The Noninvasive Biomarkers of Meditation

based on Central & Autonomic Nervous System

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Common types of meditation (DOI: 10.1161/JAHA.117.002218)

Meditation	Description	Origins and Well-Known Teachers in the West
Samatha meditation	Samatha is translated to mean "calm" and samatha meditation is often referred to as calm, abiding meditation. Samatha meditation is the practice of calming the mind by practicing single-pointed meditation through mindful concentration focusing on the breath, image, or object.	Buddhist practice, dating to the time of the Buddha or even before
Vipassana meditation (insight meditation)	Vipassana is translated to mean, "to see things as they really are." Vipassana emphasizes awareness of the breath, tuning into the air passing in and out through the nose. Vipassana teaches one to label thoughts and experiences as they arise, taking mental notes as one identifies objects that grab one's attention. Vipassana meditation is often taught at 10-day retreats.	Traditional Buddhist and Indian meditation. Well-known teachers include Mahasi Sayadaw, S.N. Goenka, Sharon Salzberg, Joseph Goldestein, Jack Kornfield, and Michael Stone
Mindful meditation	An umbrella term for the category of techniques used to create awareness and insight by practicing focused attention, observing, and accepting all that arises without judgment. This type of meditation is also referred to as "open monitoring," in which one allows one's attention to flow freely without judgment or attachment.	Origins come from Buddhist teaching. Well-known Western teachers include Jon-Kabat Zinn, Tara Brach, Sharon Salzberg, Joseph Goldestein, Jack Kornfield, and Pema Chodron
Zen meditation (zazen)	A type of meditation where one focuses one's awareness on one's breath and observes thoughts and experiences as they pass through the mind and environment. In some senses similar to Vipassana meditation, but with an emphasis on a focus of the breath at the level of the belly and on posture while sitting.	Buddhist meditation from Japan. Well-known teachers include Thich Nhat Hanh and Joan Halifax Roshi
Raja yoga meditation	Referred to also as "mental yoga," "yoga of the mind," or Kriya yoga. A practice of concentration to calm the mind and bring it to one point of focus. Includes a combination of mantra, breathing techniques, and meditation on the chakras/spinal cord focus points.	Hindu practice dating back thousands of years. Introduced to the West in 1893 by Swami Vivekananda. Further clarified and taught by Paramhansa Yogananda for the Western audience
Loving-kindness (metta) meditation	Loving-kindness meditation involves sending loving kindness to oneself, then continuing to send it to a friend or loved one, to someone who is neutral in your life, to a difficult person, and then out to the universe. Through this practice, the meditator cultivates a feeling of benevolence toward oneself and others.	Originates from Buddhist teachings, mainly Tibetan Buddhism. Well-known instructors include Sharon Saltzberg and Pema Chodron
Transcendental meditation	Mantra-based meditation technique in which each practitioner is given a personal mantra that is used to help settle the mind inward. Transcendental meditation is taught by certified teachers through a standard 4-day course of instruction. Transcendental meditation is practiced for 20 minutes twice daily.	Origins in ancient Vedic traditions of India. Popularized in the West by the Maharishi Mahesh Yogi and now taught in the United States by the Maharishi Foundation
Relaxation response	A multifaceted practice that can involve awareness and tracking of breaths or repetition of a word, short phase, or prayer	A term and practice pioneered by Dr Herbert Benson in the 1970s, based in part of the practice of transcendental meditation

Meditation, Default Mode Network and Age-Associated Brain Changes

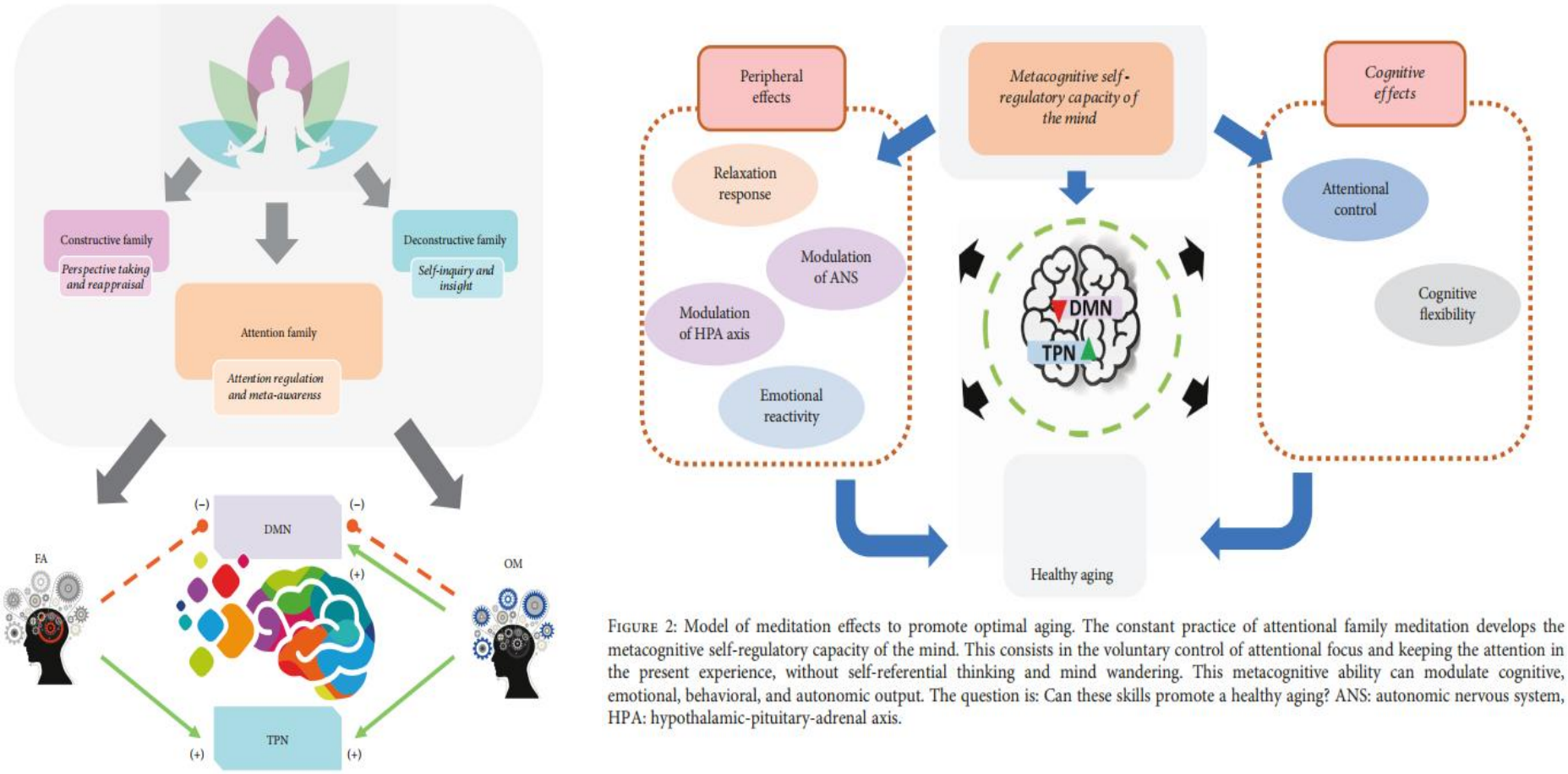
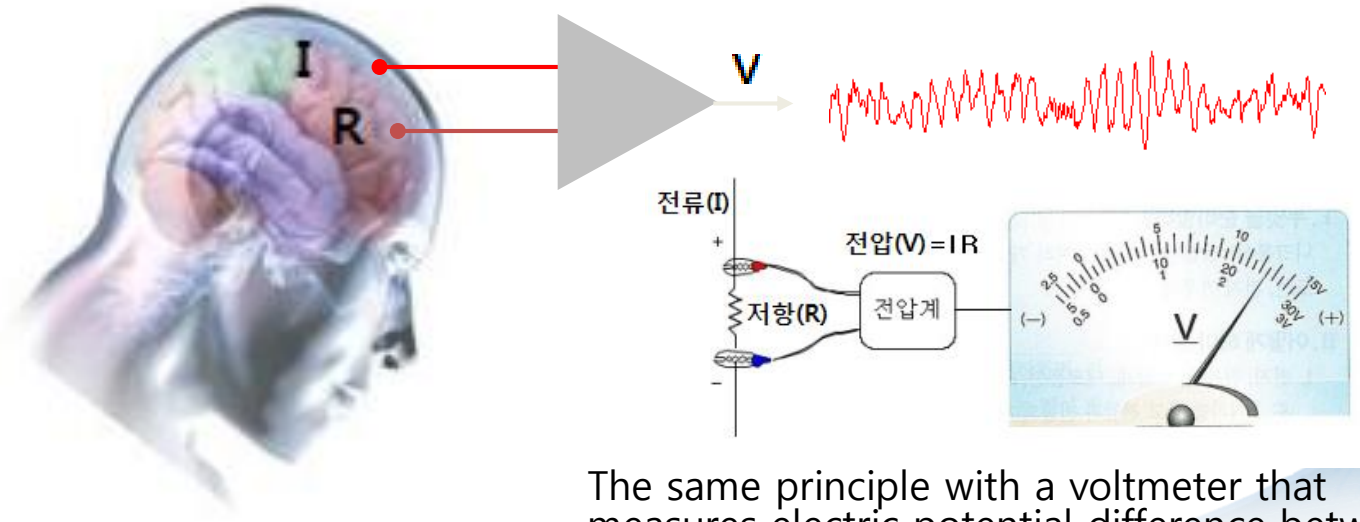


FIGURE 2: Model of meditation effects to promote optimal aging. The constant practice of attentional family meditation develops the metacognitive self-regulatory capacity of the mind. This consists in the voluntary control of attentional focus and keeping the attention in the present experience, without self-referential thinking and mind wandering. This metacognitive ability can modulate cognitive, emotional, behavioral, and autonomic output. The question is: Can these skills promote a healthy aging? ANS: autonomic nervous system, HPA: hypothalamic-pituitary-adrenal axis.

Neural Plasticity, 2019, Article ID:7067592

Central Nervous System : Non-Invasive EEG

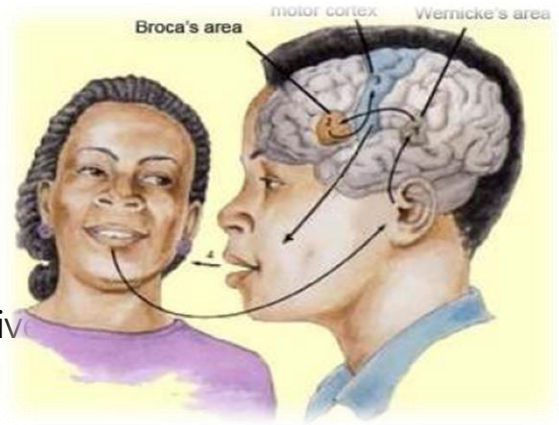


The same principle with a voltmeter that measures electric potential difference between two points in an electric circuit

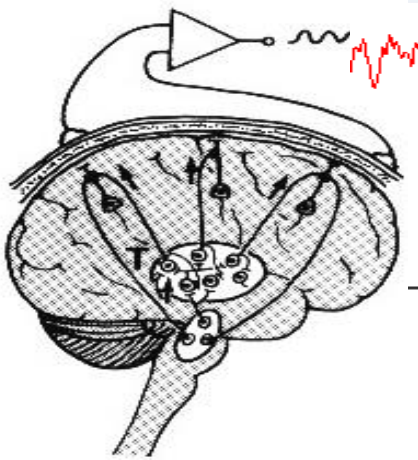
Complicated oscillation

Minute electrical potential signal in uV level

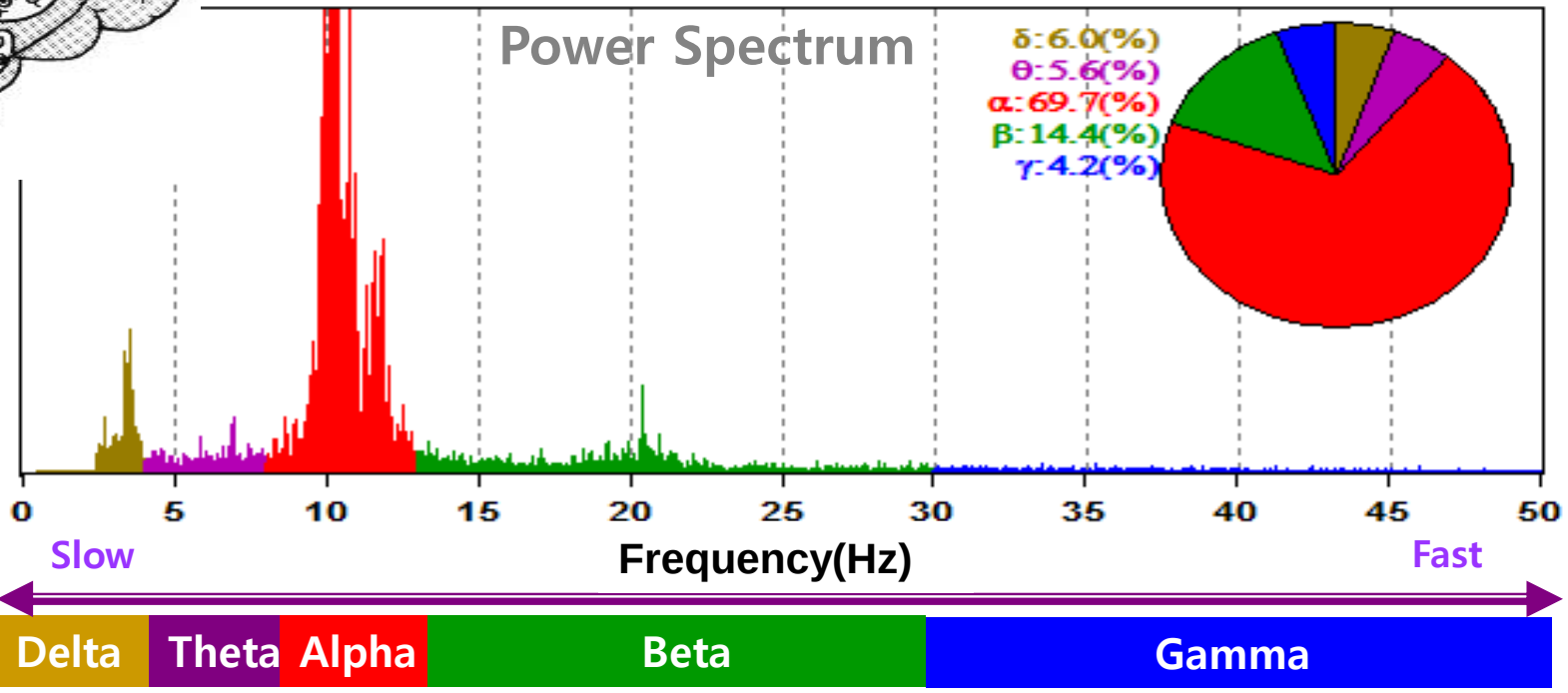
Spontaneous and continuous generation while aliv



Default Mode Network
Intrinsic oscillation in the eye-closed resting EEG



- sinusoidal 5-13 Hz waveform
- modulated by thalamo-cortical and cortico-cortical interactions.



Idling cortical state

(Internal Mental Processing)

(External Mental Processing)

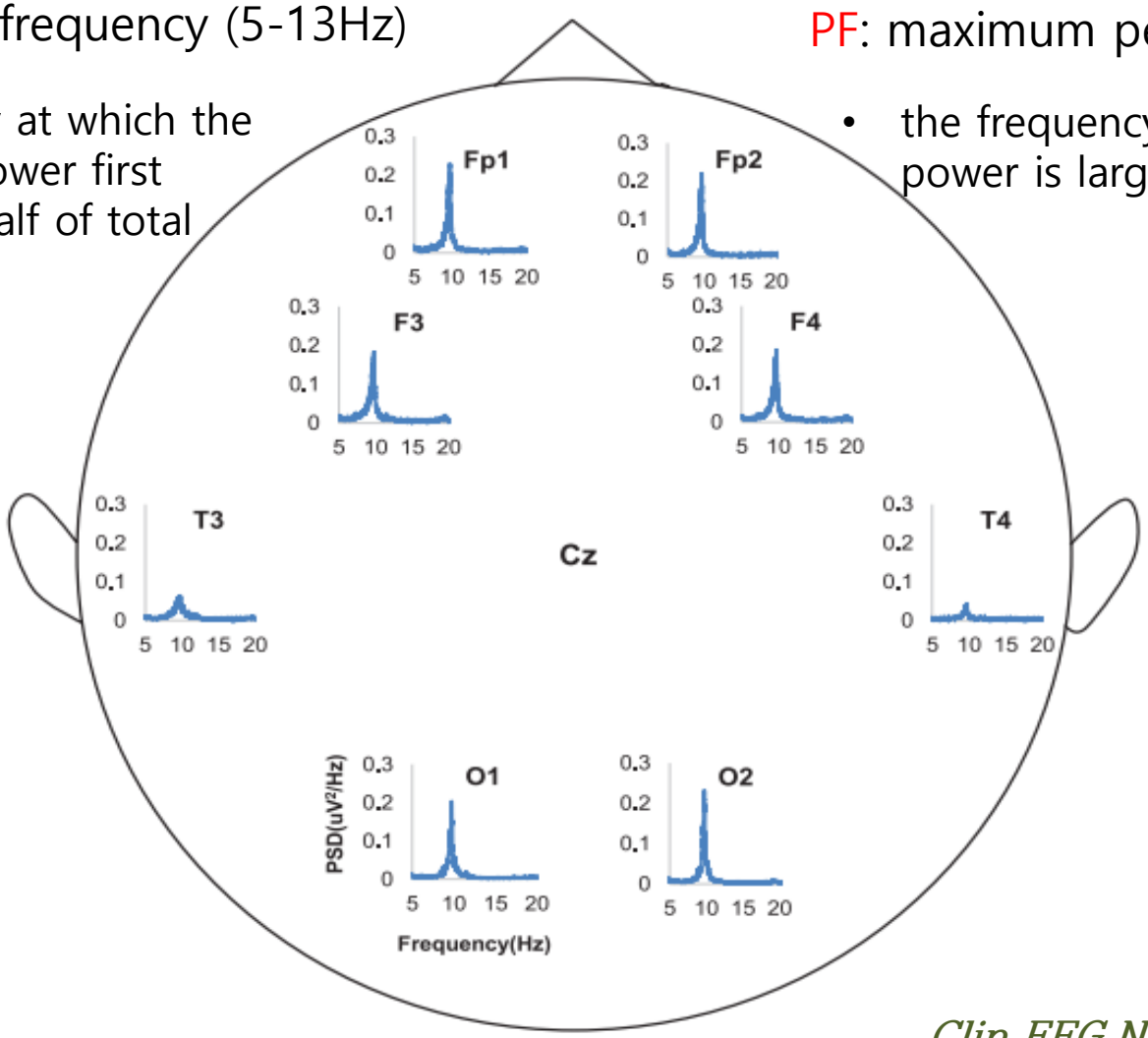
Intrinsic oscillation with same patterns in all brain regions

MDF: median frequency (5-13Hz)

- the frequency at which the cumulative power first exceeded a half of total power

PF: maximum peak frequency

- the frequency at which the power is largest

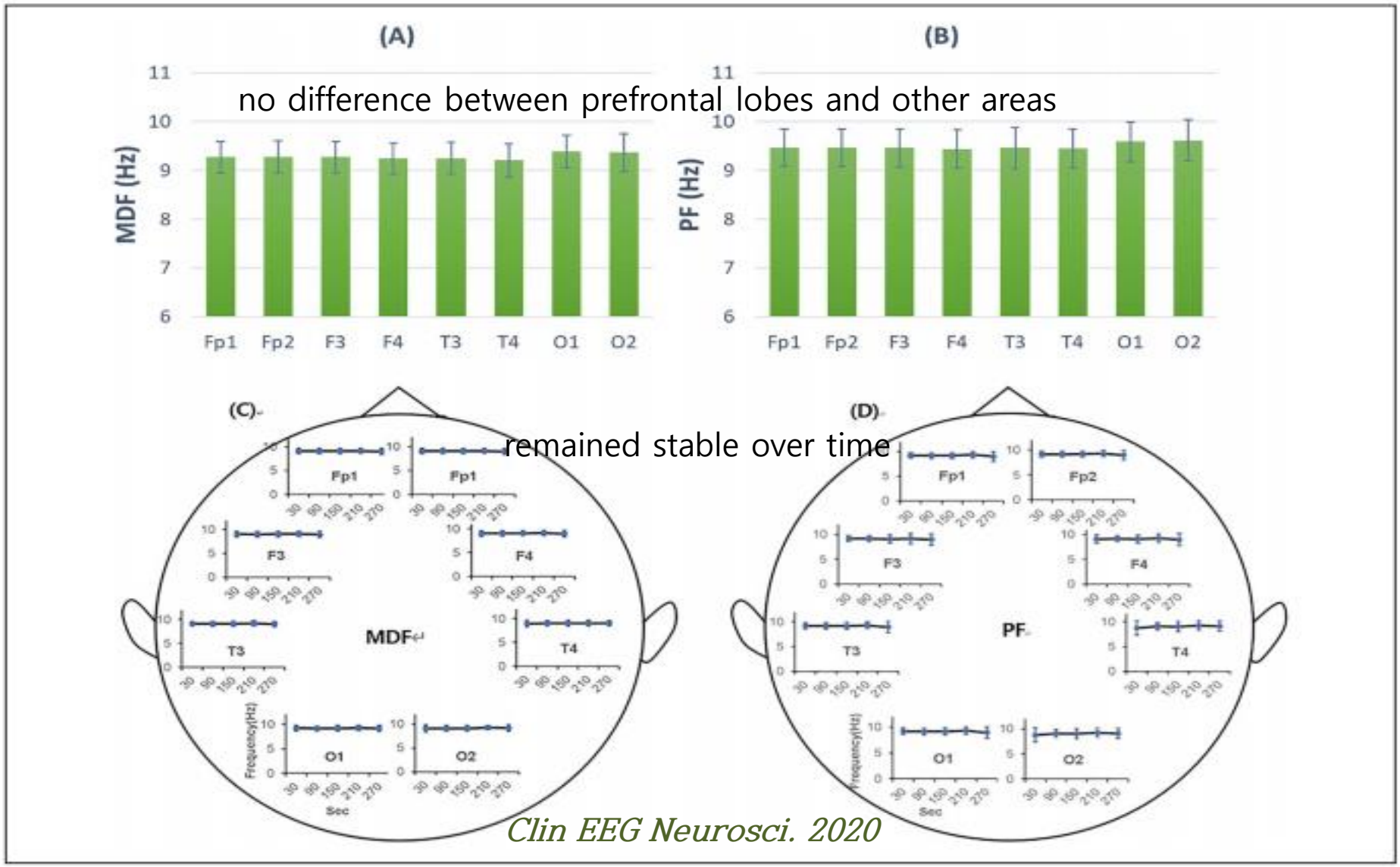


Clin EEG Neurosci. 2020

The characteristics of this intrinsic oscillation can be quantified by some EEG markers such as MDF or PF.

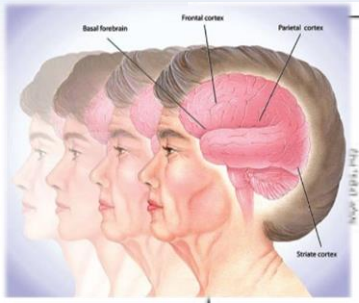
Accuracy and reproducibility of prefrontal EEG markers

by comparing with those of other sites and other time zones



The prefrontal EEG markers such as MDF, PF were reliable with good consistency and good reproducibility.

