggest that the degree of training can influence the spectral distribution of the ongoing baseline EEG. The age of the subject was not a confounding factor in this effect as suggested by the low correlation between the practitioner age and the relative gamma ($r = 0.23$).

Go to:

Discussion

We found robust gamma-band oscillation and long-distance phase-synchrony during the generation of the nonreferential compassion meditative state. It is likely based on descriptions of various meditation practices and mental strategies that are reported by practitioners that there will be differences in brain function associated with different types of meditation. In light of our initial observations concerning robust gamma oscillations during this compassion meditation state, we focused our initial attention on this state. Future research is required to characterize the nature of the differences among types of meditation. Our resulting data differ from several studies that found an increase in slow alpha or theta rhythms during meditation (21). The comparison is limited by the fact that these studies typically did not analyze fast rhythms. More importantly, these studies mainly investigated different forms of voluntary concentrative meditation on an object (such as a meditation on a mantra or the breath). These concentration techniques can be seen as a particular form of top-down control that may exhibit an important slow oscillatory component (22). First-person descriptions of objectless meditations, however, differ radically from those of concentration meditation. Objectless meditation does not directly attend to a specific object but rather cultivates a state of being. Objectless meditation does so in such a way that, according to reports given after meditation, the intentional or object-oriented aspect of experience appears to dissipate in meditation. This dissipation of focus on a particular object is achieved by letting the very essence of the meditation that is practiced (on compassion in this case) become the sole content of the experience, without focusing on particular objects. By using similar techniques during the practice, the practitioner lets his feeling of loving-kindness and compassion permeate his mind without directing his attention toward a particular object. These phenomenological differences suggest that these various meditative states (those that involve focus on an object and those that are objectless) may be associated with different EEG oscillatory signatures.

The high-amplitude gamma activity found in some of these practitioners are, to our knowledge, the highest reported in the literature in a nonpathological context (23). Assuming that the amplitude of the gamma oscillation is related to the size of the oscillating neural population and the degree of precision with which cells oscillate, these data suggest that massive distributed neural assemblies are synchronized with a high temporal precision in the fast frequencies during this state. The gradual increase of gamma activity during meditation is in agreement with the view that neural synchronization, as a network phenomenon, requires time to develop (24), proportional to the size of the synchronized neural assembly (25). But this increase could also reflect an increase in the temporal precision of the thalamo-cortical and corticocortical interactions rather than a change in the size of the assemblies (8). This gradual increase also corroborates the Buddhist subjects' verbal report of the chronometry of their practice. Typically, the transition from the neutral state to this meditative state is not immediate and requires 5-15 s, depending on the subject. The endogenous gamma-band synchrony found here could reflect a change in the quality of moment-to-moment awareness, as claimed by the Buddhist practitioners and as postulated by many models of consciousness (26, 27).

In addition to the meditation-induced effects, we found a difference in the normative EEG spectral profile between the two populations during the resting state before meditation. It is not unexpected that such differences would be detected during a resting baseline, because the goal of meditation practice is to transform the baseline state and to diminish the distinction between formal meditation practice and everyday life. Moreover, Gusnard and Raichle (28) have highlighted the importance of characteristic patterns of brain activity during the resting state and argue that such patterns affect the nature of task-induced changes. The differences in baseline activity reported here suggest that the resting state of the brain may be altered by long-term meditative practice and imply that such alterations may affect task-related changes.
Our practitioners and control subjects differed in many respects, including age, culture of origin, and first language, and they likely differed in many more respects, including diet and sleep. We examined whether age was an important factor in producing the baseline differences we observed by comparing the three youngest practitioners with the controls and found that the mean age difference between groups is unlikely the sole factor responsible for this baseline difference. Moreover, hours of practice but not age significantly predicted relative gamma activity during the initial baseline period. Whether other demographic factors are important in producing these effects will necessarily require further research, particularly longitudinal research that follows individuals over time in response to mental training.

Our study is consistent with the idea that attention and affective processes, which gamma-band EEG synchronization may reflect, are flexible skills that can be trained (29). It remains for future studies to show that these EEG signatures are caused by long-term training itself and not by individual differences before the training, although the positive correlation that we found with hours of training and other randomized controlled trials suggest that these are training- related effects (2). The functional consequences of sustained gamma-activity during mental practice are not currently known but need to be studied in the future. The study of experts in mental training may offer a promising research strategy to investigate high-order cognitive and affective processes (30).

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