Negative correlations between intrinsic median frequency and brain aging



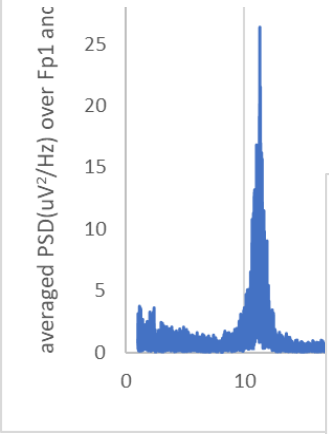
(A) healthy females and healthy males (B)

in the 8 brain regions, such as the left/right prefrontal, frontal, temporal and occipital lobes

Intrinsic median frequency for young adults is around 10 Hz. In older adults, it is lower, about 9 Hz. These correlations with brain aging were significant in all brain regions. *Clin EEG Neurosci. 2020*

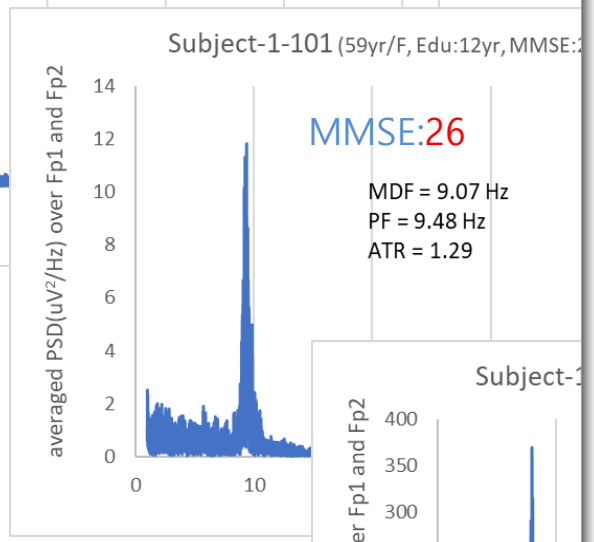
Cognitive decline,
explained by the prefrontal intrinsic oscillations

In the elderly population, the global cognitive function by Mini-Mental State Examination



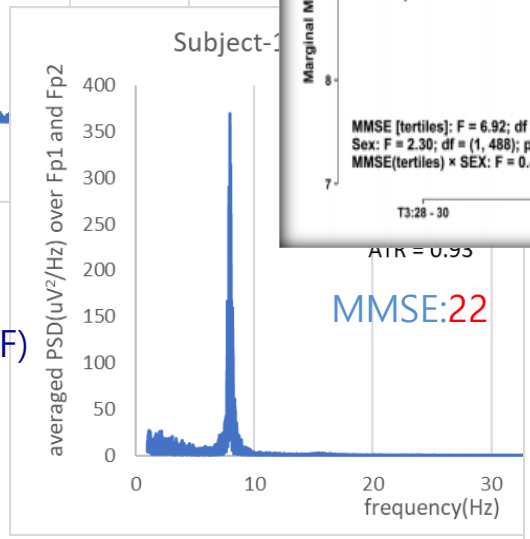
MMSE:30

MDF = 10.8 Hz
PF = 11.0 Hz
ATR = 2.16

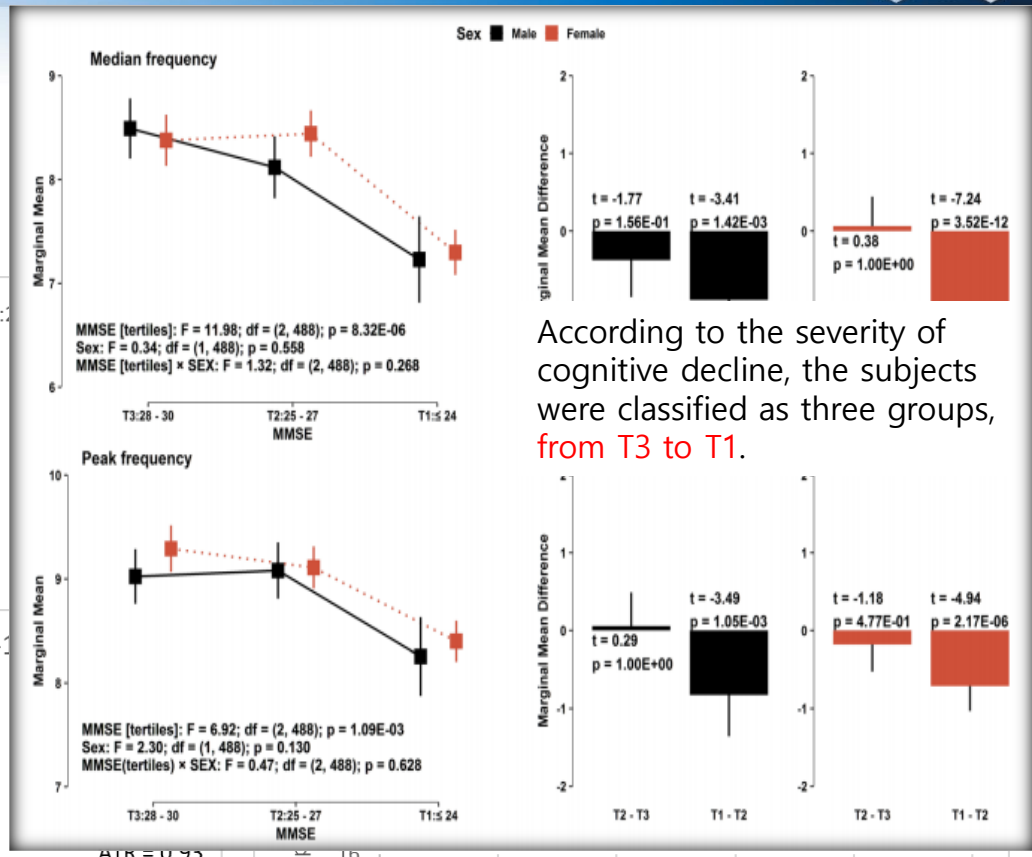


MMSE:26

MDF = 9.07 Hz
PF = 9.48 Hz
ATR = 1.29

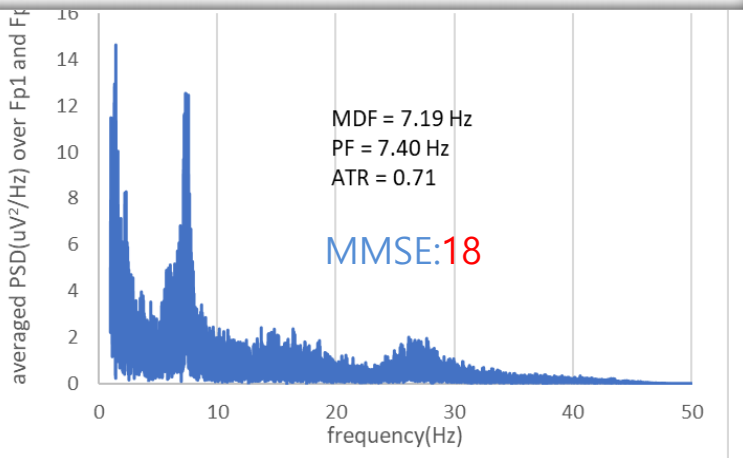


MMSE:22



According to the severity of cognitive decline, the subjects were classified as three groups, from T3 to T1.

In result,
prefrontal EEG markers (MDF, PF)
decreased monotonically
as MMSE-scores decreased!



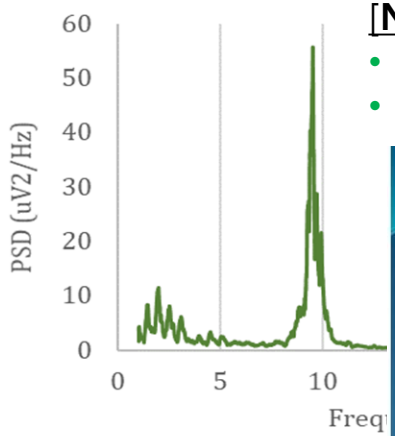
MDF = 7.19 Hz
PF = 7.40 Hz
ATR = 0.71

MMSE:18

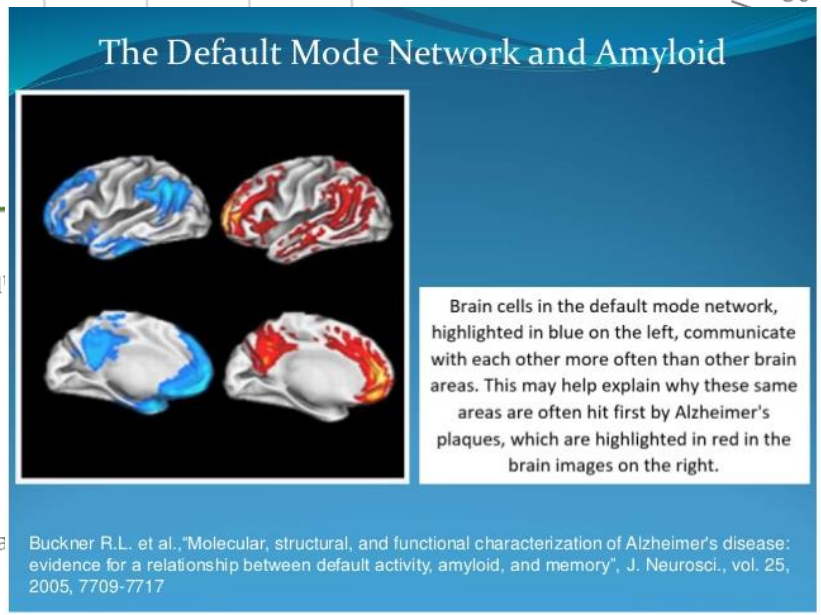
Scientific Reports, 2019

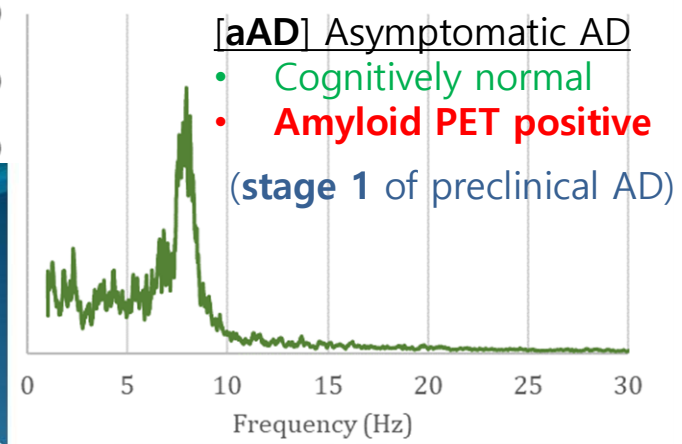
Amyloid load, which is the main pathology of Alzheimer's disease explained by the prefrontal intrinsic oscillations

divided the subjects into four groups, according to the combination of their **amyloid** and **cognitive status**



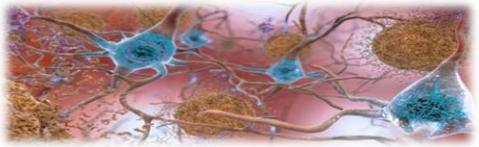
[**NC**] Healthy control
- Cognitively normal
- **Amyloid PET negative**



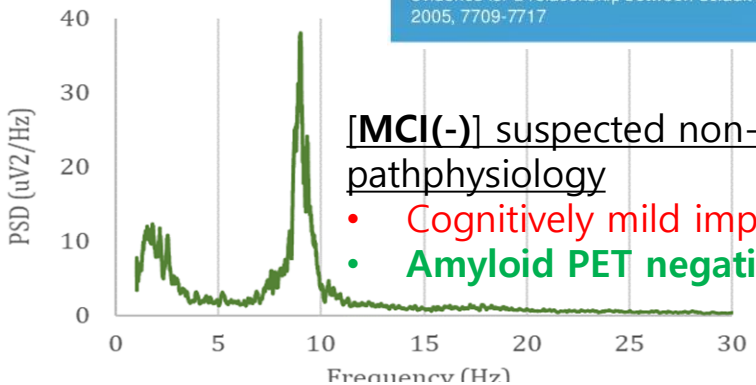


[**aAD**] Asymptomatic AD
- Cognitively normal
- **Amyloid PET positive**

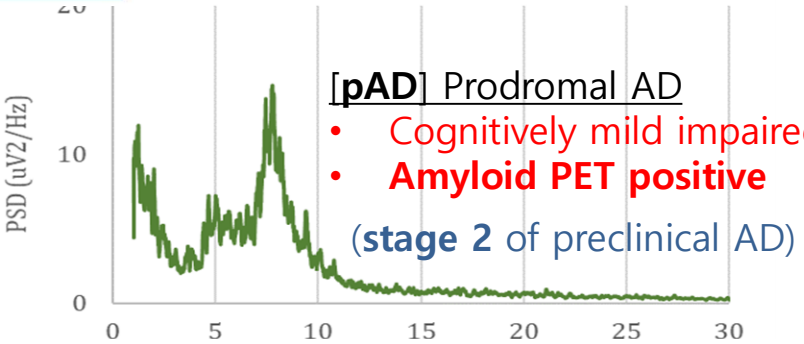
(**stage 1** of preclinical AD)



amyloid positive groups showed more decreased median frequency than negative groups



[**MCI(-)**] suspected non-Alzheimer's pathphysiology
- Cognitively mild impaired
- **Amyloid PET negative**



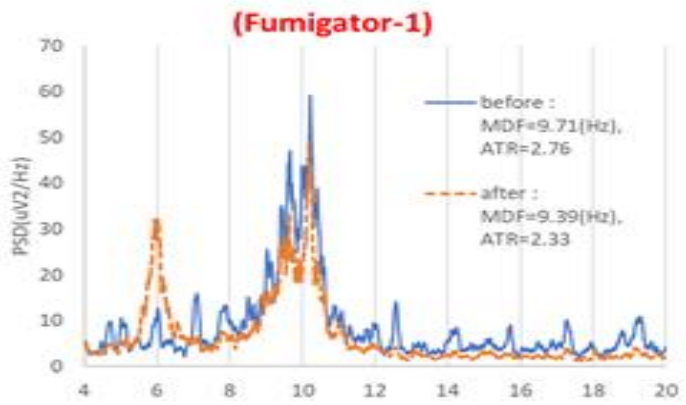
[**pAD**] Prodromal AD
- Cognitively mild impaired
- **Amyloid PET positive**

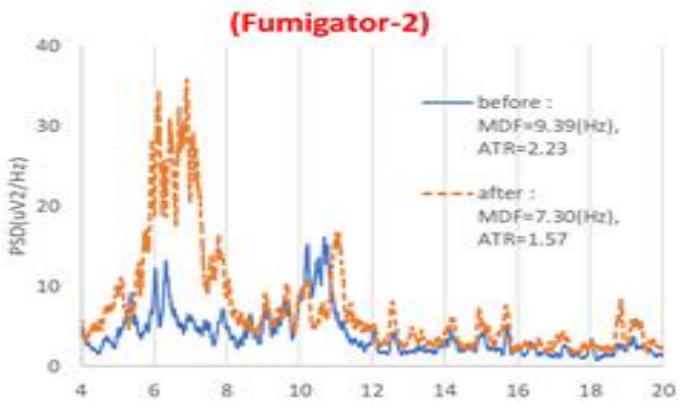
(**stage 2** of preclinical AD)

This preclinical AD's EEG change would be non-invasive and cost-effective screening tools and could help to predict the future progression to clinical AD.

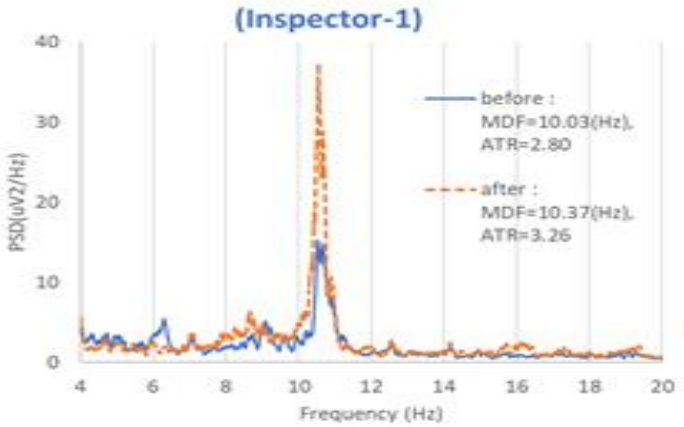
Negative effect of Methyl Bromide fumigation work on central nervous system

Methyl bromide(MB) is a fumigant that has been widely used for killing pests on plants in trade, soils, and structures worldwide.





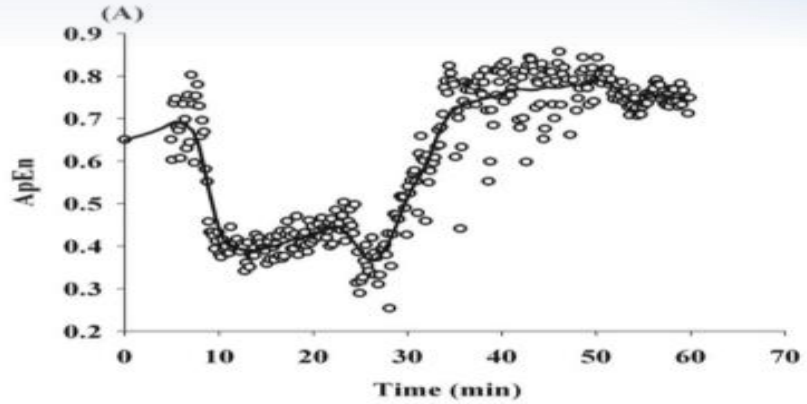
The fumigator post-work median frequencies were significantly decreased compared to the pre-work.
In contrast, there were no differences in control group (inspector).

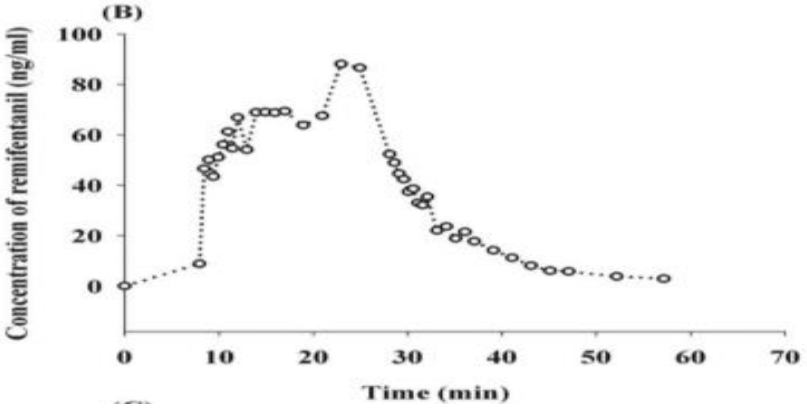


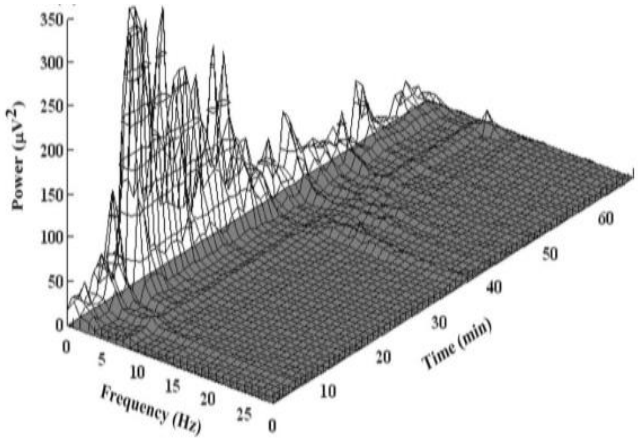
Also, the urinary bromide ion levels were negatively correlated with prefrontal median frequency.
It suggested that occupational exposure to MB negatively affected the health of workers.

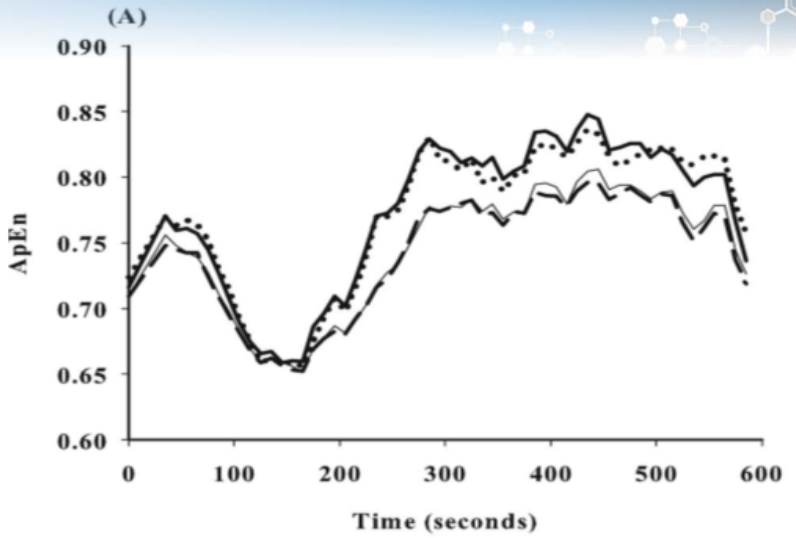
PLOS ONE, 2020

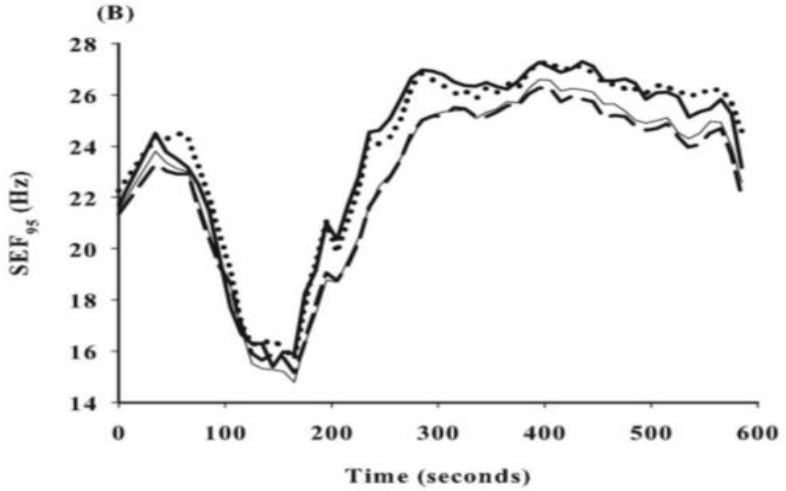
Coherent DMN activity under condition of sedation and general anesthesia (Greicius et al., 2008; Vincent et al., 2007)











Anesthesiology 2006; 104:921–32

Electroencephalographic Approximate Entropy Changes in Healthy Volunteers during Remifentanil Infusion

Gyu-Jeong Noh, M.D., Kye-Min Kim, M.D.,† Yong-Bo Jeong, M.D,‡ Seong-Wook Jeong, M.D.,§ Hee-Suk Yoon, M.D.,‖ Sung-Moon Jeong, M.D.,‡ Sung-Hong Kang, Ph.D.,# Olinto Linares, M.S.,** Steven E. Kern, Ph.D.††*

Vulnerable Brain : Low Frontal Alpha Power

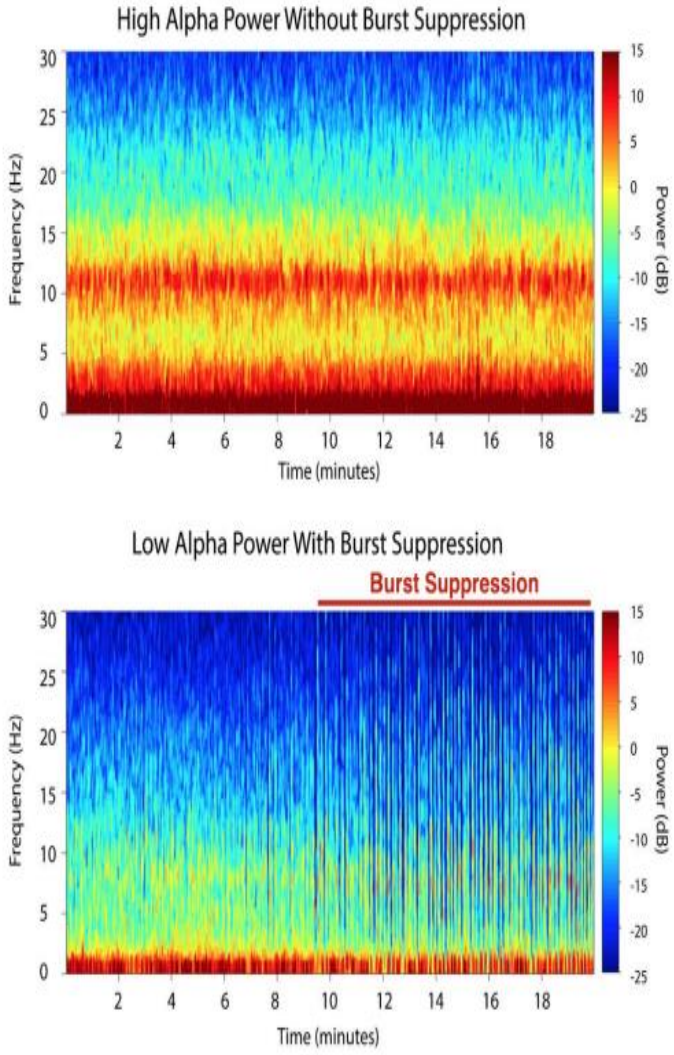
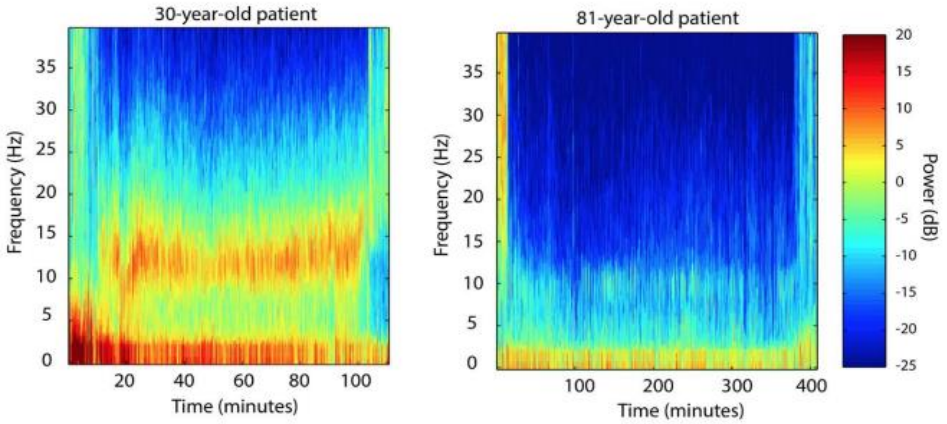


Figure 2. Electroencephalogram spectrograms from individual patients illustrating the relationship between power in anesthesia-induced alpha band activity and burst suppression. Top, The spectrogram shows an example of a patient with high alpha power and no burst suppression. Bottom, The spectrogram shows an example of a different patient with low alpha power and prolonged burst suppression.



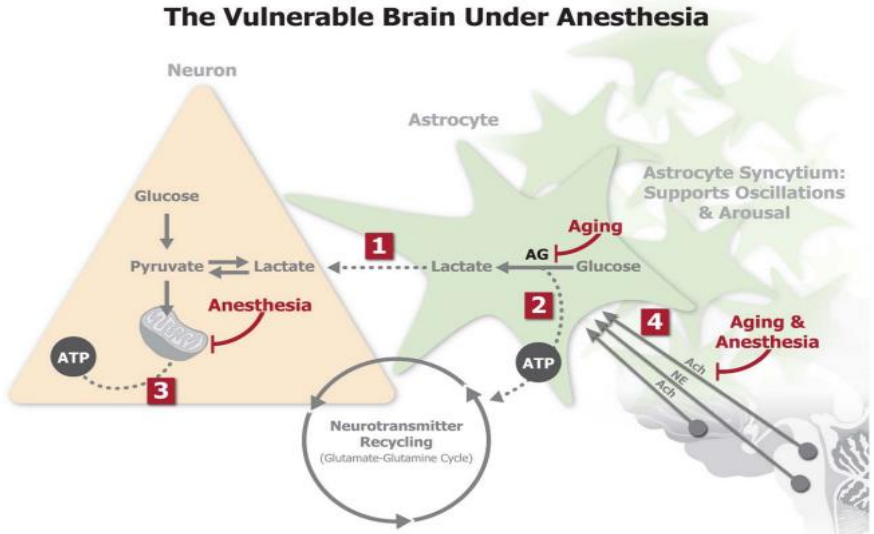


Figure 6. The "vulnerable brain" under anesthesia: a hypothesis linking metabolism, brain oscillations, burst suppression, and cognitive decline. Decreased astrocytic AG in prefrontal cortex fails to provide adequate metabolic support for neuronal oxidative phosphorylation (1) and sustained synaptic neurotransmission (2). Burst suppression is thought to occur when the brain has an inadequate supply of ATP. If metabolism is compromised as in (1) and (2), further depression of brain metabolism by anesthetic drugs via impaired mitochondrial function (3) results in a higher propensity for burst suppression. Astrocytes support brain metabolism, but are also thought to support brain oscillations through their highly connected syncytial networks. In the aging brain with preexisting neuromodulatory deficits, general anesthesia further inhibits subcortical neuromodulatory inputs on astrocyte syncytial networks (4) and suppresses astrocyte–neuron metabolic interactions, leading to less robust brain oscillations. Ach indicates acetylcholine; AG, aerobic glycolysis; ATP, adenosine triphosphate; NE, norepinephrine.

Anesthesia & Analgesia, 2020, 131(5)

Brain networks of meditation

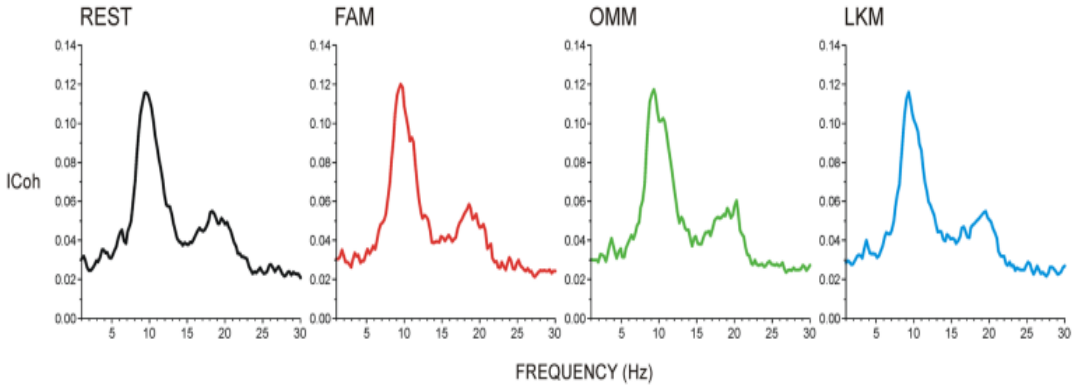
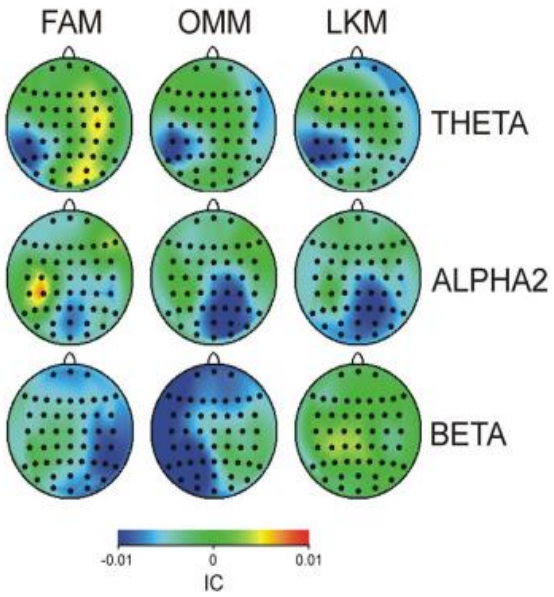


Figure 1. Grand average of the imaginary part of coherence (*ICoh*) as a function of frequency pooled for all investigated electrode combinations during resting state (REST), focused attention meditation (FAM), open monitoring meditation (OMM), and loving kindness meditation (LKM).



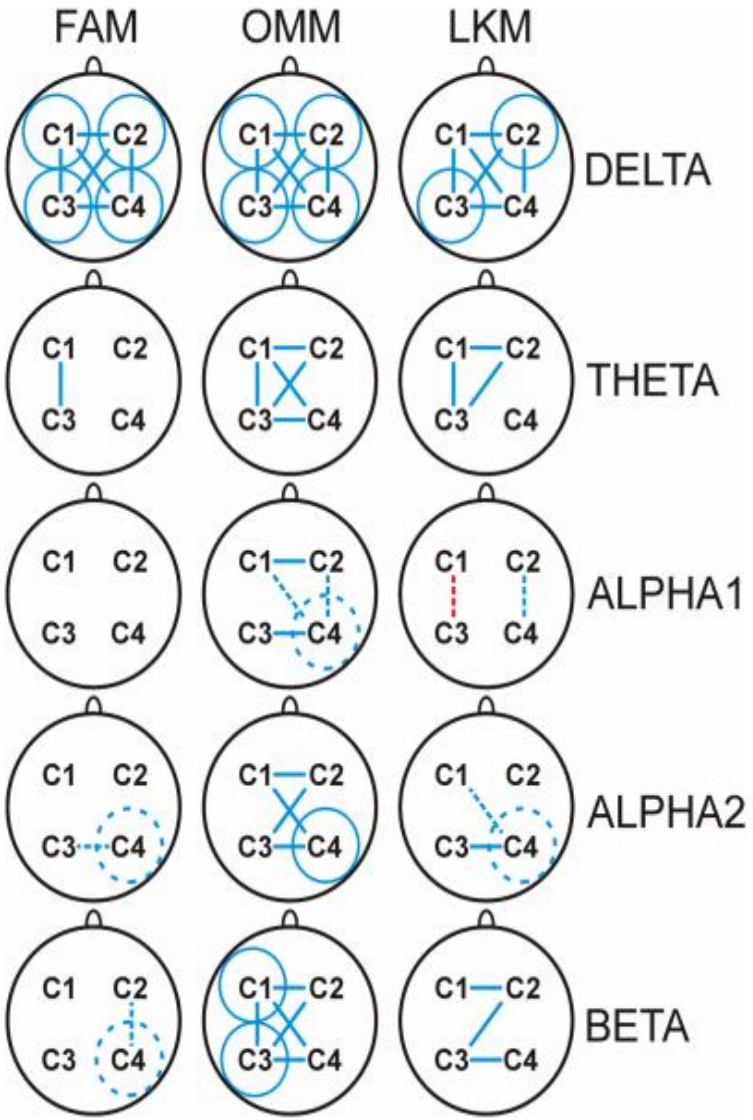


Figure 5. Topography maps of grand average integrated connectivity (*IC*) presented as a difference between REST and the respective meditation condition (FAM, OMM, and LKM) for three frequency ranges (theta, alpha 2, and beta), which showed systematic differences. Blue colour indicates meditation-related increase; red colour indicates meditation-related decrease.

Scientific Reports, 2020, 10:7431

Neuronal activation during meditation

- FA, OM, TM, and LK meditation are associated with global increases in oscillatory activity in meditators compared to meditation-naïve adults, with larger changes occurring as the length of meditation training increases.
- Alpha activity increases in posterior brain regions during both FA and OM. In anterior regions, FA shows a bilateral increase in alpha power, while OM shows a decrease only in left-sided power.
- Gamma activity in these meditation practices is similar in frontal regions, but increases are variable in parietal and occipital regions.

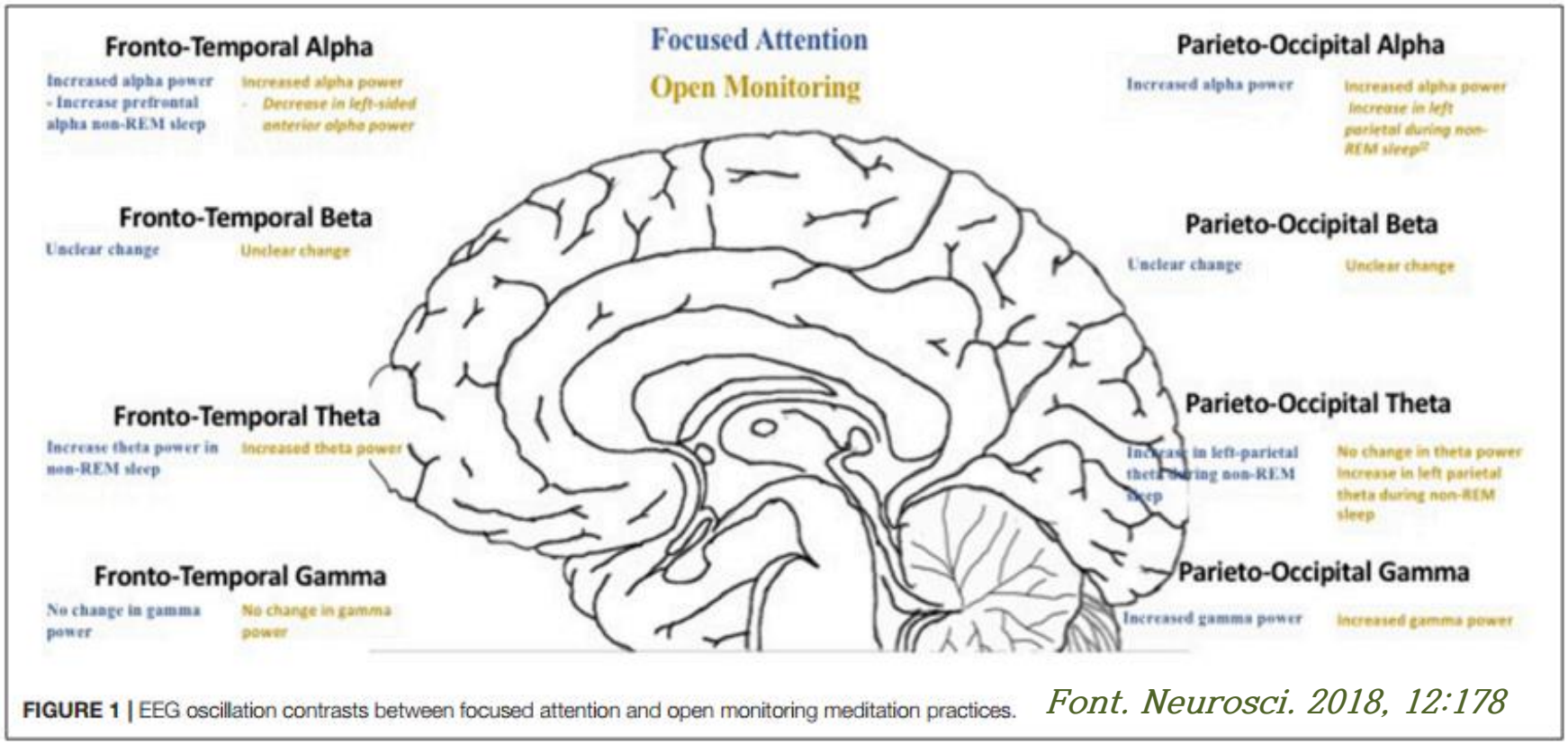


FIGURE 1 | EEG oscillation contrasts between focused attention and open monitoring meditation practices.

Font. Neurosci. 2018, 12:178

Transcendental Meditation (TM) : EEG Coherence

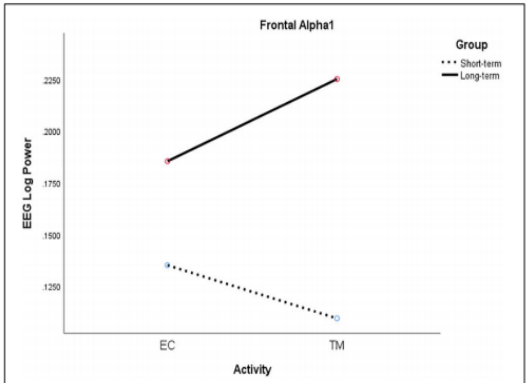


FIGURE 6 | Significant activity × group interaction for frontal alpha1 log power for ST (broken) and LT (solid) meditators during EC rest and TM practice, collapsing across all conditions.

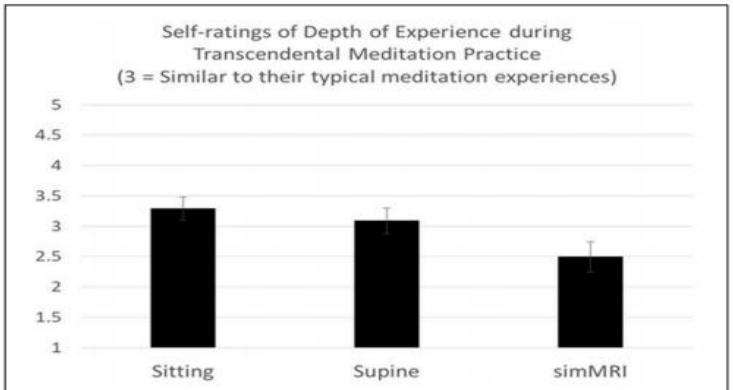


FIGURE 1 | Means and standard errors of self-rating of experiences during Transcendental Meditation practice (1 = Less Deep to 5 = Deeper).

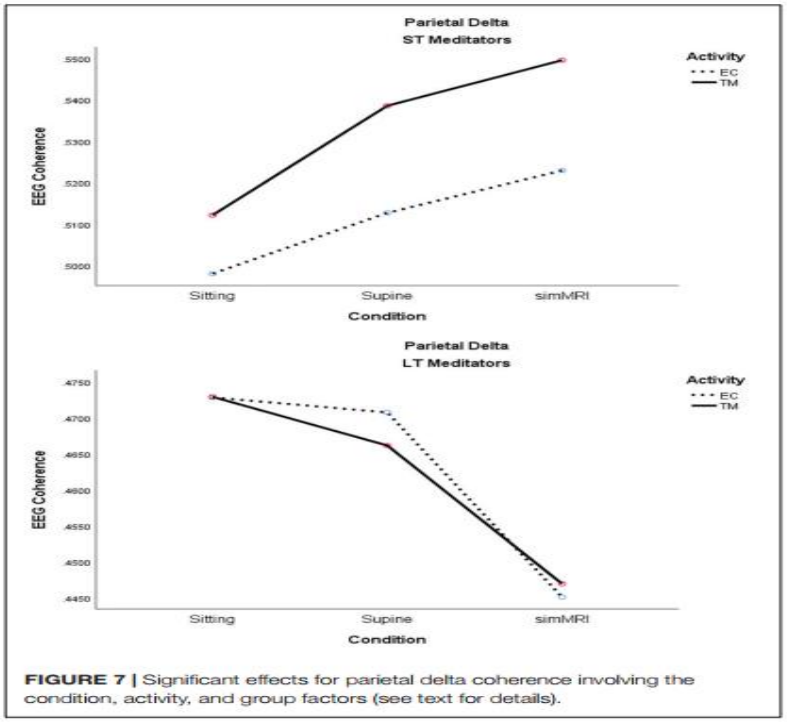


FIGURE 7 | Significant effects for parietal delta coherence involving the condition, activity, and group factors (see text for details).

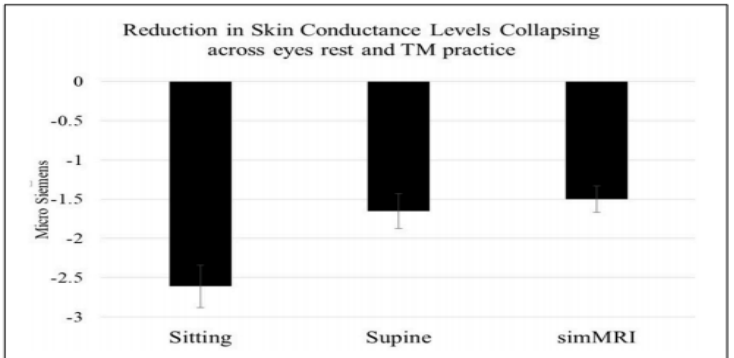
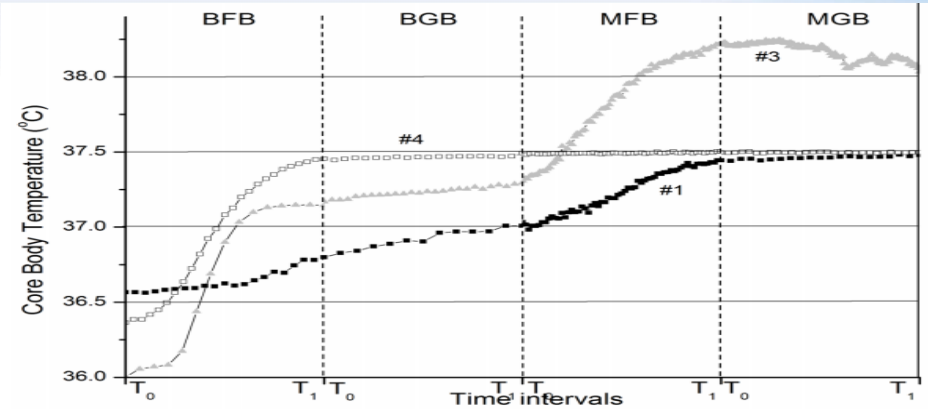


FIGURE 2 | Mean and standard error EDA reductions within each condition (from beginning to 3 min into each session), collapsing across activity and experience group. Skin conductance level decreases when sitting were significantly larger than during both the supine and simMRI conditions.

Frontiers in Psychology, 2020 (vol.11:728)

G-Tummo Meditation



Forceful Breath (FB) and Gentle Breath (GB).

1) Baseline FB (BFB)
2) Baseline GB (BGB)
3) Meditation FB (MFB)
4) Meditation GB (MGB)

*Participants' eyes remained opened during all the conditions.

Figure 3. CBT increases for Study 1 participants #1, #3, and #4 during BFB, BGB, MFB, and MGB performed in a continuous sequence. Since the duration of each of the four practices varied from participant to participant, to simplify the figure presentation, the duration of each practice is rescaled from 0 to 1, with t0 the starting point of each practice, and t1 the ending point.
doi:10.1371/journal.pone.0058244.g003

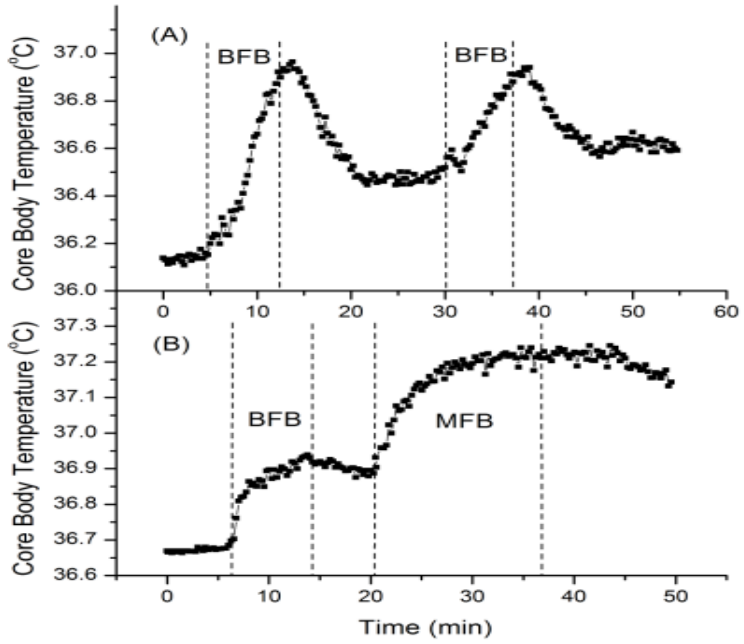


Figure 7. CBT increases during FB as performed by a Western non-meditator and a Western g-tummo practitioner. The vertical dashed lines indicate the beginning/end of different phases of the practice; (A, Western non-meditator): rest, BFB, rest, BFB, rest, and (B, Western g-tummo pract itioner): rest, BFB, rest, MFB, rest.
doi:10.1371/journal.pone.0058244.g007

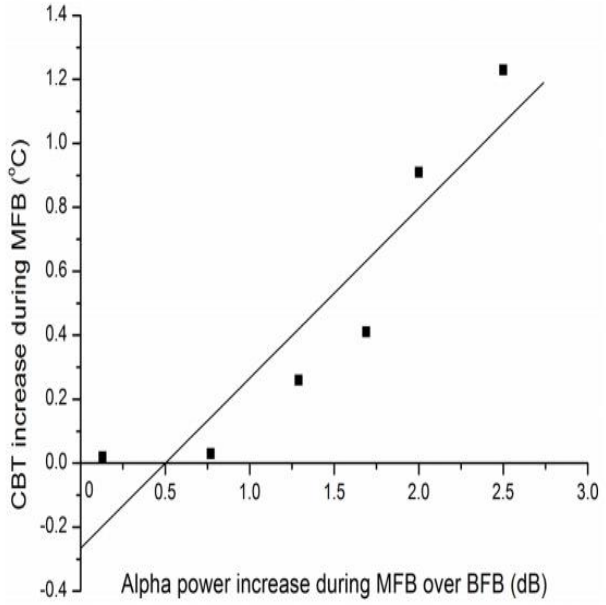


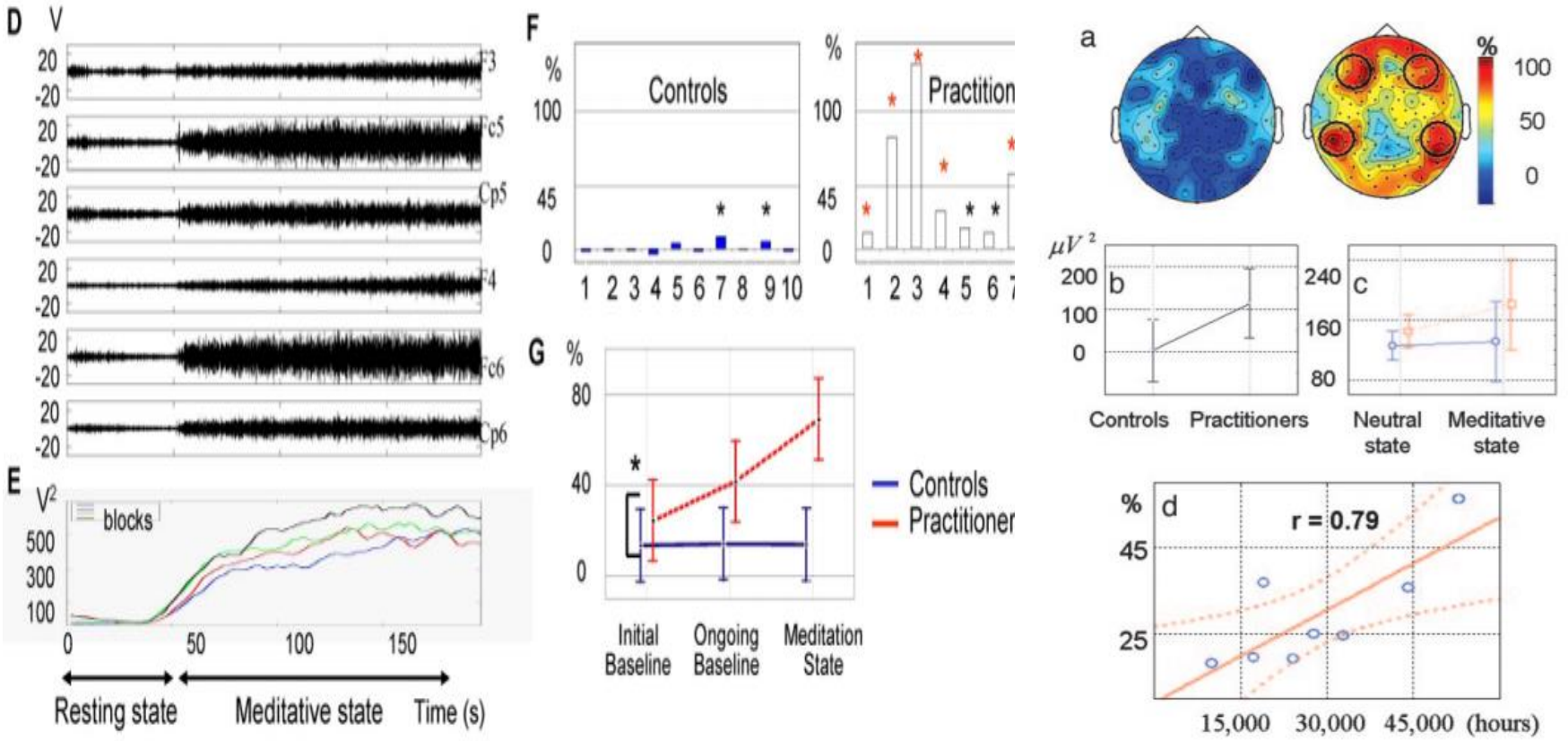
Figure 5. CBT increases during FB meditation in Study 1as a function of alpha power increases during MFB over BFB (solid line represents regression).
doi:10.1371/journal.pone.0058244.g005

Figure 2. Hand position during g-tummo meditation.
doi:10.1371/journal.pone.0058244.g002

PLoS ONE. 2013, 8(3)

Buddha's Brain : Long-term Buddhist practitioners

High amplitude gamma synchronizations may play a crucial role in the constitution of transient networks that integrate distributed neural processes into highly ordered cognitive and affective functions.



PNAS, 2004, vol.101, no.46

IEEE Signal Process Mag. 2008, 25(1)

Coherent Gamma Mechanism: Cognitive Binding

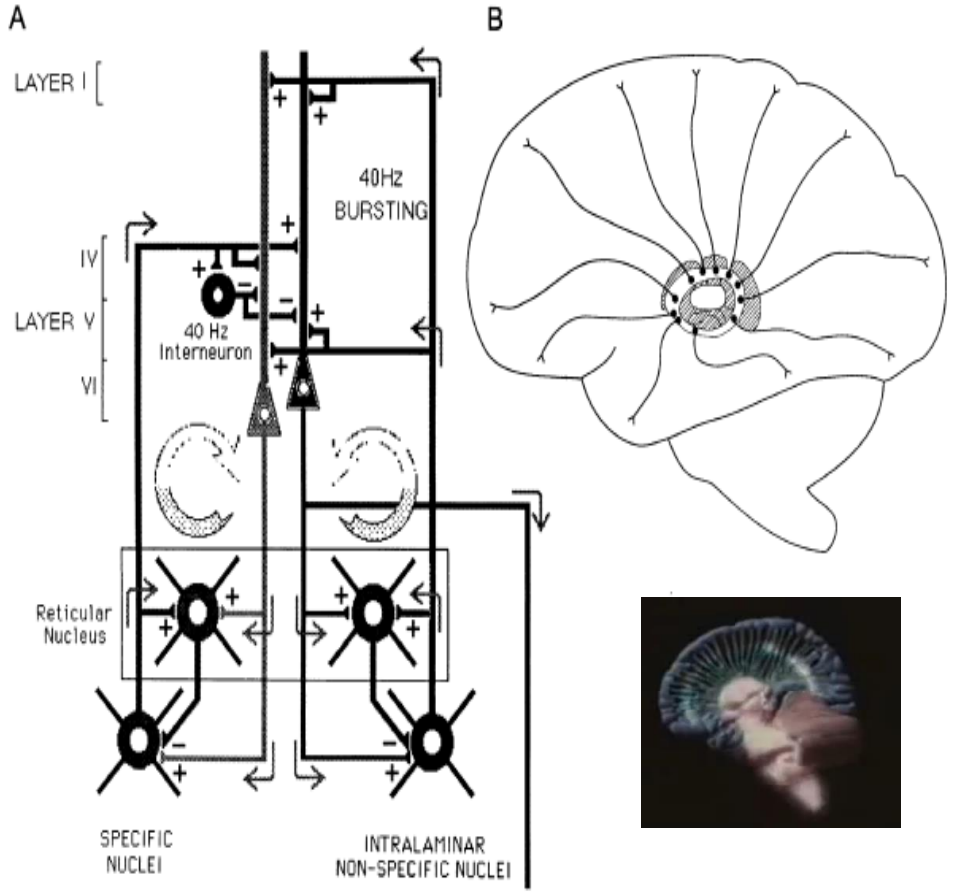


FIG. 4. Thalamocortical circuits proposed to serve temporal binding. (*A*) Diagram of two thalamocortical systems. (*Left*) Specific sensory or motor nuclei project to layer IV of the cortex, producing cortical oscillation by direct activation and feed-forward inhibition via 40-Hz inhibitory interneurons. Collaterals of these projections produce thalamic feedback inhibition via the nucleus reticularis. The return pathway (circular arrow on the right) reenters this oscillation to specific and reticularis thalamic nuclei via layer VI pyramidal cells. (*Right*) Second loop shows nonspecific intralaminary nuclei projecting to the most superficial layer of the cortex and giving collaterals to the reticular nucleus. Layer V pyramidal cells return oscillation to the reticular and the nonspecific thalamic nuclei, establishing a second resonant loop. The conjunction of the specific and nonspecific loops is proposed to generate temporal binding. (*B*) Diagram of the intralaminar nuclear complex, seen as a circular neuronal mass (stippled shading). Other nuclei in the thalamus are shown as hatched shading. The intralaminary nuclear complex projects throughout neocortical layer I.

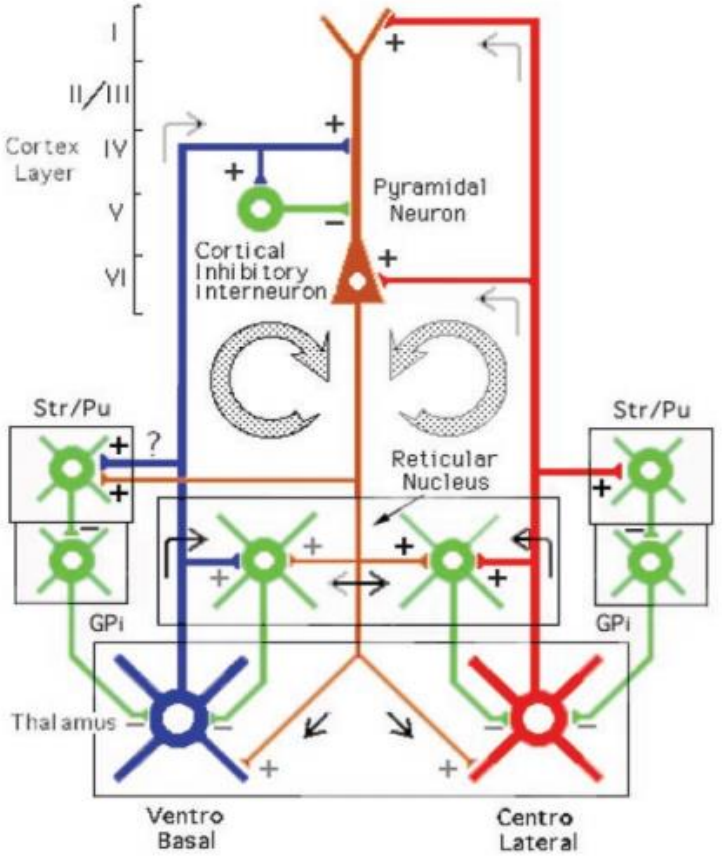
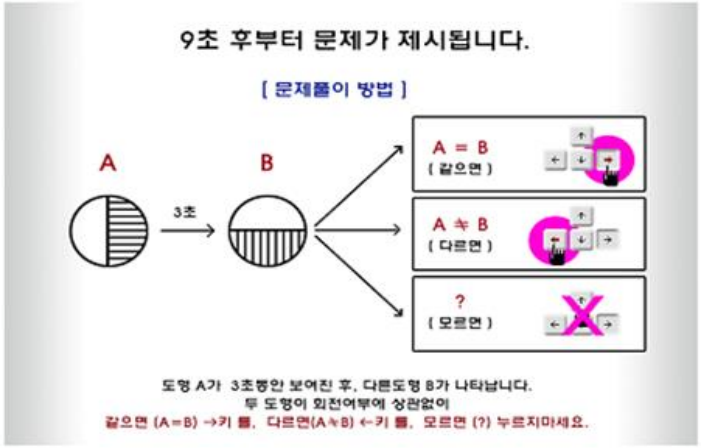


Fig. 5. Thalamocortical circuits proposed to subserve temporal binding; diagram of the two thalamocortical systems. The first loop shows the specific ventrobasal nucleus projecting to layer IV of the cortex and to inhibitory interneurons and collaterally to reticular nucleus and striatum/putamen. The second loop shows the nonspecific centrolateral intralaminar nucleus projecting to layers I and VI and also giving collaterals to reticular nucleus and striatum/putamen. Collaterals of these two thalamocortical projections also produce thalamic feedback inhibition via the reticular nucleus and globus pallidus (GPi). The return pathway (in brown) from deep layers V–VI returns the oscillation to the thalamic reticular, ventrobasal, and centrolateral nuclei.

PNAS 1993, Vol.90

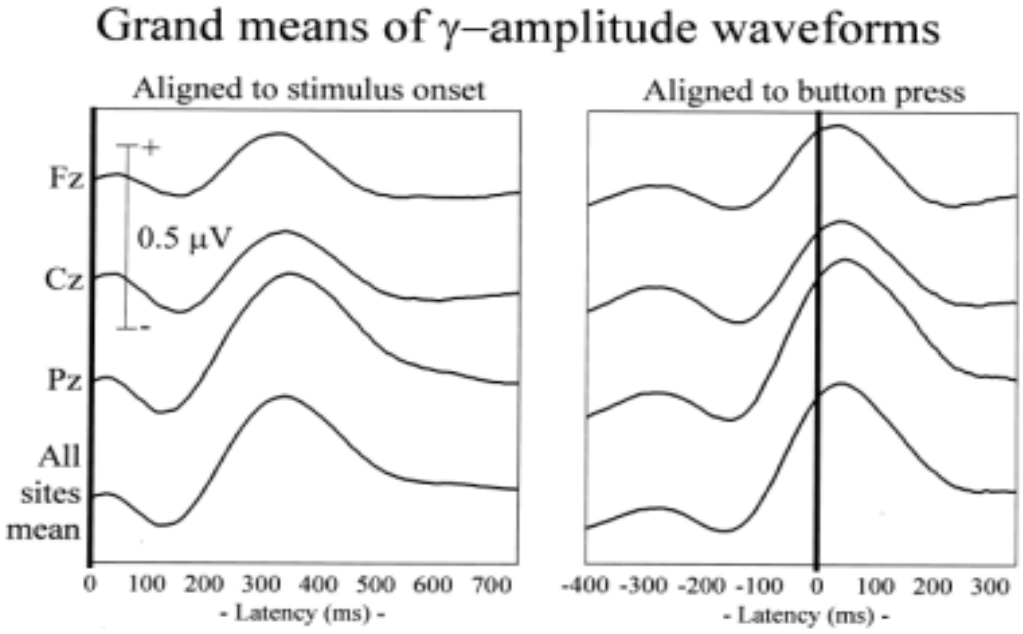
PNAS 2002, Vol.99

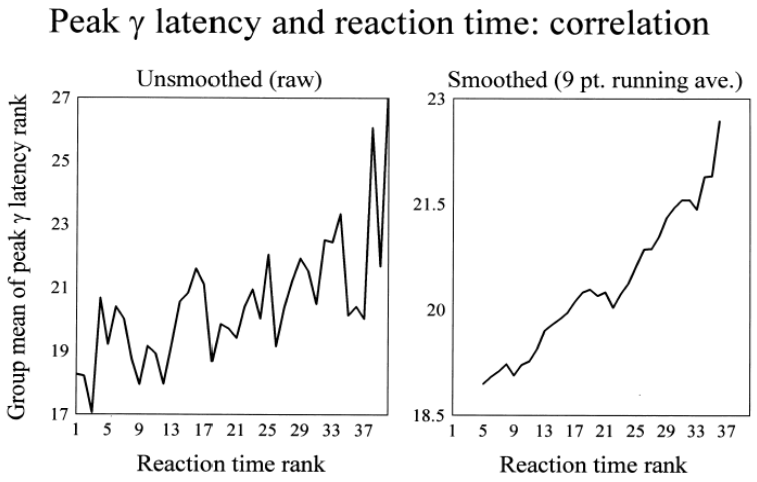
Gamma: Higher Order Cognitive Function



Cognitive Discrimination Task

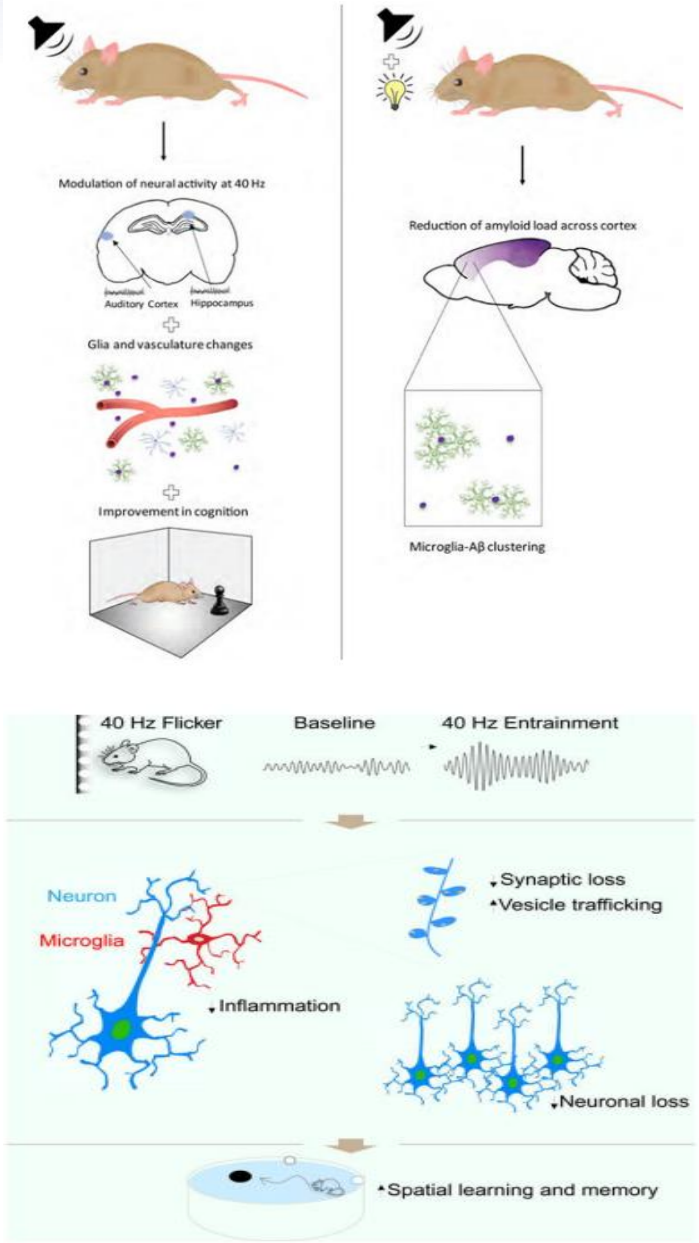
Cognition Task that requires effective binding of Higher Cognitive Processes such as perception, attention, recognition memory match with LTM, short term memory(STM), reasoning, and comparison





International journal of Psychophysiology, 1996, Vol.24.
Frontal gamma-band enhancement during multistable visual perception

Gamma Entrainment
: Binds Higher Order Brain Regions and Offers Neuroprotection



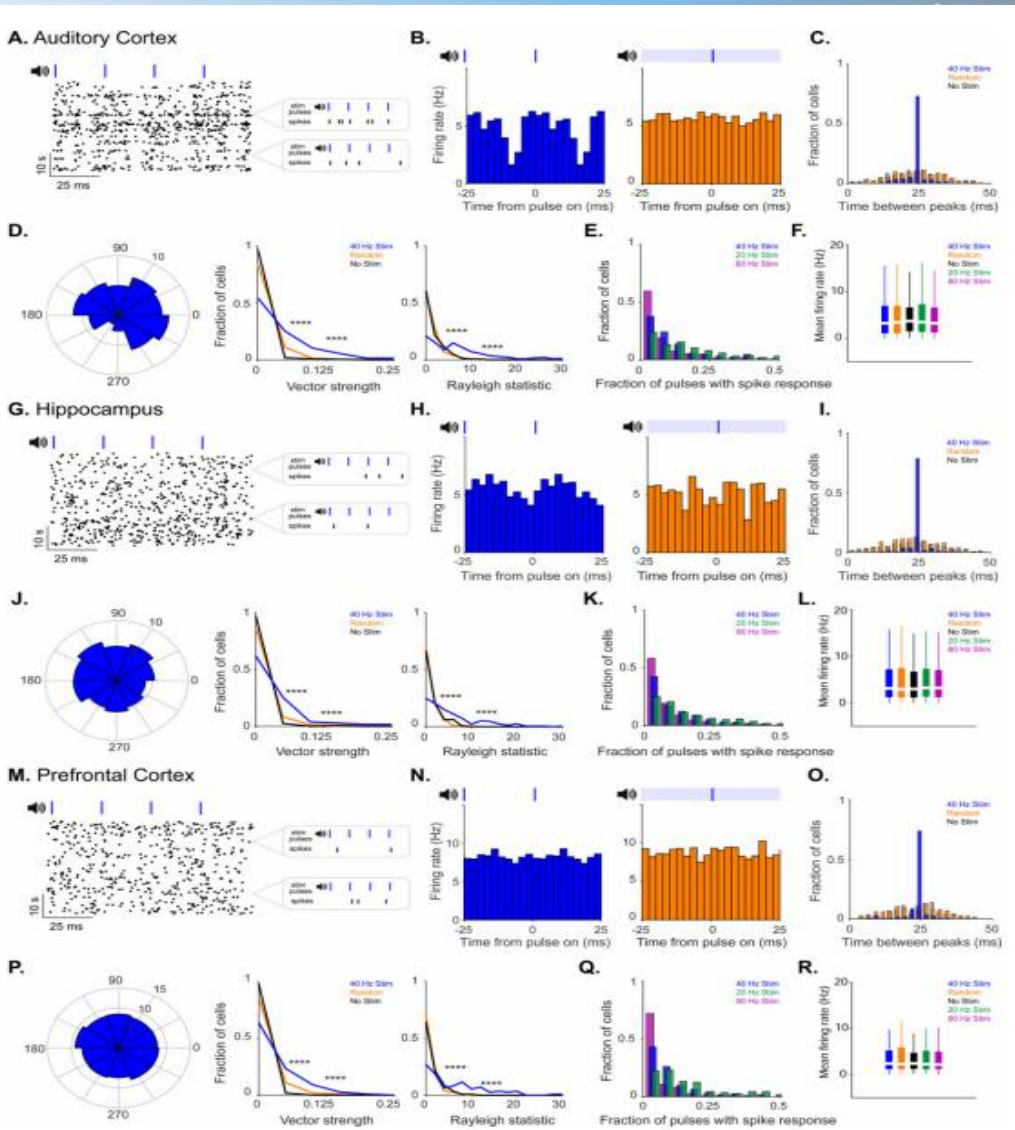


Figure 1. 40 Hz auditory stimulation modulates spiking activity in AC, CA1, and mPFC

Martorell AJ, et al. *Cell*. 2019.
Adaikkan C, et al. *Neuron*. 2019.

Buddhist Jhana Meditation

Buddhist meditation comprises two strands, Samatha and Vipassana; the former often translated as tranquility or serenity, and the latter as insight or wisdom.
Jhana meditation falls within the samatha division. "absorption,"

First rūpa jhāna factors

- Applied attention, or initial thought (= *vitakka*)
- Sustained attention or thought (= *vicāra*)
- Energized interest, or "joy" (= *pīti*)
- Happiness, contentment or bliss (= *sukha*)
- One-pointedness of mind (= *ekaggatācitta*)

Second rūpa jhāna factors

- Energized interest, or "joy" (= *pīti*)
- Happiness, contentment or bliss (= *sukha*)
- One-pointedness of mind (= *ekaggatācitta*)

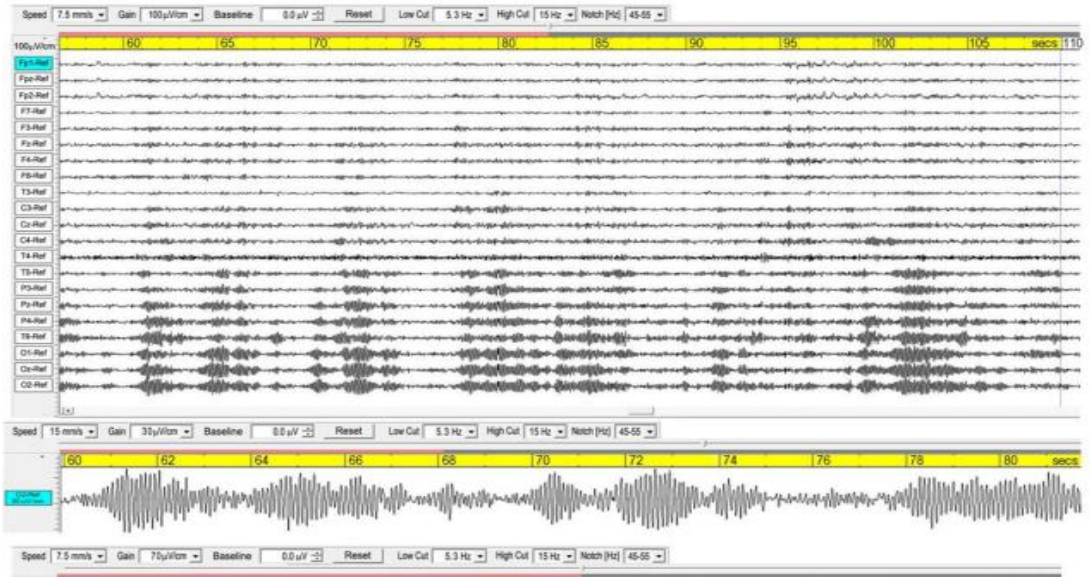
Third rūpa jhāna factors

- Happiness, contentment or bliss (= *sukha*)
- One-pointedness of mind (= *ekaggatācitta*)

Fourth rūpa jhāna factors

- One-pointedness of mind (= *ekaggatācitta*)
- Equanimity(= *upekkha*)

1. Spindles



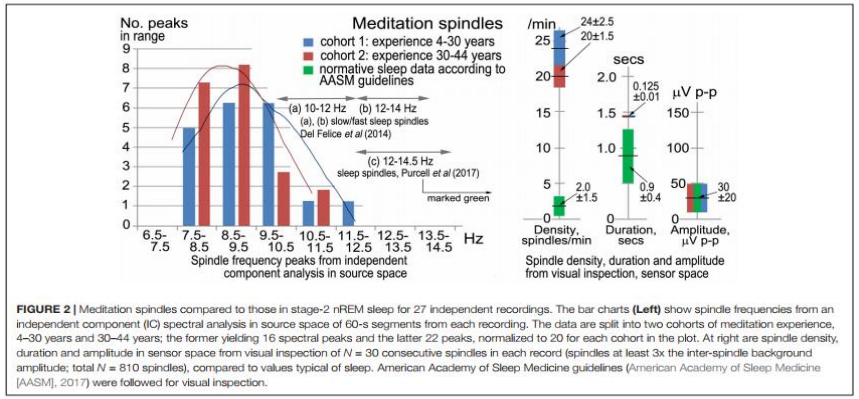
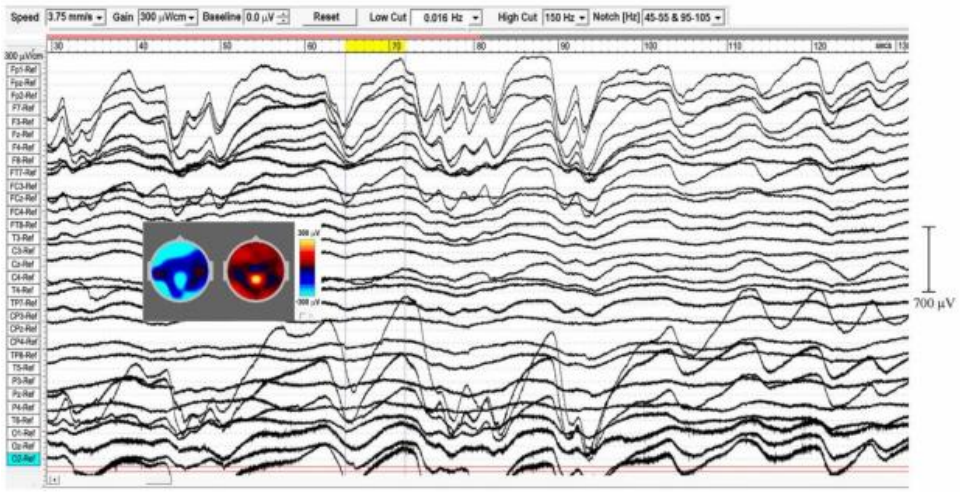


FIGURE 2 | Meditation spindles compared to those in stage-2 nREM sleep for 27 independent recordings. The bar charts **(Left)** show spindle frequencies from an independent component (IC) spectral analysis in source space of 60-s segments from each recording. The data are split into two cohorts of meditation experience, 4–30 years and 30–44 years; the former yielding 16 spectral peaks and the latter 22 peaks, normalized to 20 for each cohort in the plot. At right are spindle density, duration and amplitude in sensor space from visual inspection of $N = 30$ consecutive spindles in each record (spindles at least 3x the inter-spindle background amplitude; total $N = 810$ spindles), compared to values typical of sleep. American Academy of Sleep Medicine guidelines (American Academy of Sleep Medicine [AASM], 2017) were followed for visual inspection.

Frontiers in Human Neuroscience, 2019, 13:178

Buddhist Jhana Meditation

2. Infraslow-Wave (ISW) Activity



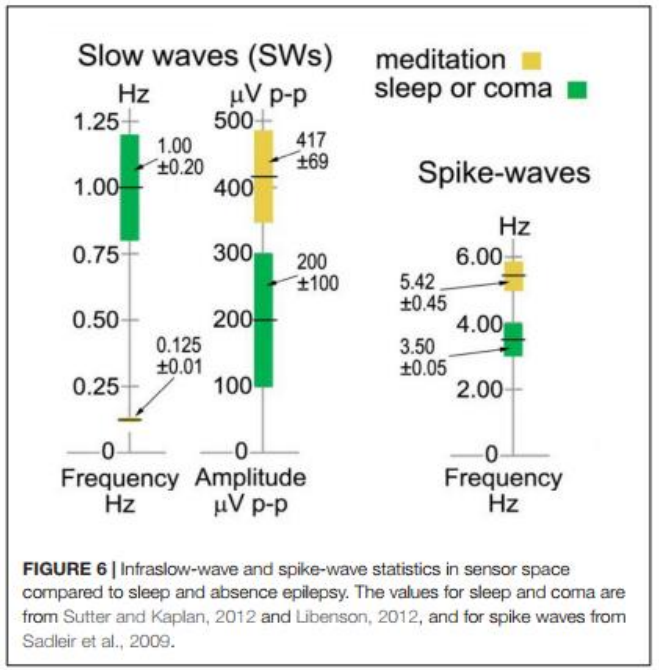


FIGURE 6 | Infraslow-wave and spike-wave statistics in sensor space compared to sleep and absence epilepsy. The values for sleep and coma are from Sutter and Kaplan, 2012 and Libenson, 2012, and for spike waves from Sadleir et al., 2009.

3. Spike-Wave Activity

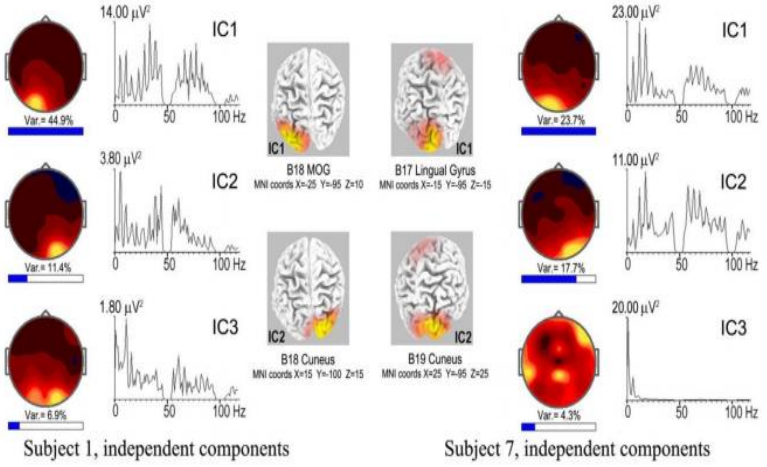
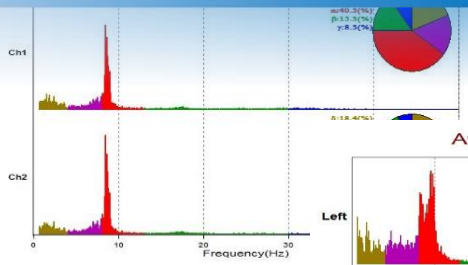


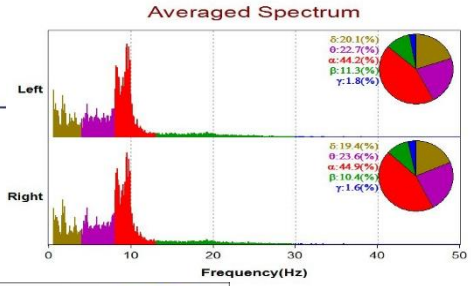
FIGURE 10 | Above are four examples of spike-wave bursts at occipital sites, using a bandwidth 0.53–70/150 Hz. Top to bottom are excerpts from an 8.6-s burst, subject 11, 2015; a 50-s burst, subject 26, 2016; an 8.3-s burst, subject 15, 2018; and a 3.025-s burst, subject 1, 2015. Below are the strongest ICs for subjects 1 and 7, from 3.025-s and 7.0-s bursts respectively, computed using eLoreta, showing harmonic spectral structure, spectral intensity distributions, and 3D source maps.

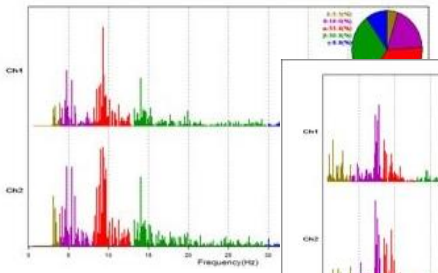
Frontiers in Human Neuroscience, 2019, 13:178

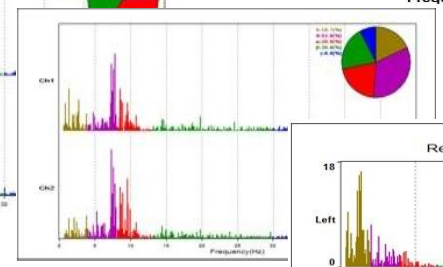
Main Features of Meditative EEG

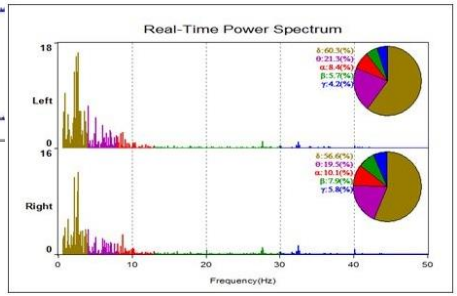
1. alpha peak stability (centrality)
2. alpha peak amplification (increased alpha peak achieved even with eyes open)
3. alpha peak modulation
4. theta peak appearance
5. delta peak appearance
6. Nirvana wave
7. gamma peak appearance
8. Free upward/downward modulat

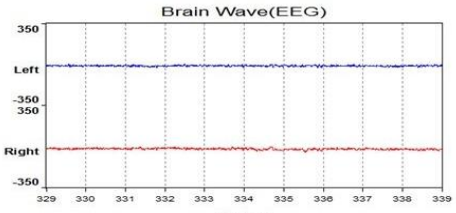


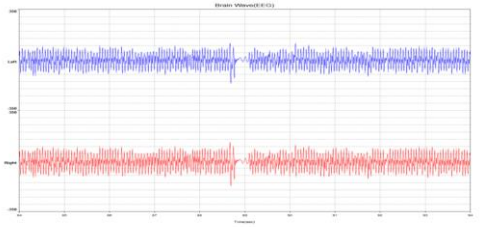


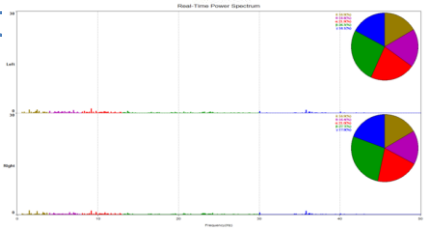


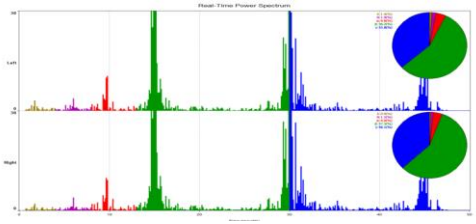












Zen Brain Reflections by James H. Austin, 2006

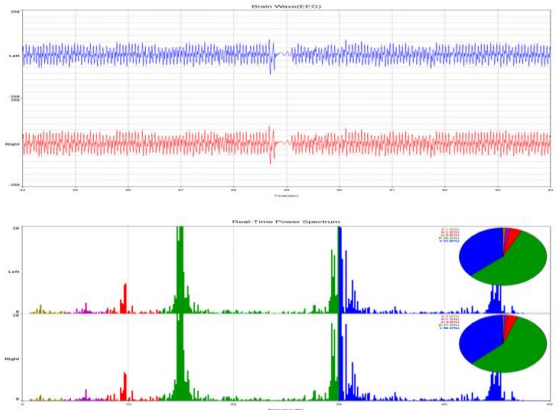
High-level consciousness ◆ Changed (Low-level) consciousness

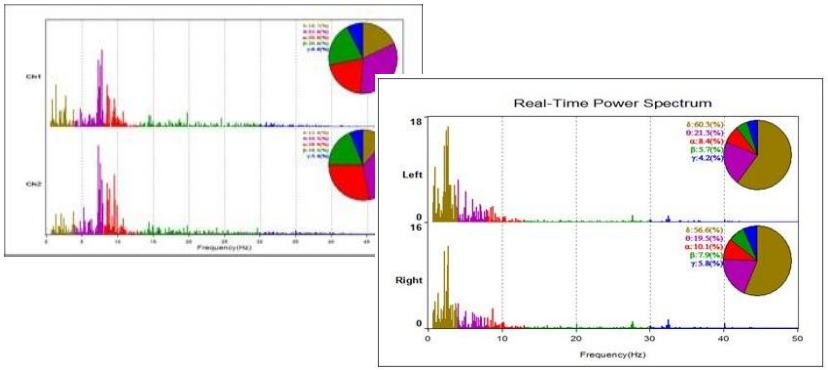
High-level consciousness: fast brain wave rhythm

- Awakened consciousness
- The frontal lobe works in the frequency of 8Hz or above in order to maintain concentration and perceive an integrated experience. In order to perceive the experience of being one with the universe and all things under the sun, the frontal lobe needs to be in the gamma wave band, which is as high as 40 Hz.
- Spiritual experience of being awakened mainly activates the frontal lobe and engages the right hemisphere in addition. When the frontal lobe activities increase while it is well integrated with the active right hemisphere, one feels that all the people are inter-connected while feeling to be one with the universe as well as all things under the sun.
- The real world becomes more real. The fast gamma wave in 40 Hz is engaged in combining all the sensory information input transforming it into a perfect experience. The sensory information processed at a very fast speed allows the person to experience the world in high definition (HD).

Changed consciousness: slow brain wave rhythm

- Areas of unconscious and subconsciousness
- Induces the passive, calm, empty or semi-awakened state where alpha wave or theta wave appears.
- The deep-seated brain structures such as the limbic system engages the right hemisphere. The frontal lobe and the entire left hemisphere are not active and rather suppressed.
- One experiences something mysterious as the right hemisphere is activated. An illusion or strange spectacle that the subconsciousness presents is often taken as a signal or mental awakening.
- Staying in such a low-level consciousness allows one to face the subconsciousness and experience the reality as if it were a dream

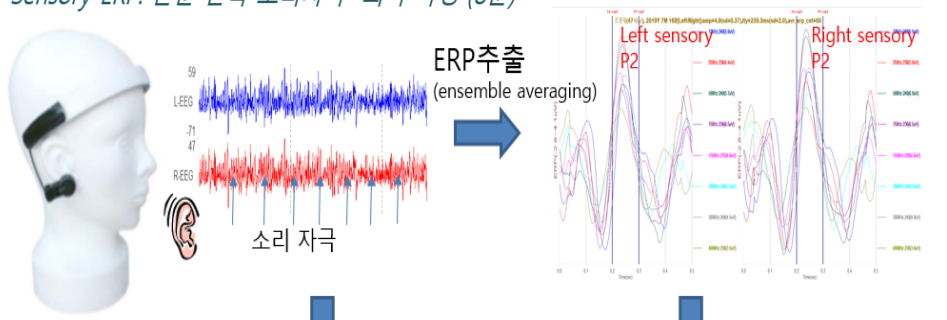




New Brain, New World, Eric Hoffmann, 2012

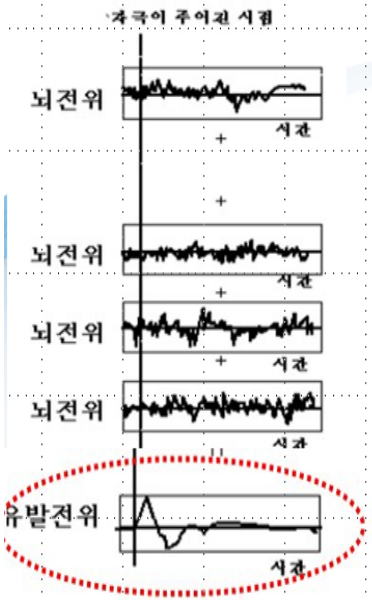
ERP: Sensory function evaluation

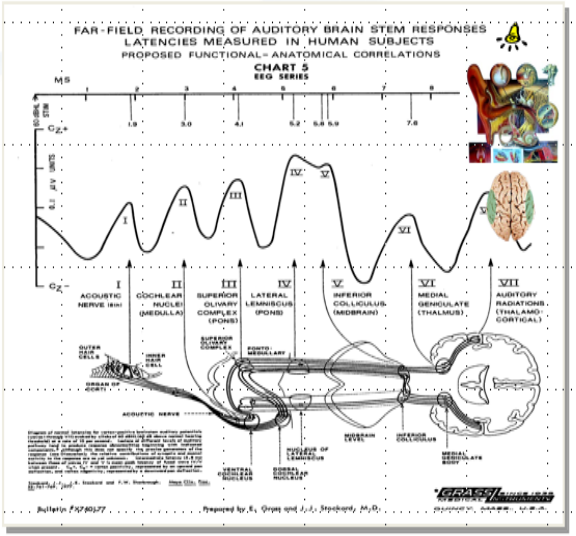
Sensory-ERP: 단순 반복 소리자극 뇌파 측정 (8분)



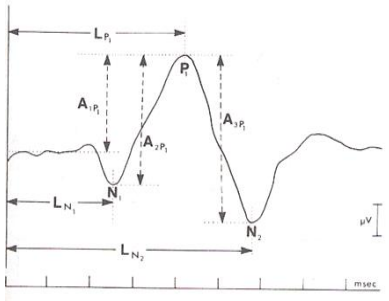
정량적 특징지표 (S1~S95) 추출

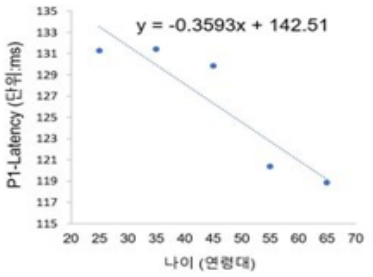
S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
amp(125Hz)	amp(250Hz)	amp(500Hz)	amp(750Hz)	amp(1500Hz	amp(2000Hz	amp(3000Hz	amp(4000Hz	L-amp_Avr	R-amp_Avr	amp_SD	L-Latency_Av	R-Latency_Av	Latency_SD	LR_EOG-MEF
2.23	2.573	4.344	4.319	3.586	3.431	2.408	3.69	3.356	3.289	0.281	269.5	282.5	25.223	0

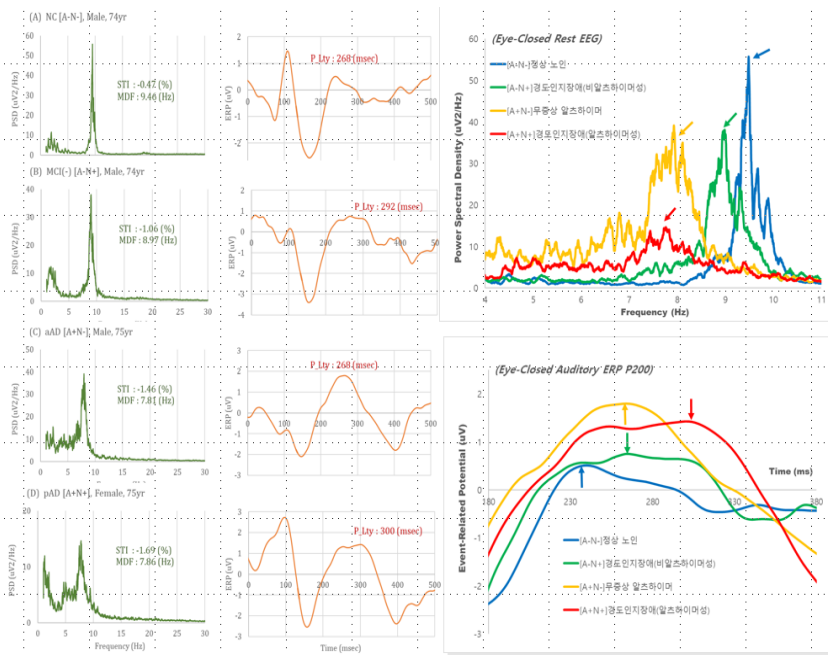




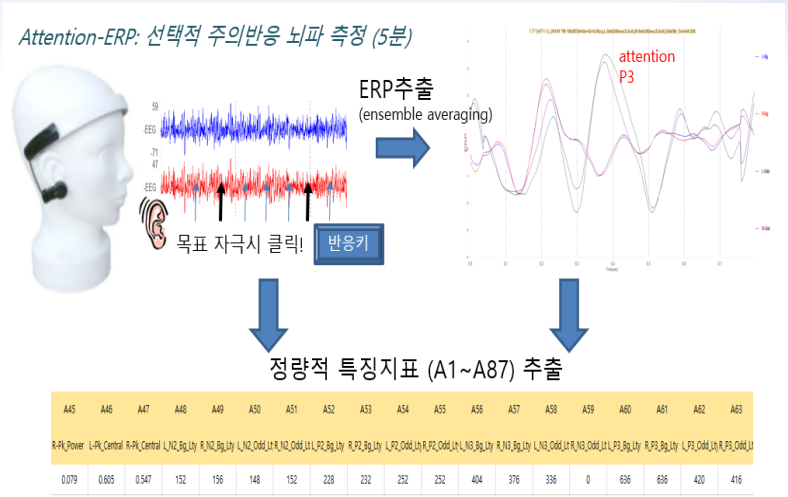
- Sensory-Event Related Potential(ERP) means the brain's electrical responses to various sound stimuli in the audible frequency range.
- Brain's perception function can be evaluated by the amplitude and the latency of Sensory-ERP peak.



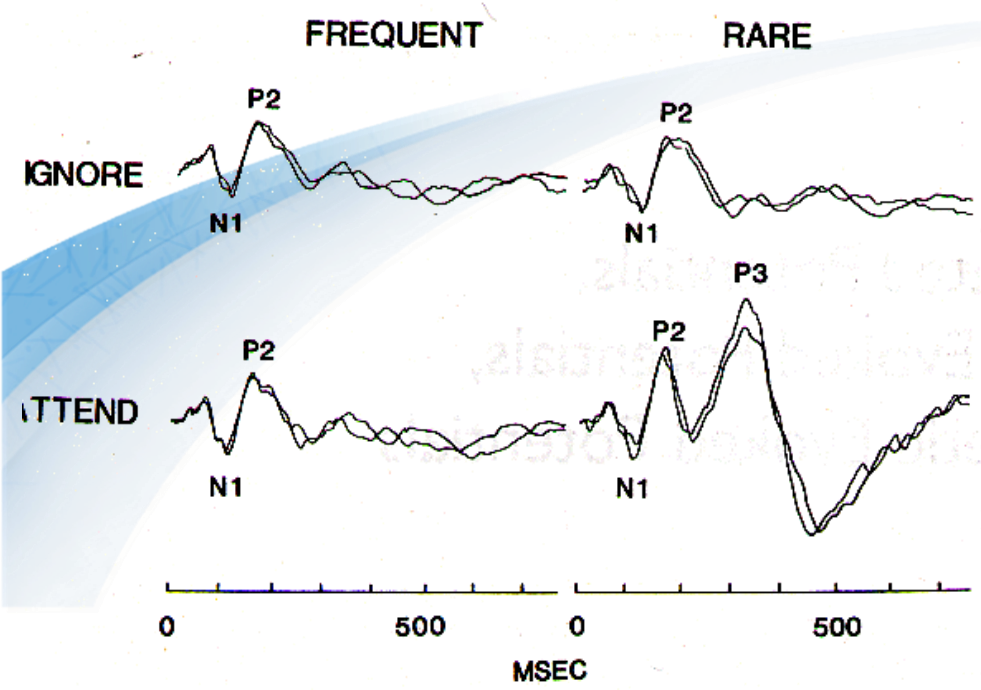




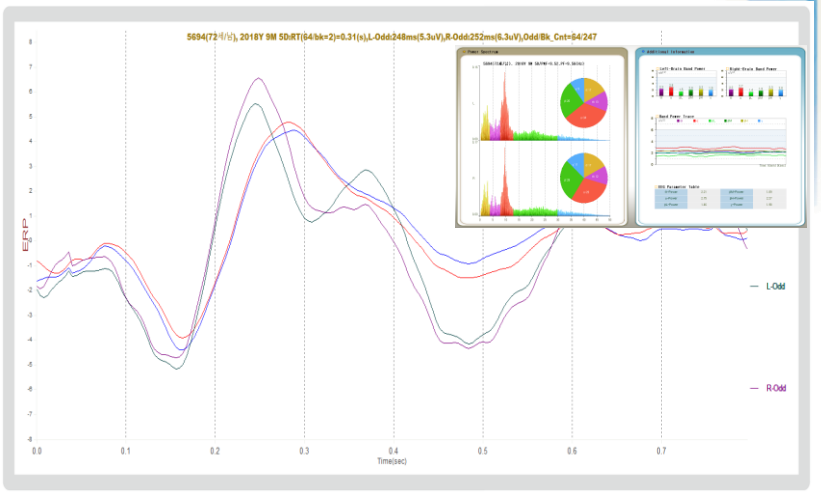
ERP: Attention P300 Evaluation

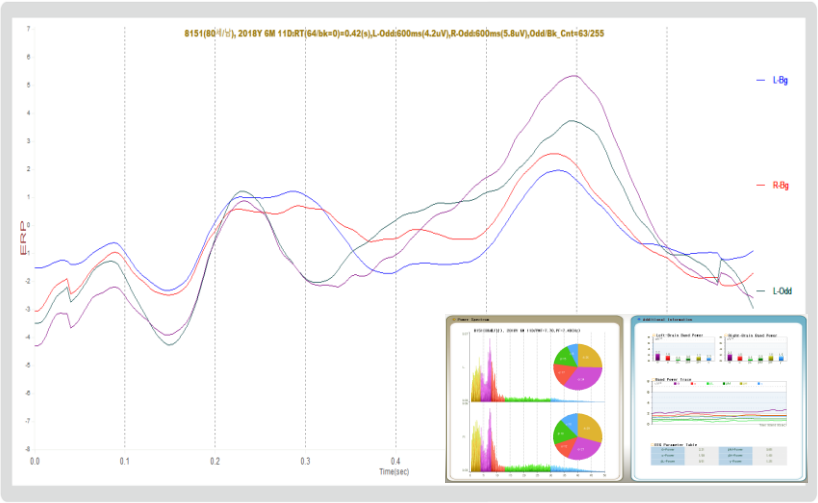


A45	A46	A47	A48	A49	A50	A51	A52	A53	A54	A55	A56	A57	A58	A59	A60	A61	A62	A63
R-Pk_Power	L-Pk_Central	R-Pk_Central	L_N2_Bg_Lty	R_N2_Bg_Lty	L_N2_Odd_Lt	R_N2_Odd_Lt	L_P2_Bg_Lty	R_P2_Bg_Lty	L_P2_Odd_Lh	R_P2_Odd_Lh	L_N3_Bg_Lty	R_N3_Bg_Lty	L_N3_Odd_Lt	R_N3_Odd_Lt	L_P3_Bg_Lty	R_P3_Bg_Lty	L_P3_Odd_Lh	R_P3_Odd_Lt
0.079	0.605	0.547	152	156	148	152	228	232	252	252	404	376	336	0	636	636	420	416

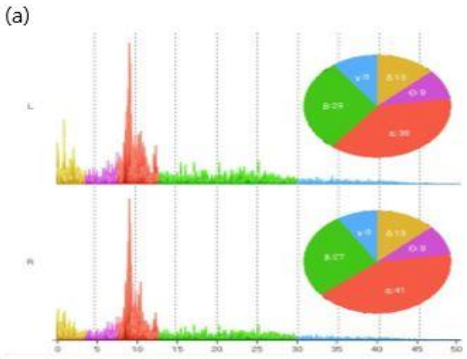


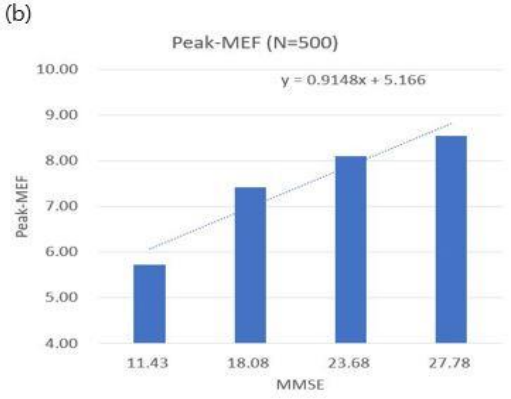
- In oddball task, brain's electrical response of rare stimuli has the positive peak at 300ms, sometimes called by P3.
- The amplitude and the latency of P3 reflect the brain's attention function. Generally, dementia shows the longer latency and the smaller amplitude.

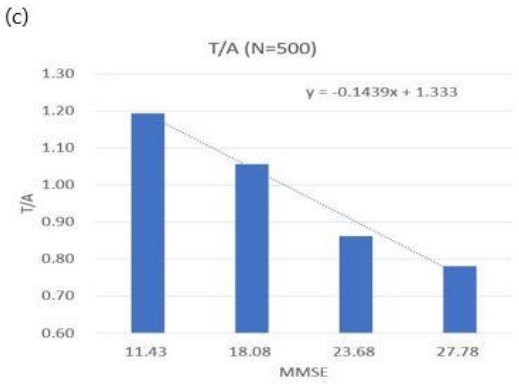




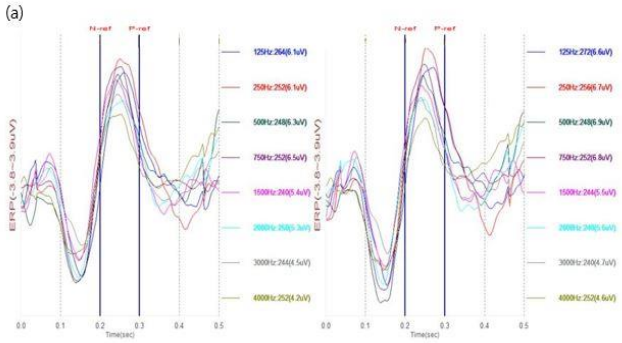
Prefrontal EEG/ERP biomarkers and the MMSE socres

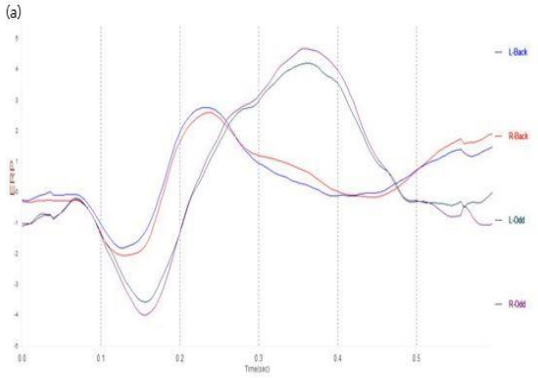


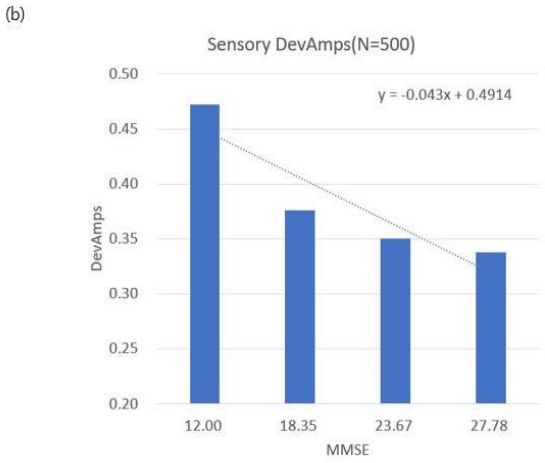


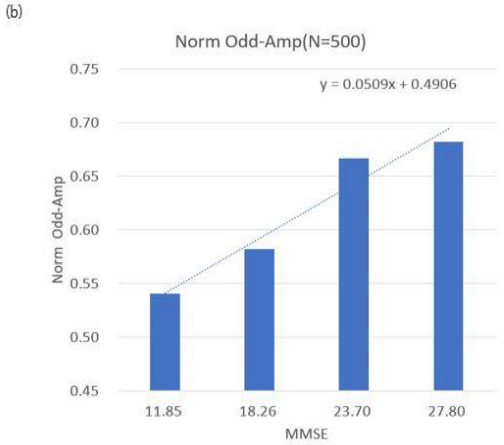


According to the severity of cognitive decline, as estimated by the MMSE, we classified subjects into the four cognitive stages of M4 (prodromal, MMSE 26-30), M3 (mild, MMSE 21-25), M2 (moderate, MMSE 16-20), and M1 (severe, MMSE 0-15).









Some EEG biomarkers decrease monotonically as the cognitive decline.

Focused attention meditation (FAM, 8 weeks)
: longitudinal ERP study

- significantly higher P3 amplitude during the oddball task
- shorter reaction time (RT) for target stimuli

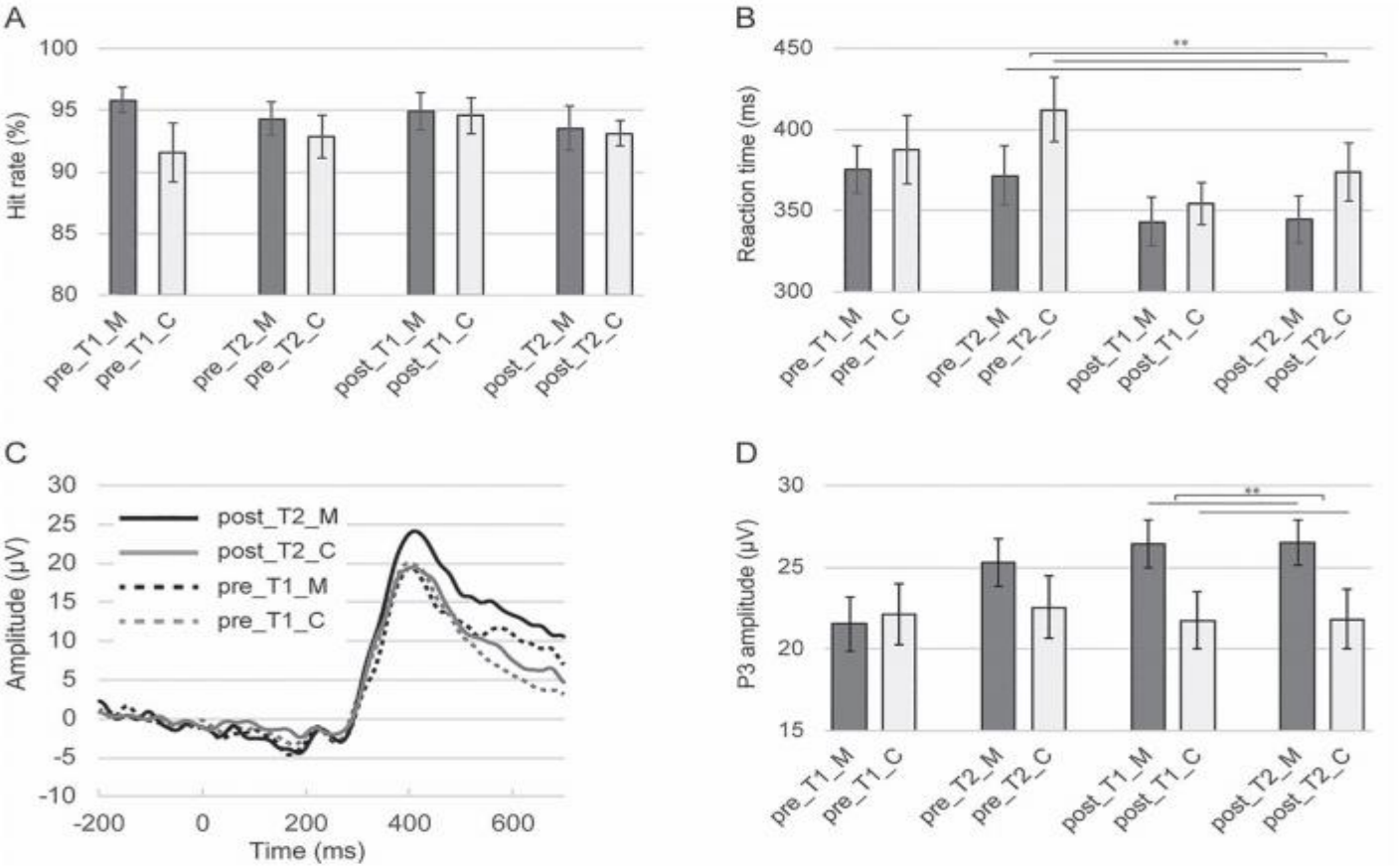


Fig. 1. Behavioral and event-related potential (ERP) results during three-stimulus oddball task. (A) indicates hit rate in each condition. (B) indicates reaction time to target stimuli in each condition. (C) indicates ERP waveform at Pz at the time that participants responded to target stimuli. (D) indicates P3 amplitude at Pz at the time that participants responded to target stimuli. pre_T1_M, pre-training, T1 condition, meditation group; pre_T1_C, pre-training, T1 condition, control group; pre_T2_M, pre-training, T2 condition, meditation group; pre_T2_C, pre-training, T2 condition, control group; post_T1_M, post-training, T1 condition, meditation group; post_T1_C, post-training, T1 condition, control group; post_T2_M, post-training, T2 condition, meditation group and post_T2_C, post-training, T2 condition, control group. *$P < 0.05$; **$P < 0.01$. Error bars indicate standard error.

Social Cognitive and Affective Neuroscience, 2020, 215–223

Enhanced response inhibition : Vipassana meditators

Emotional Go/Nogo task

: Meditation may improve response inhibition and control over emotional reactivity.

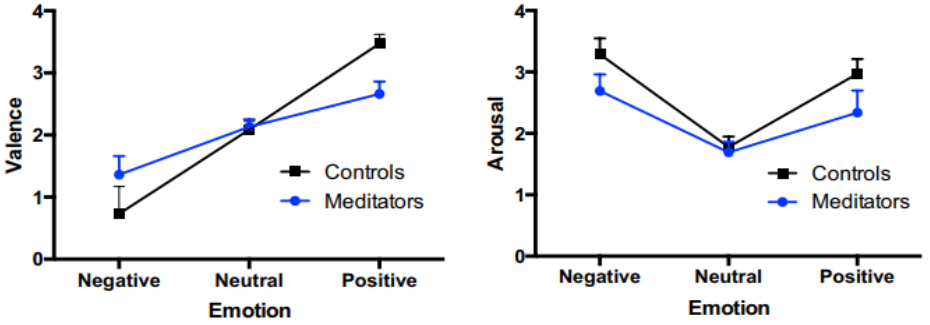


Figure 1. Valence (left) and arousal (right) ratings of the emotional pictures used in the emotional Go/Nogo task. The meditators subjectively evaluated the emotional pictures lower in valence and arousal than the athlete control participants.

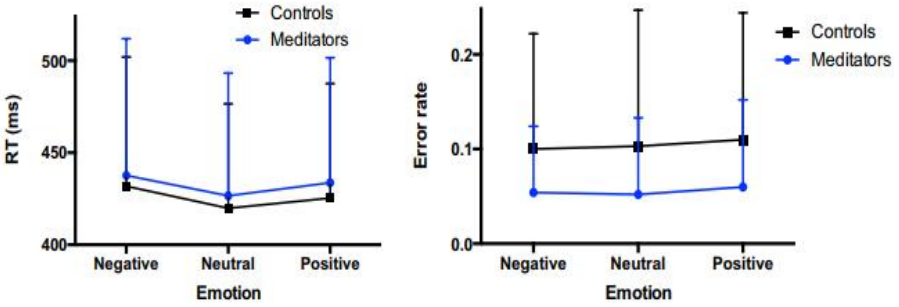


Figure 2. Reaction times for Go trials (left) and total error rates (right) for the emotional Go/Nogo task for each emotional condition. Meditators made significantly fewer errors than controls, while being equally fast on the task.

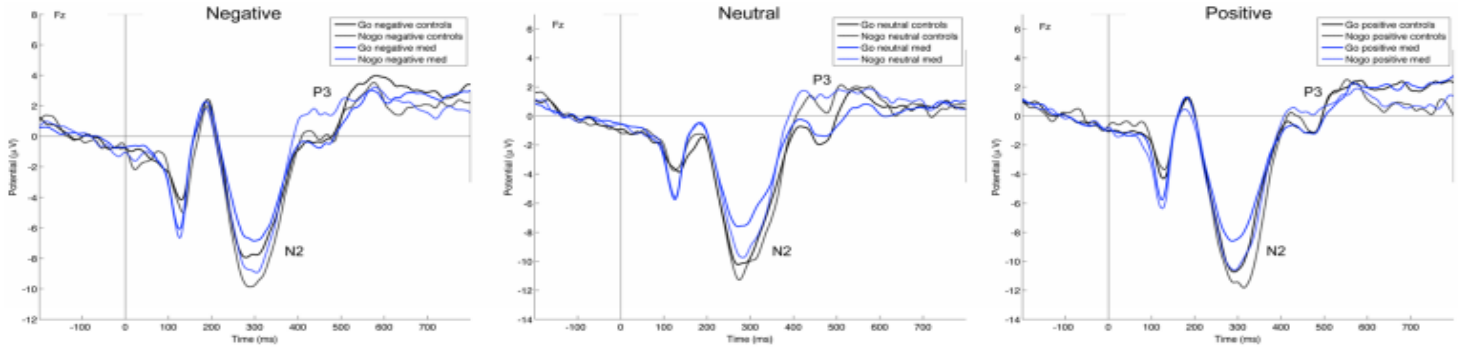


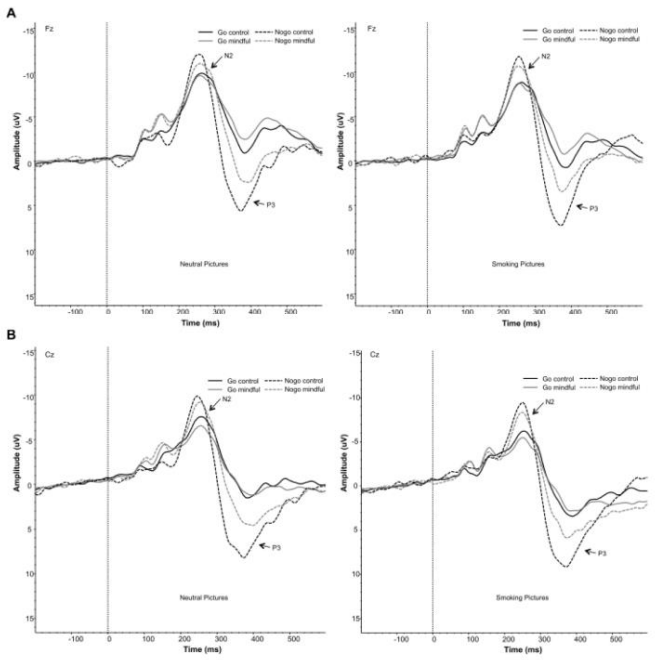
Figure 3. This figure displays grand-average stimulus-locked ERP waveforms at electrode Fz, separately for correct Go and Nogo trials and for negative (left), neutral (central) and positive (right) pictures, for the meditator and control group. Meditation experience was not associated with differences in ERP indices of response inhibition. That is, the difference in N2 and P3 amplitude in NoGo vs. Go trials did not differ between groups.

Scientific Reports, 2019, 9:13215

ERP: Effects of mindfulness
on neural indices of response inhibition.

Go/NoGo task

8-week MBRP program



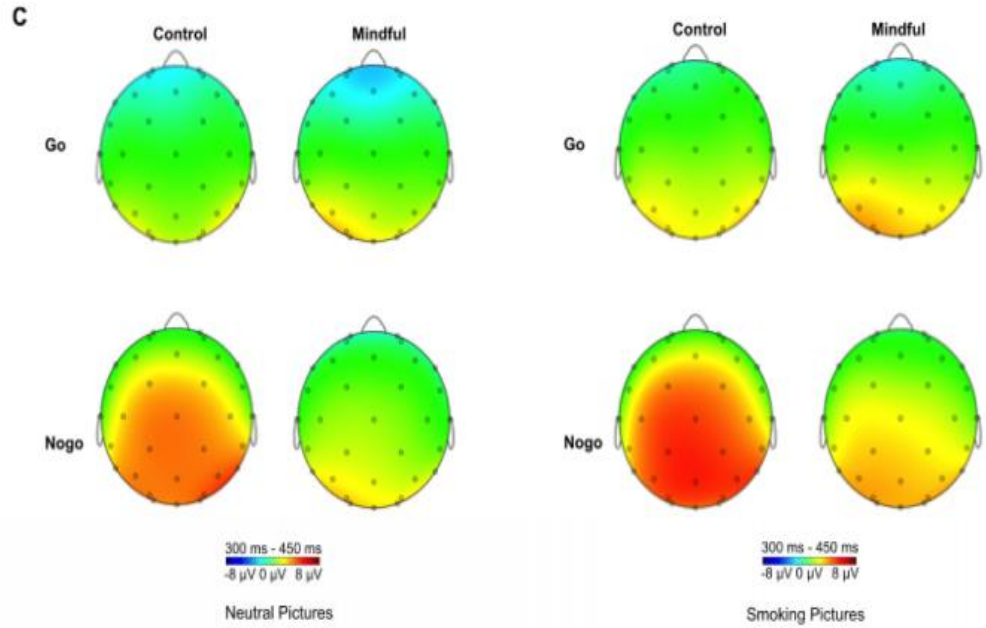


Fig 3. Effects of mindfulness on neural indices of response inhibition. Shown are grand-average stimulus-locked ERP waveforms for neutral (left) and smoking pictures (right) at Fz (Panel A) and Cz (Panel B), separately for correct Go and NoGo trials and the mindfulness and control group. Scalp voltage maps are shown in Panel C for mean amplitude for 300–450 ms. As can be seen, the mindfulness group displayed a reduced NoGo P3 compared to the control group.

PLoS ONE, 2018, 13(1)

No Detectable EEG Activity in Tukdam
(Tibetan Buddhist Meditators]

ERP responses
for MMN
in HB(healthy Baseline)
and PM(postmortem) subjects.

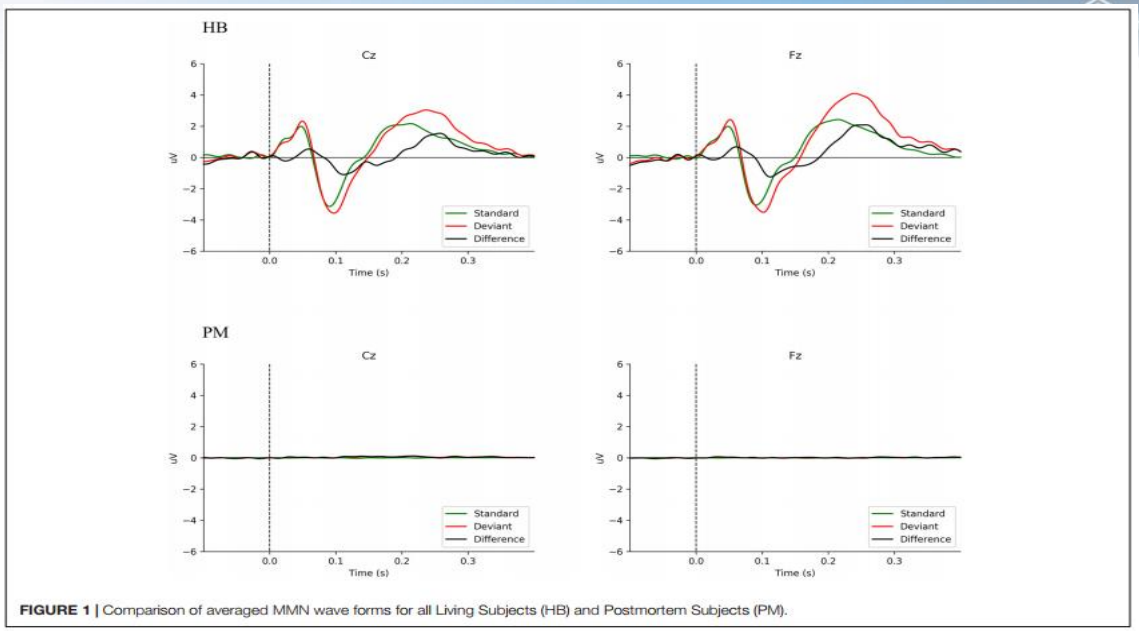


FIGURE 1 | Comparison of averaged MMN wave forms for all Living Subjects (HB) and Postmortem Subjects (PM).

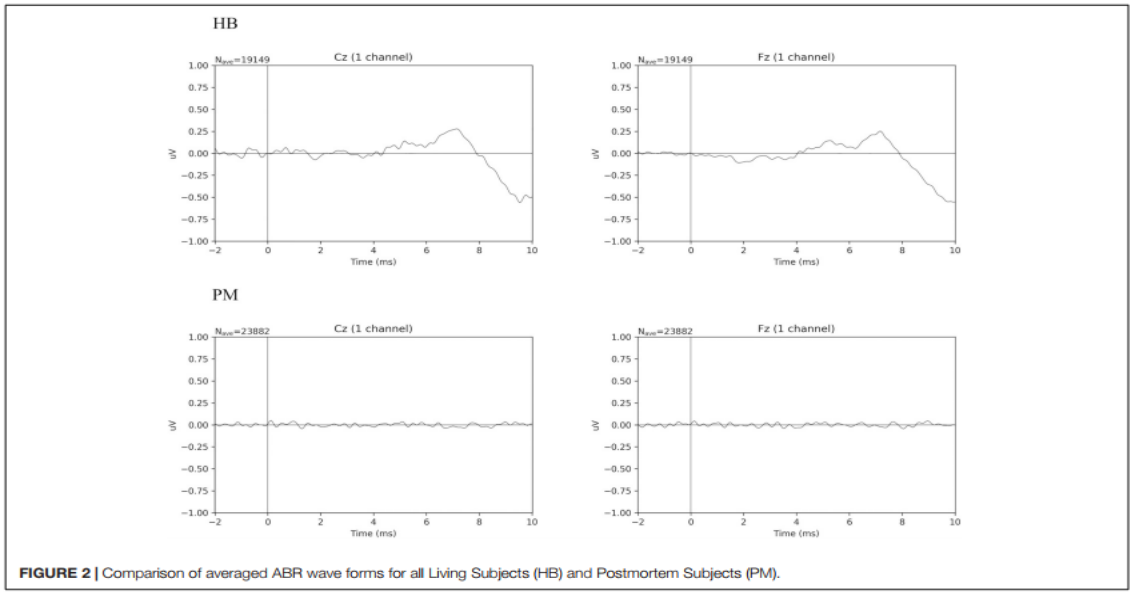
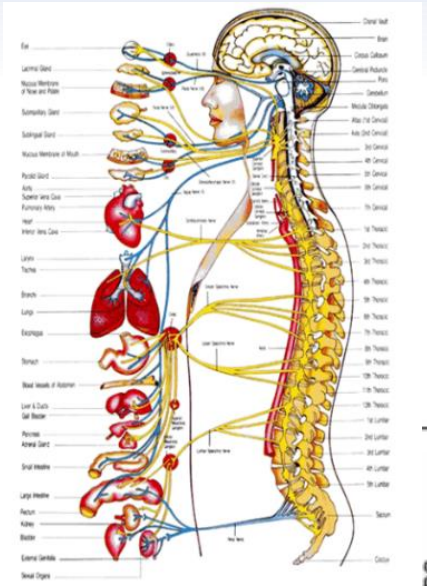


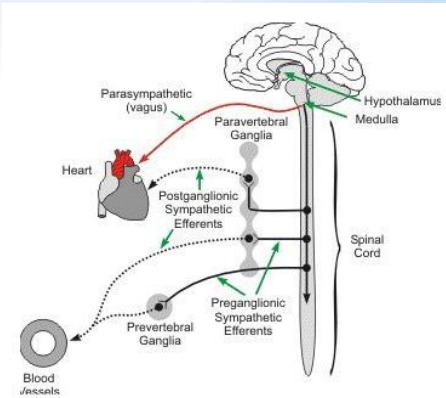
FIGURE 2 | Comparison of averaged ABR wave forms for all Living Subjects (HB) and Postmortem Subjects (PM).

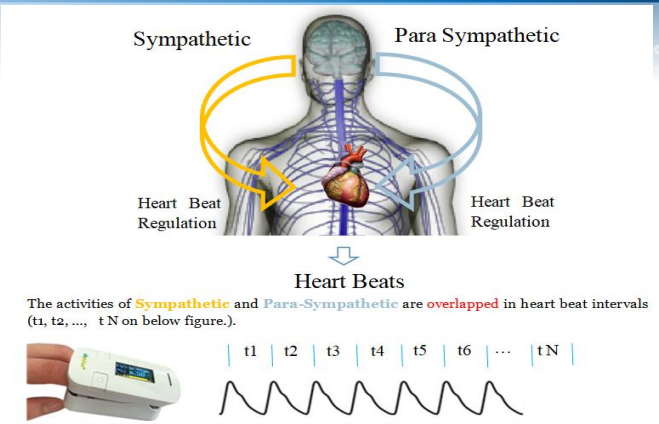
Auditory Brainstem
Response (ABR)

Frontiers in Psychology, 2021, 11:599190

Autonomic Nervous System: Heart Rate Variability







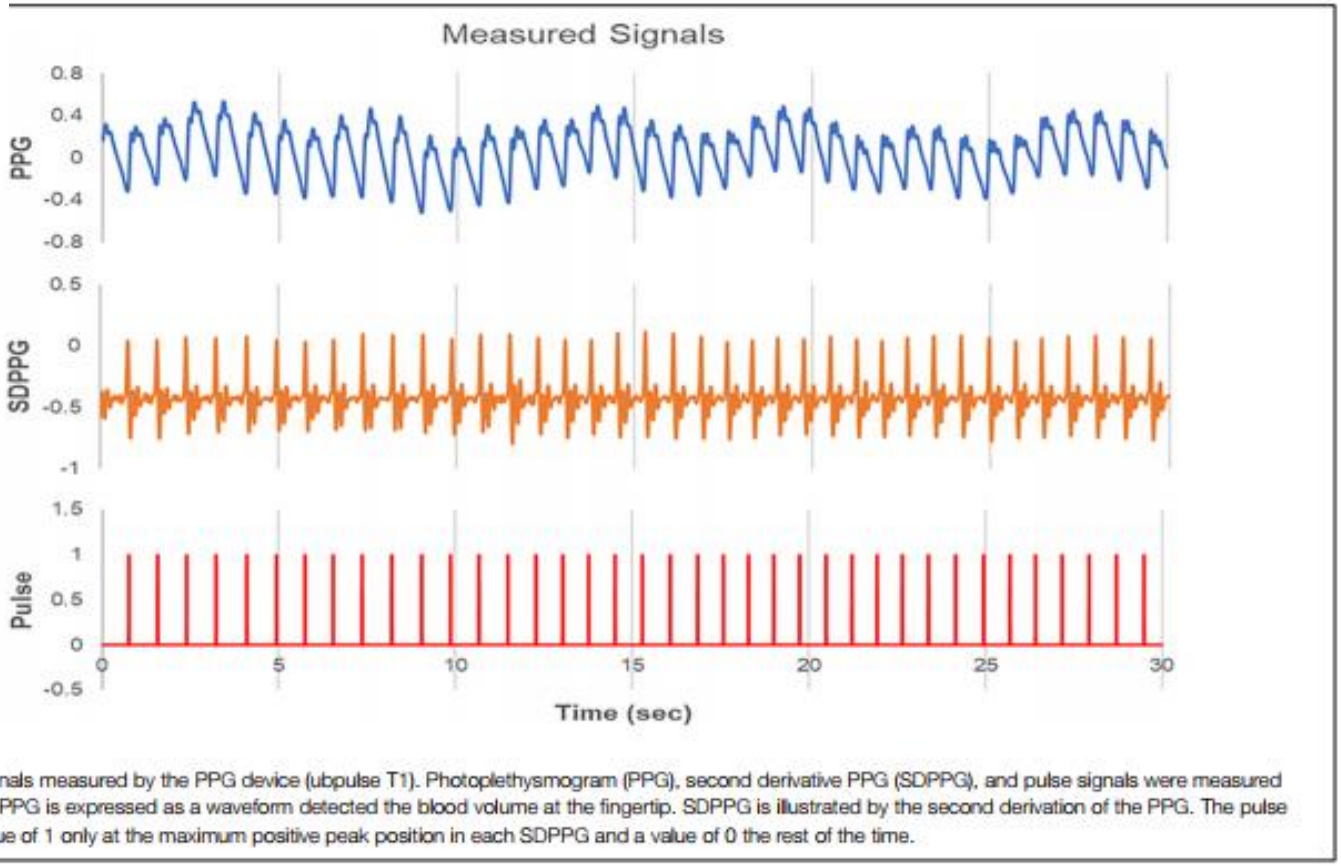
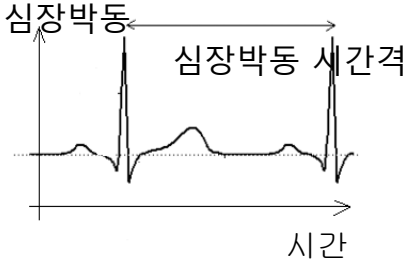
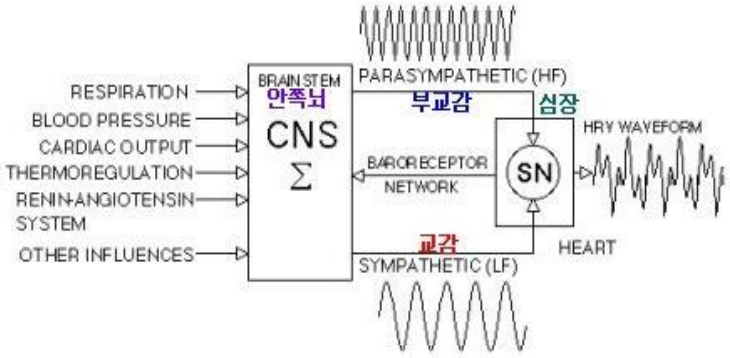
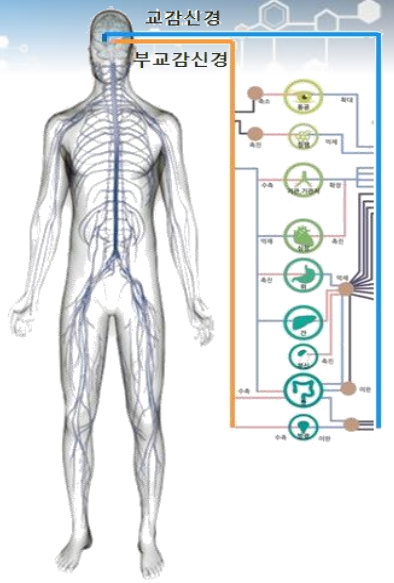


FIGURE 1 | Signals measured by the PPG device (ubpulse T1). Photoplethysmogram (PPG), second derivative PPG (SDPPG), and pulse signals were measured simultaneously. PPG is expressed as a waveform detected the blood volume at the fingertip. SDPPG is illustrated by the second derivation of the PPG. The pulse signal has a value of 1 only at the maximum positive peak position in each SDPPG and a value of 0 the rest of the time.

ANS function: Heart Rate Variability Indices







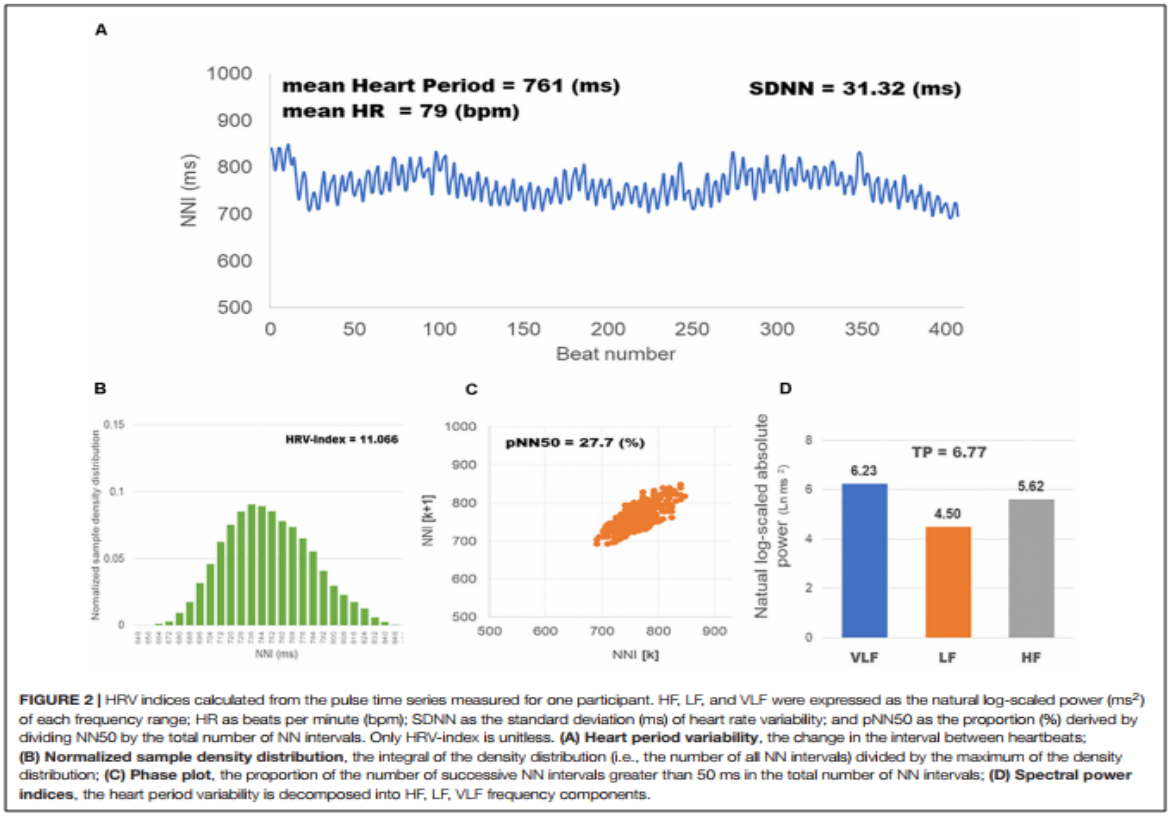
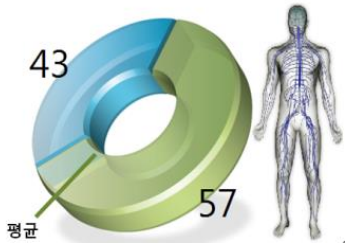


FIGURE 2 | HRV indices calculated from the pulse time series measured for one participant. HF, LF, and VLF were expressed as the natural log-scaled power (ms^2) of each frequency range; HR as beats per minute (bpm); SDNN as the standard deviation (ms) of heart rate variability; and pNN50 as the proportion (%) derived by dividing NN50 by the total number of NN intervals. Only HRV-index is unitless. **(A) Heart period variability**, the change in the interval between heartbeats; **(B) Normalized sample density distribution**, the integral of the density distribution (i.e., the number of all NN intervals) divided by the maximum of the density distribution; **(C) Phase plot**, the proportion of the number of successive NN intervals greater than 50 ms in the total number of NN intervals; **(D) Spectral power indices**, the heart period variability is decomposed into HF, LF, VLF frequency components.

상대 교감활성 $norm\ LF = \left(\frac{LF}{LF+HF}\right)\times 100$

$norm\ HF = \left(\frac{HF}{LF+HF}\right)\times 100$ **상대 부교감활성**

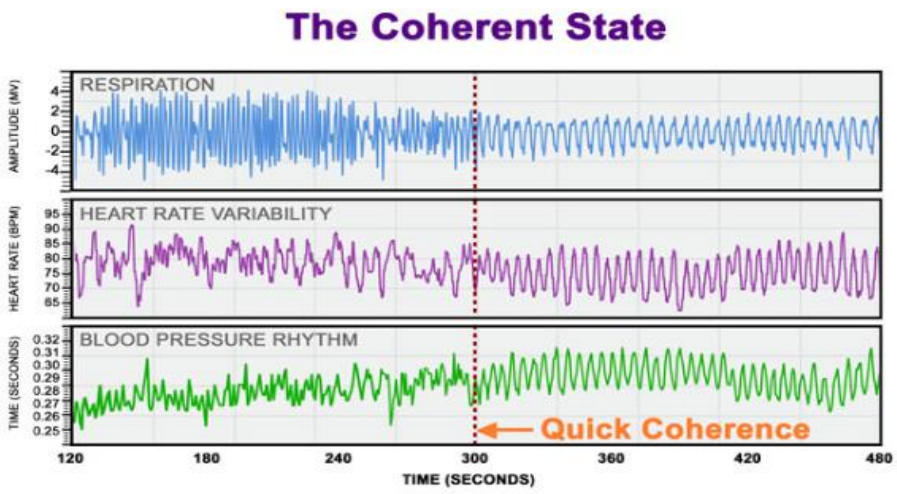


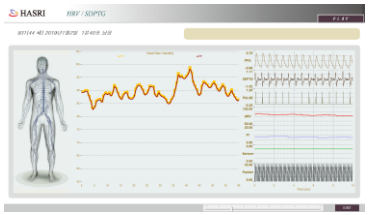
Frontiers in Aging Neuroscience, 2020

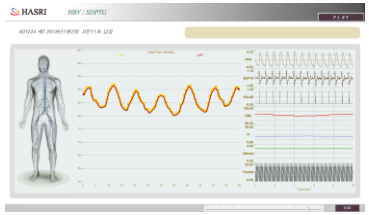
Meditation Induced Coherence: Brain, Heart, Body Coupling

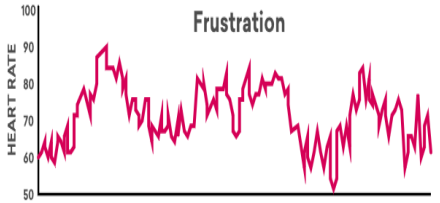
Physiological entrainment during coherence.

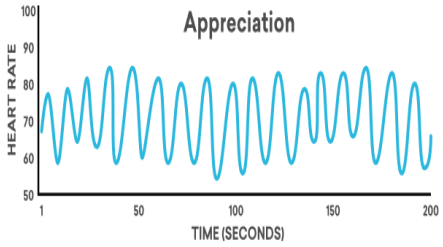
https://www.heartmath.com/science/

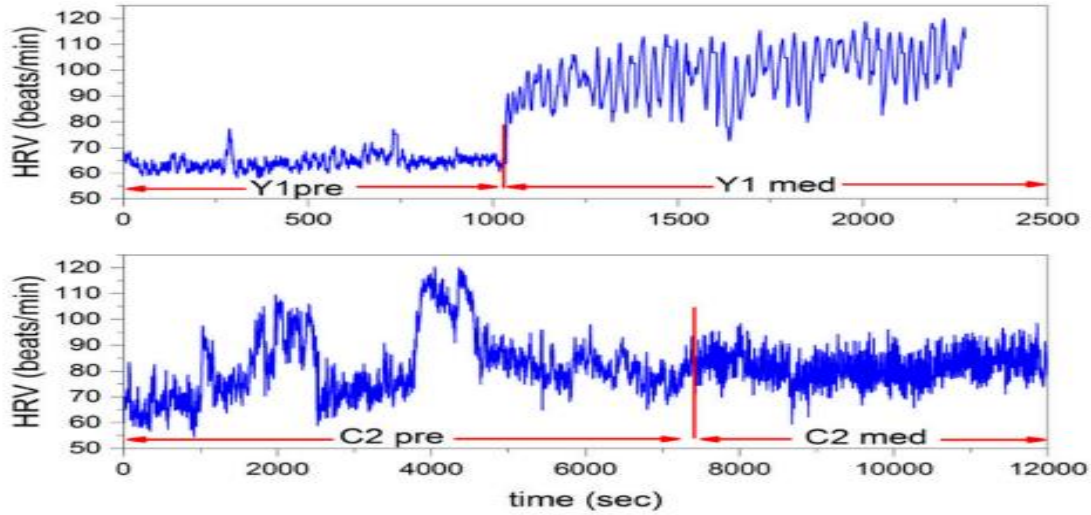












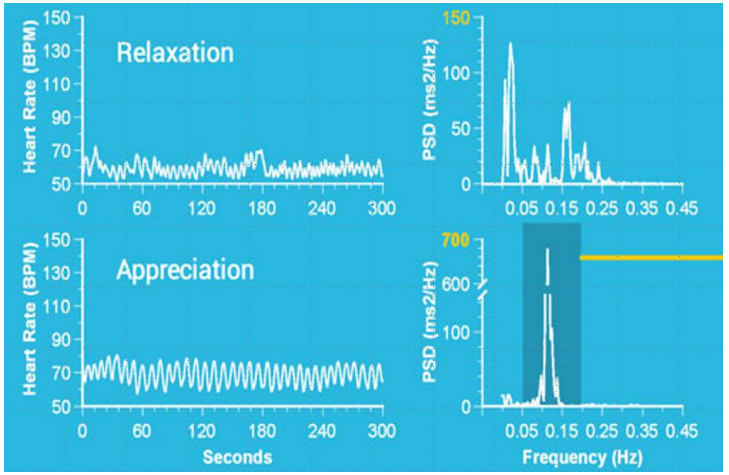
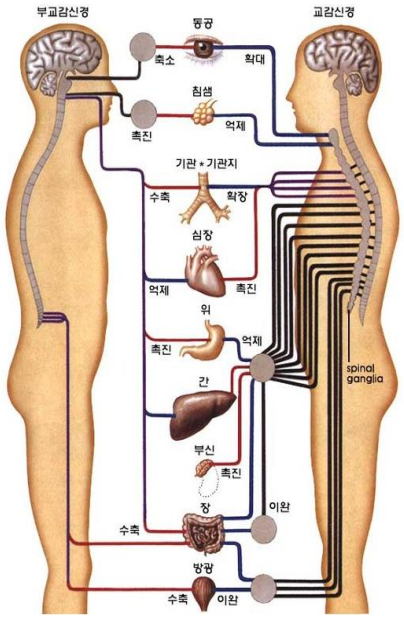
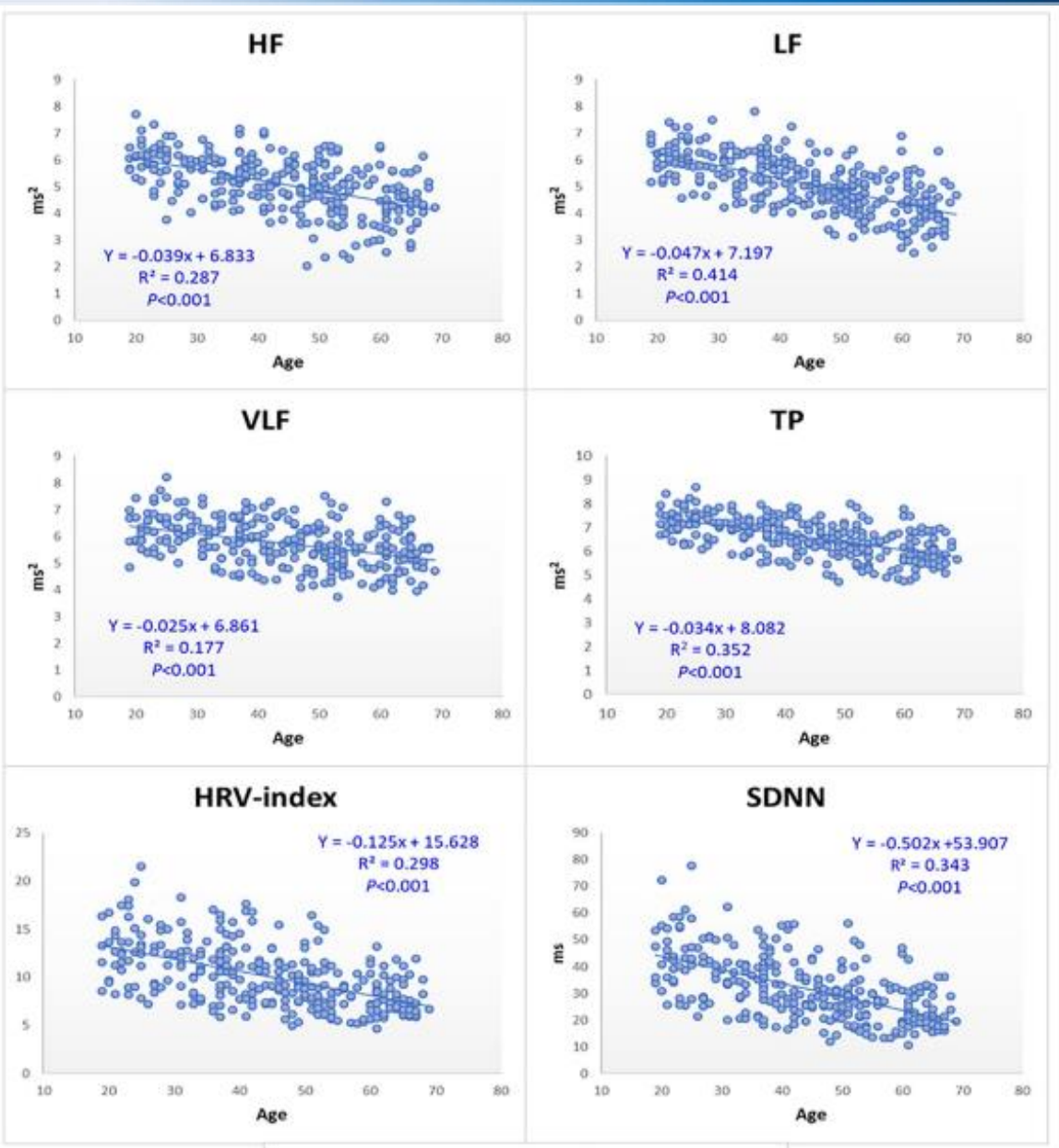


FIGURE 4 | HRV time series of Yoga meditator (Y1), at the top, and the Chi meditator (C2), at the bottom. The vertical red lines denote the time at which the two meditations start.

Frontiers in Physiology, 2018, 9(626)

Declining Trends of Heart Rate Variability According to Aging





Frontiers in Aging Neuroscience, 2020

ANS function: Heart rate variability analysis in workers exposed to methyl bromide

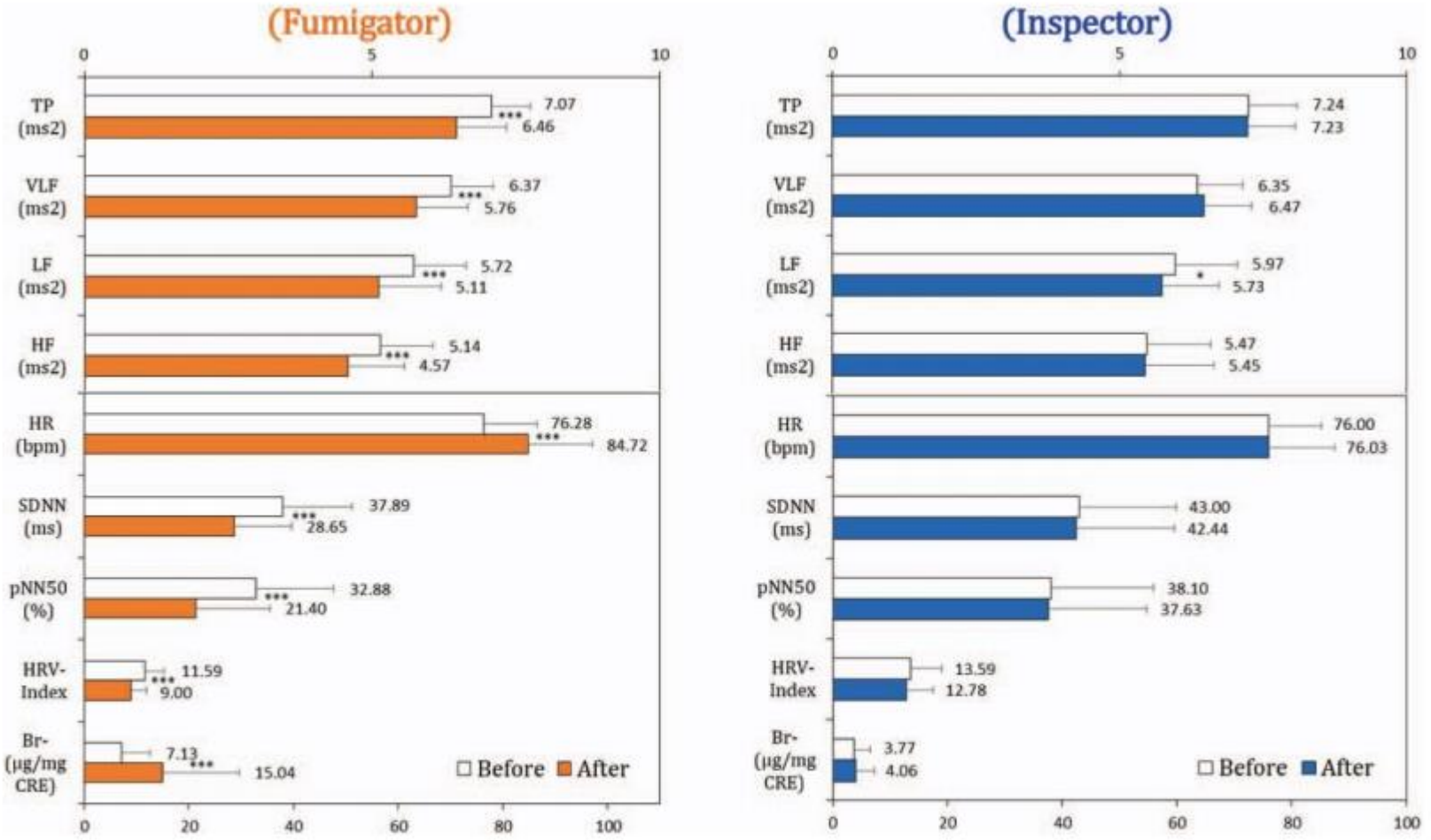


FIGURE 1. HRV indices and Br^- concentrations before and after fumigation work for fumigators and inspectors. A paired *t* test was performed to determine whether the HRV indices and Br^- were different before and after fumigation work within each of the groups. TP, VLF, LF, and HF were expressed as the log-scaled power (ms^2) of each frequency range; HR as beats per minute (bpm); SDNN as standard deviation (ms) of heart rate variability; pNN50 as the proportion (%) derived by dividing NN50 by the total number of NN intervals; HRV-index is unitless; and Br^- as bromide ion concentration in urine (μg/mg CRE). $^{*}P < 0.05$, $^{**}P < 0.01$ and $^{***}P < 0.001$.

Journal of Occupational and Environmental Medicine, 2021

HRV is enhanced during Mindfulness Practice

a fully randomized 10-day longitudinal trial

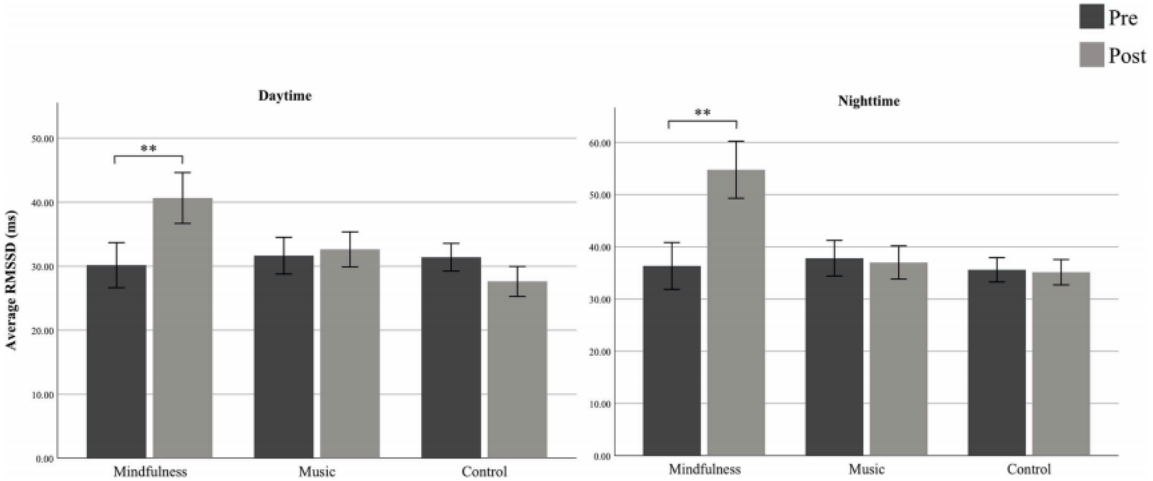


Fig 1. Group means of RMSSD (ms.) during daytime (left panel) and nighttime (right panel) for the chronic phase (i.e. pre and post measurement). The mindfulness-group showed at pre a mean RMSSD during daytime of 30.16ms. (SD = 12.2) and of 36.35ms. (SD = 15.6) during nighttime. At post-measurement the group showed a RMSSD mean of 40.65ms. (SD = 13.8) during daytime and 54.76ms. (SD = 19.0) during nighttime. The music group showed at pre a RMSSD-mean of 31.64ms. (SD = 10.7) during daytime and of 37.82ms. (SD = 12.7) during sleep. At post measurement the group showed a RMSSD-mean of 32.64ms. (SD = 10.2) during daytime and 37.0ms. (SD = 11.8) during nighttime. The control-group had a mean RMSSD at pre-measurement of 31.40ms. (SD = 8.2) during daytime and 35.61ms. (SD = 8.8) during nighttime. The control group showed a mean RMSSD at post measurement of 27.62ms. (SD = 8.8) at daytime and of 35.14ms. (SD = 9.2) during nighttime. Error bars are 95% CI.

Table 2. *Chronic* and *acute* frequency-domain HRV data for the three groups, shown as mean and standard deviation collected pre and post-intervention.

	Mindfulness group	Music group	Control group
Chronic HRV variables:			
Daytime:			
HF *baseline*	3.4 ± 2.5	2.8 ± 2.5	2.7 ± 2.9
HF *post*	4.3 ± 2.8	3.2 ± 2.1	3.5 ± 2.7
LF/HF ratio *baseline*	3.2 ± 2.6	3.3 ± 2.6	2.4 ± 2.7
LF/HF ratio *post*	2.6 ± 2.4	2.6 ± 2.2	2.9 ± 3.2
Nighttime:			
HF *baseline*	4.2 ± 1.8	3.8 ± 2.1	3.9. ± 2.4
HF *post*	4.9 ± 2.1	4.3 ± 2.4	4.5. ± 2.5
LF/HF ratio *baseline*	2.8. ± 1.8	2.7. ± 2.2	2.8. ± 2.3
LF/HF ratio *post*	2.2 ± 1.9	2.5. ± 2.1.	2.6 ± 2.2
Acute HRV variables:			
HF-HRV[a]	4.4 ± 1.9	3.8 ± 2.5	.
LF/HF ratio[b]	1.4 ± 1.3	2.6 ± 3.0	.

- Firstly, for the acute phase we found increased HRV during the daily practice sessions in both the mindfulness and active-control group indicating that both interventions were effective in decreasing acute physiological stress.
- Secondly, for the chronic phase we found increased HRV in both the day- and nighttime indicating increased sleep quality, specifically in the mindfulness group.

PLoS ONE, 2020, 15(12): e0243488

Table 2. Summary of Findings on Studies of Meditations and Cardiovascular Risk Reduction*

Topic	Findings
Neurophysiology and neuroanatomy	• Neurophysiological and neuroanatomical studies suggest that meditation can have long-standing effects on brain physiology and anatomy • Studies generally are nonrandomized and involve modest numbers of participants, sometimes performed under the direction of extremely experienced (>10 000 hours) meditators • Different forms of meditation have different psychological and neurological effects, and thus the neurophysiological and neuroanatomic findings of 1 type of meditation cannot be extrapolated to other forms of meditation
Psychological, psychosocial, and physiological response to stress	• Many, although not all, studies report that meditation is associated with improved psychological and psychosocial indices • Differences in populations, control of potential confounders, and type and length of meditation evaluated may account for discrepant findings. Small sample sizes and lack of randomization are common study limitations • Further study is needed on how meditation influences physiological processes associated with the stress response
Blood pressure	• Magnitude of reductions of systolic blood pressure varies widely • Study limitations including the methods of blood pressure measurements and bias in data ascertainment, high dropout rates, and different populations studied
Smoking and tobacco use	• Some randomized data show that mindful meditation instruction improves smoking cessation rates
Insulin resistance and metabolic syndrome	• Limited data on the effects of meditation on insulin resistance and metabolic syndrome
Subclinical atherosclerosis	• A few suboptimal studies of meditation and lifestyle intervention suggest the potential for benefit on atherosclerosis regression • Studies limited by multimodality approach, attrition, and incomplete follow-up • No firm conclusions can be drawn on the effects of meditation on atherosclerosis
Endothelial function	• Three studies showed no benefit of meditation on brachial reactivity in the overall cohorts, although 1 study suggested a benefit in a subgroup of patients with coronary artery disease • No conclusions can be drawn on the effects of meditation on endothelial function
Inducible myocardial ischemia	• Limited older studies suggest that meditation can lead to improvement in exercise duration and decreased myocardial ischemia • No contemporary studies have evaluated effects of meditation on myocardial blood flow or ischemia with advanced imaging techniques
Primary prevention of CVD	• Two studies of short-term intervention report surprising mortality reductions, and thus these findings need to be reproduced in larger, multicenter studies • Overall, because of the limited evidence to date, no conclusions can be drawn as to the effectiveness of meditation for the primary prevention of CVD

Effects of Deep breathing on Central & Autonomic Nervous System

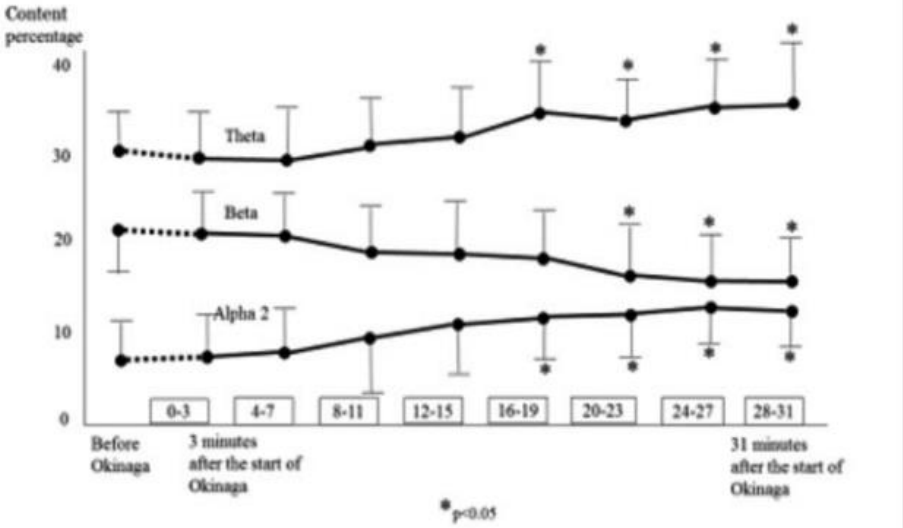


Figure 1. Changes in content percentages of theta, alpha 2, and beta waves over the time course of Okinaga.

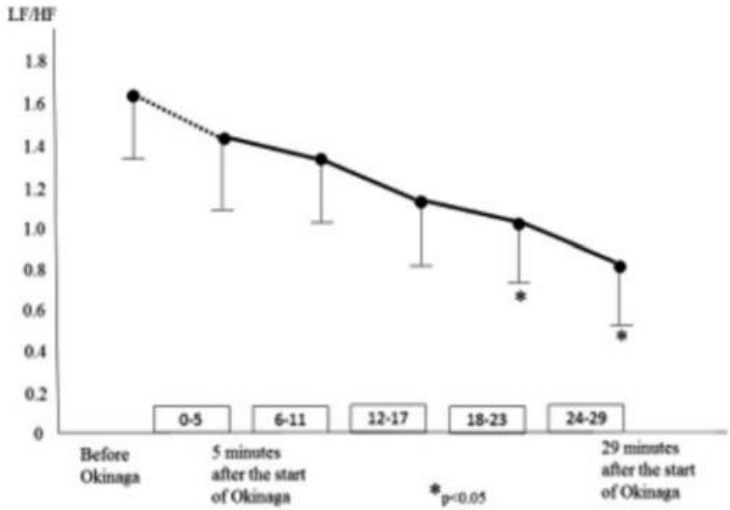


Figure 2. Changes in the LF/HF ratio over the time-course of Okinaga.

- Theta and alpha waves increased and beta waves decreased.
- Parasympathetic dominance was observed.
- The deep breathing is relaxing and relieves anxiety.

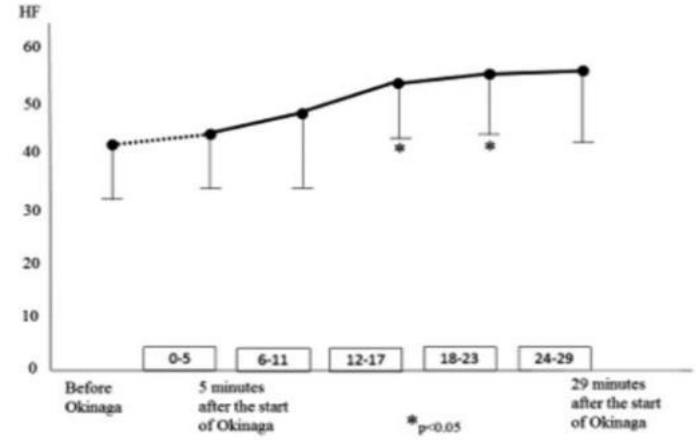


Figure 3. Changes in HF value over the time course of Okinaga.

Mental illness 2018 (vol.10:7881)

Mindfulness Practice
: increase the coordination between mind and heart activities.

8 weeks in total (8 weeks standard MBSR)
• Home assignment of formal mindfulness practice such as body scanning and mindfulness of breath o 45 min, daily o Body scanning: a practice of focusing and relaxing every part of the body o Mindfulness of breath: a practice of focusing attention on the breath
• Home assignment of informal mindfulness practice o 15 min, daily o Deliberate awareness about daily tasks. For example, paying attention while brushing teeth
• Educational class on mindfulness o 3 h, weekly o Teaching on mindfulness practice o Discussions on issues and reflections about home assignments. For example, discuss the experience of mindfulness practice such as wandering thoughts during practice
• A full day retreat of silence and mindfulness practice o 6th week of training o This also includes assessment and evaluation

Table 1. MBSR Course Overview. The 8-week MBSR training course taken by the participants.

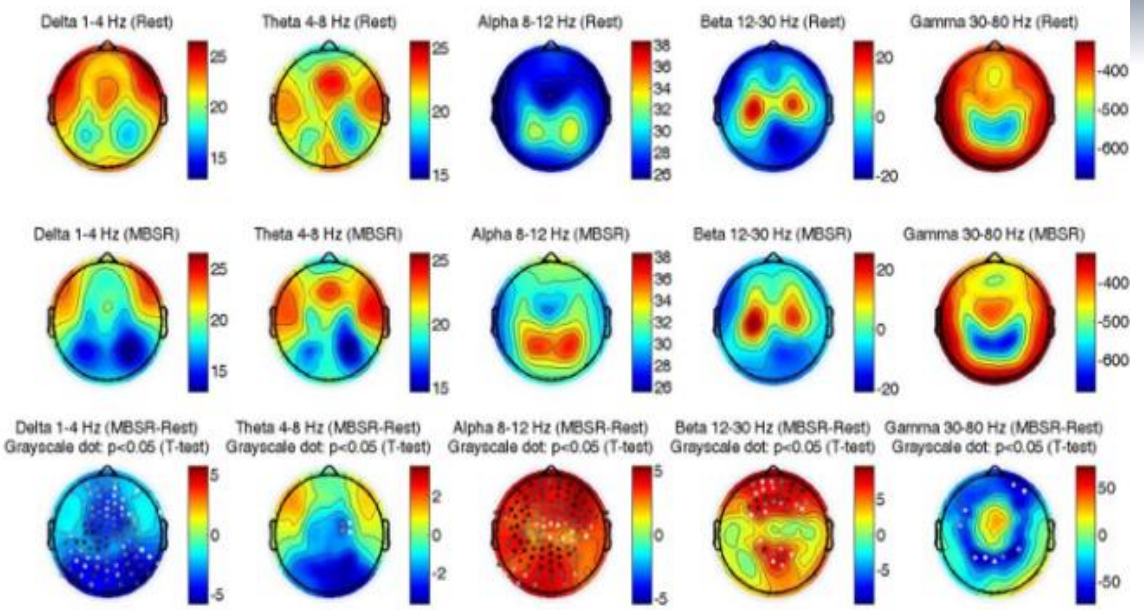


Figure 1. Spectrum Analysis of MBSR Mindful Breathing and Normal Rest Conditions.

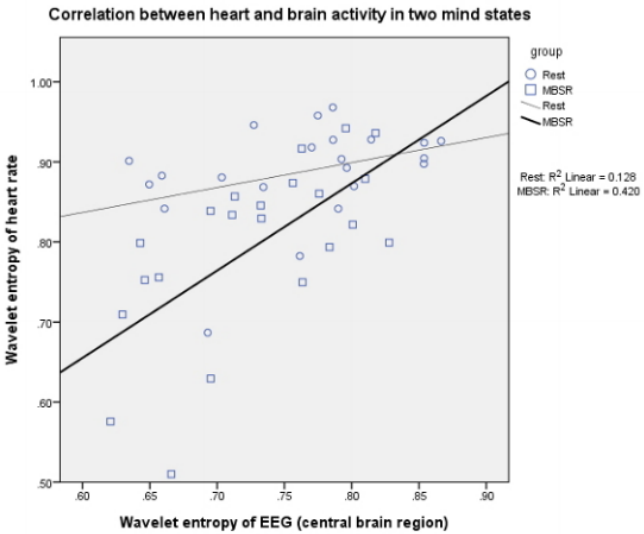


Figure 5. Correlation between the Wavelet Entropies of Electronic Activities of the Heart and Brain.

- The wavelet entropy of the brain EEG decreased during the MBSR mindful breathing state as compared to that during the closed-eye resting state.
- Similarly, a lower wavelet entropy of heartrate was found during MBSR mindful breathing.

Journal of Visualized Experiments, 2017, e55455

Arousal vs. Relaxation response

Theravada tradition : Relaxation

- Focused attention (Samatha)
- Distributed attention [Vipassana]

1. parasympathetic activation
2. Calm and relax the mind

Vajrayana tradition : Arousal

- Focused attention (Deity)
- Distributed attention [Rig-pa]

1. sympathetic activation
2. an awake quality of the mind
3. an immediate dramatic increase in cognitive performance

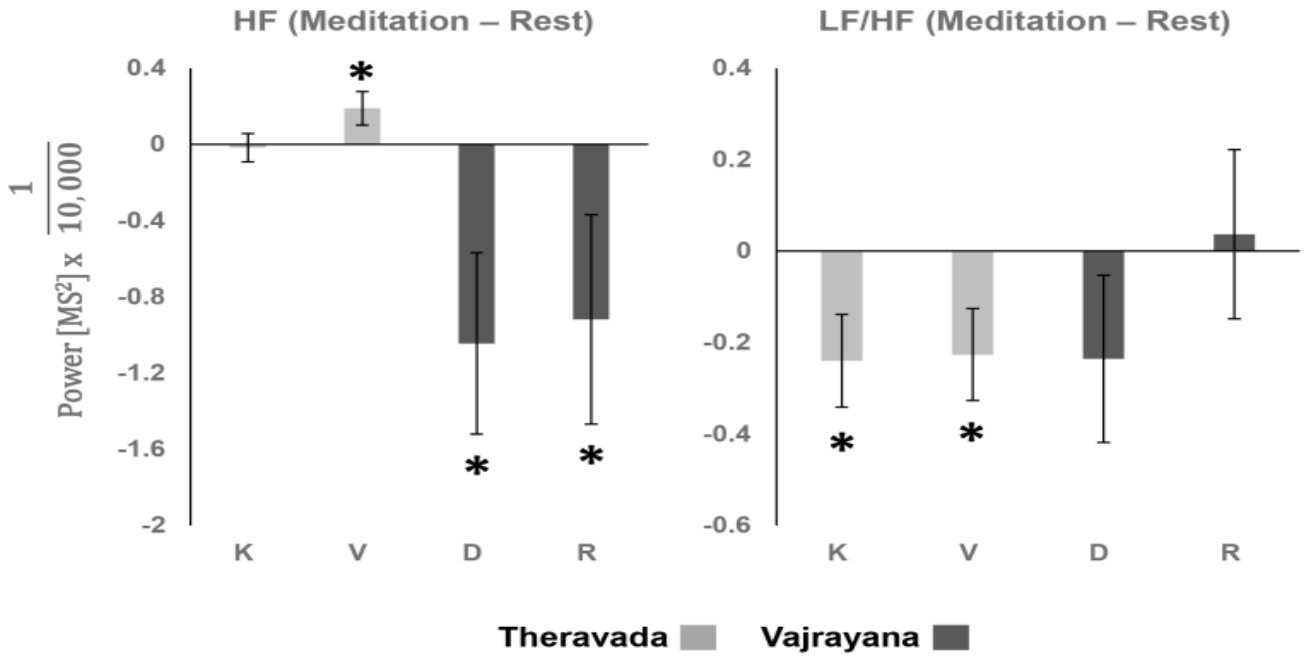
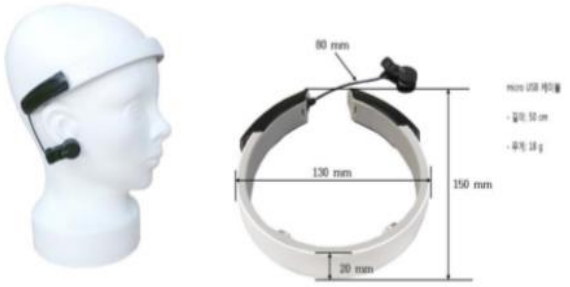
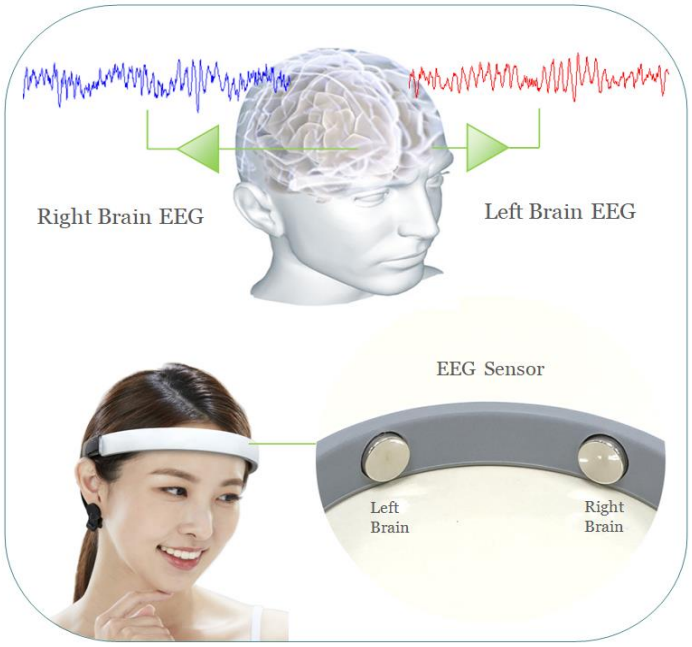


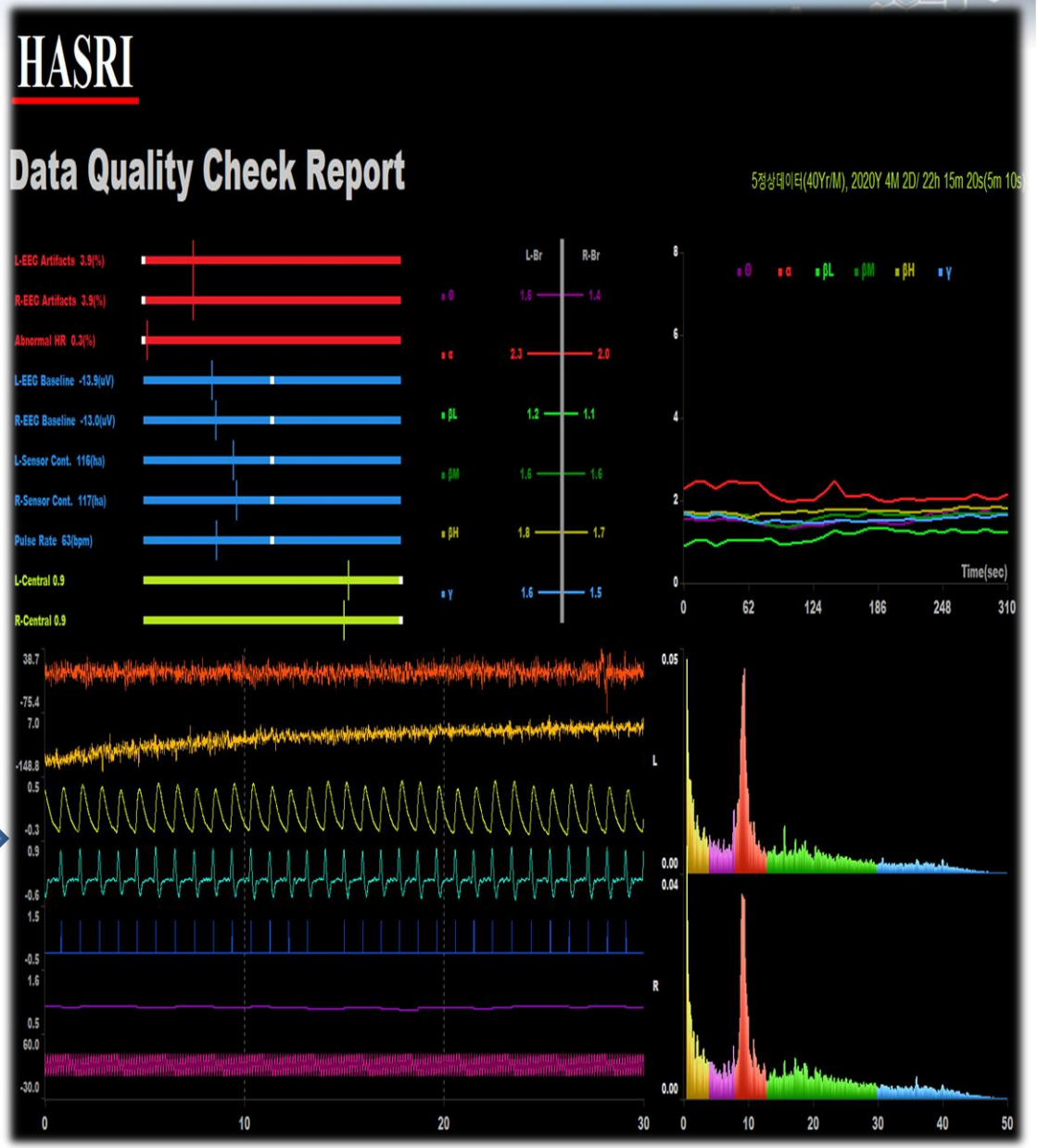
Figure 4. EKG differences between Meditation and Rest (K – Kasina, V – Vipassana, D – Deity, and R – Rig-pa).
doi:10.1371/journal.pone.0102990.g004

PLoS ONE. 2014, 9(7)

Wearable EEG, PPG devices of headset or hair-band type







Brain-care welfare project by the prefrontal EEG biomarkers in some ultra-aging communities (since 2017, south korea)

In aging society, the increasing prevalence of dementia has become a major issue in public welfare. So, there are many challenges in the field of prediction, prevention and early care of dementia.

Screened risk-group

- Proper hospitals
- Various preventive programs

community health centers

As well, they are continuously managed by tracking whether their brain functions are effectively improved.

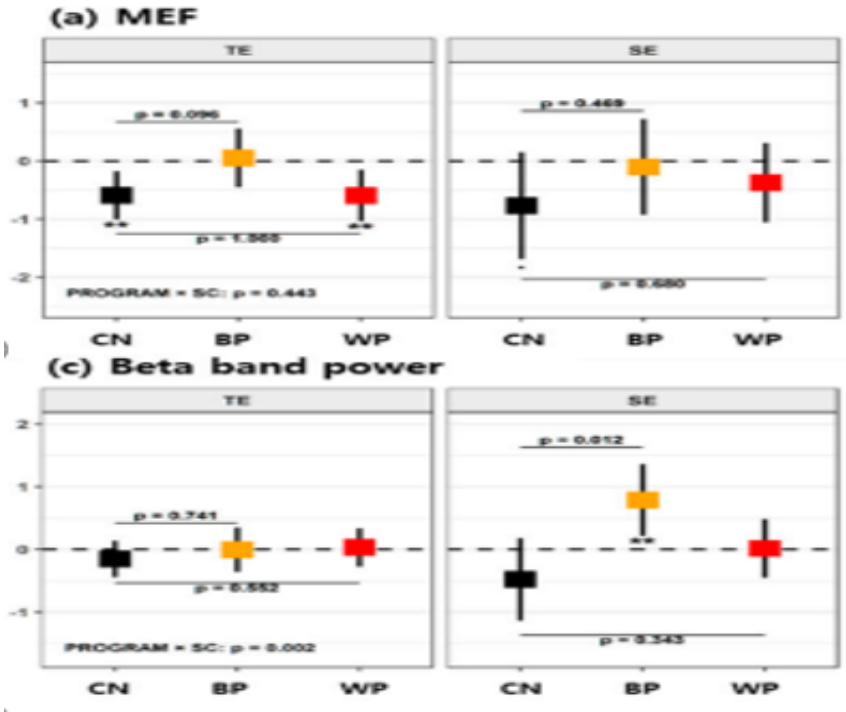
Neurophysiological benefits of two forest therapy programs to prevent the dementia

The prefrontal EEG markers can be quickly applied to investigate positive or negative effects on the central nervous system.

Breathing Program (BP), Walking Program (WP)

11 sessions over 11 weeks.

EEG	Control			Breathing Program			Walking Program		
Variable	$\bar{X}_B$	$\bar{\delta}$ (95% CI)	γ	$\bar{X}_B$	$\bar{\delta}$ (95% CI)	γ	$\bar{X}_B$	$\bar{\delta}$ (95% CI)	γ
MEF [Hz]	8.47	**−0.45 ** (−0.78, −0.11)**	**0.57**	8.40	−0.02 (−0.38, 0.34)	0.02	8.40	**−0.40 * (−0.77, −0.03)**	**0.40**
$P\alpha$ [μV^2]	2.71	−0.10 (−0.33, 0.13)	0.18	3.00	−0.17 (−0.42, 0.08)	0.28	2.65	−0.15 (−0.42, 0.11)	0.22
$P\beta$ [μV^2]	1.86	−0.10 (−0.37, 0.16)	0.17	2.31	−0.16 (−0.44, 0.12)	0.24	2.09	0.13 (−0.16, 0.42)	0.17
ATR	1.2	−0.06 (−0.13, 0.02)	0.33	1.18	0.00 (−0.08, 0.08)	0.02	1.22	**−0.15 *** (−0.23, −0.07)**	**0.68**



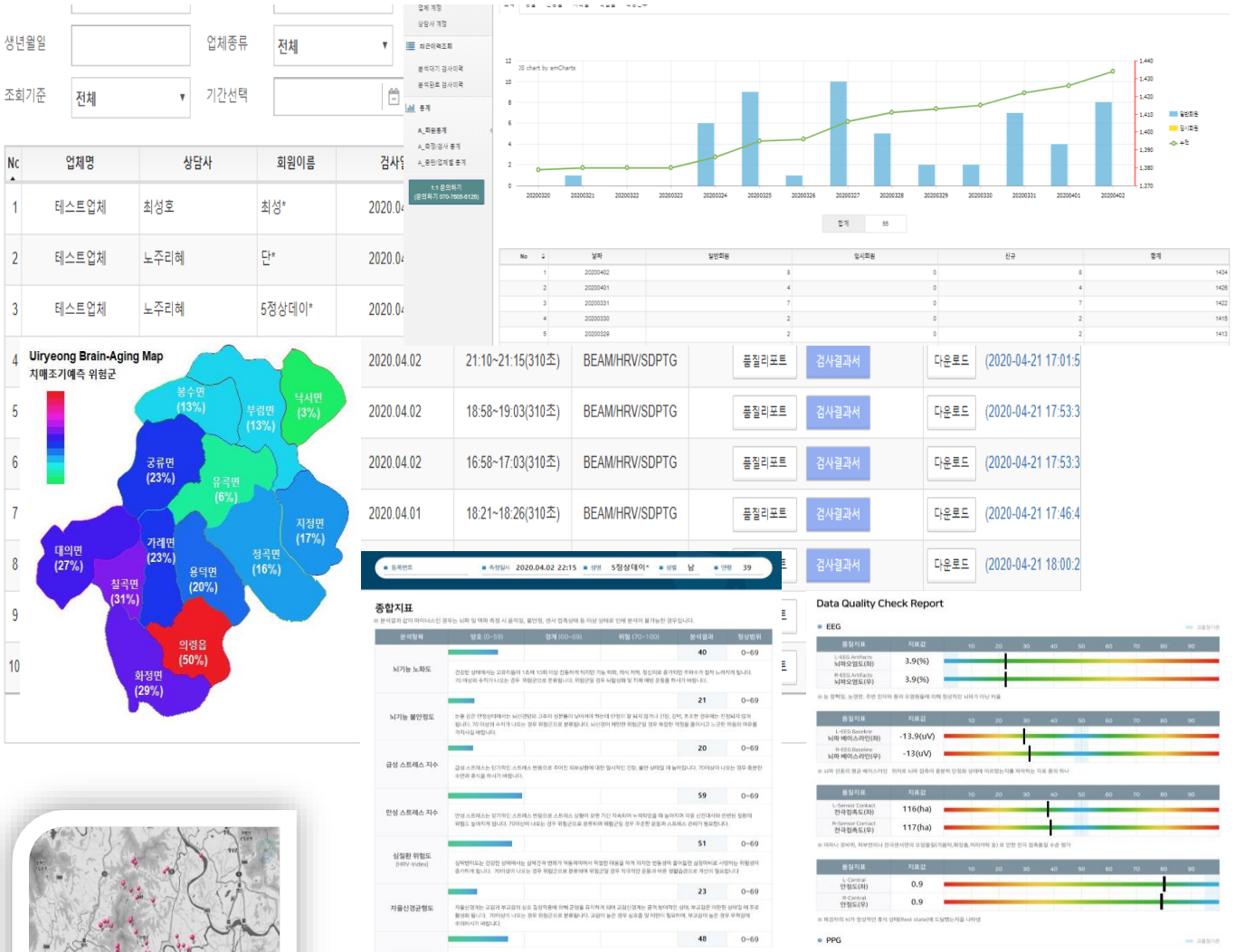
Compared with the control, both programs resulted in **benefits for neural activity**.

Specially, the breathing group showed more increased intrinsic median frequency than the walking group.

Int. J. Environ. Res. Public Health. 2019

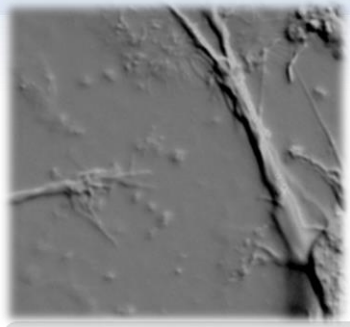
Cloud based sever platform for the data-based precision preventive medicine

If the measured EEG data is transmitted to the cloud-based server platform, the individuals can review or track their results anytime, anywhere.



Furthermore the valuable statistical information can be provided in terms of the data-based precision preventive medicine.

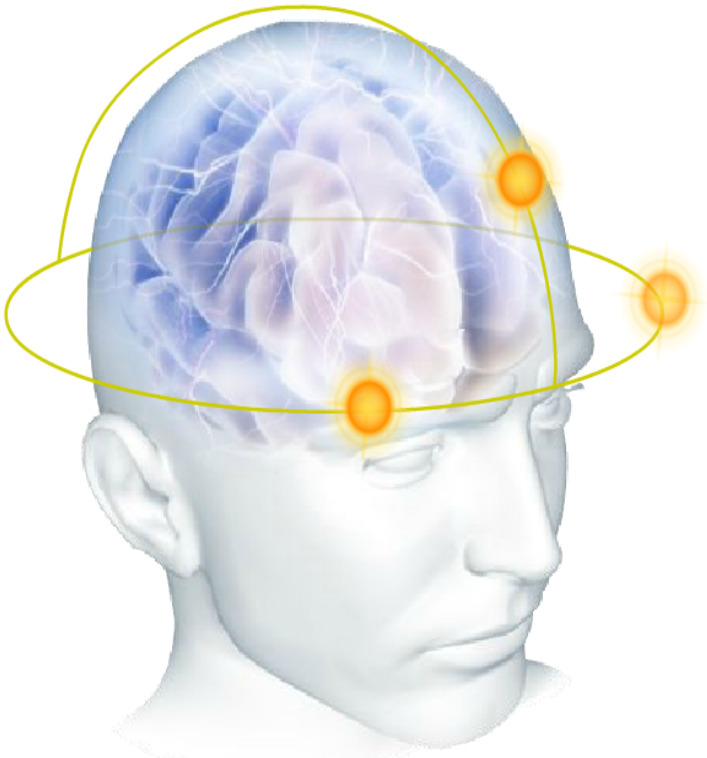
Digital drug therapy for improving the brain function

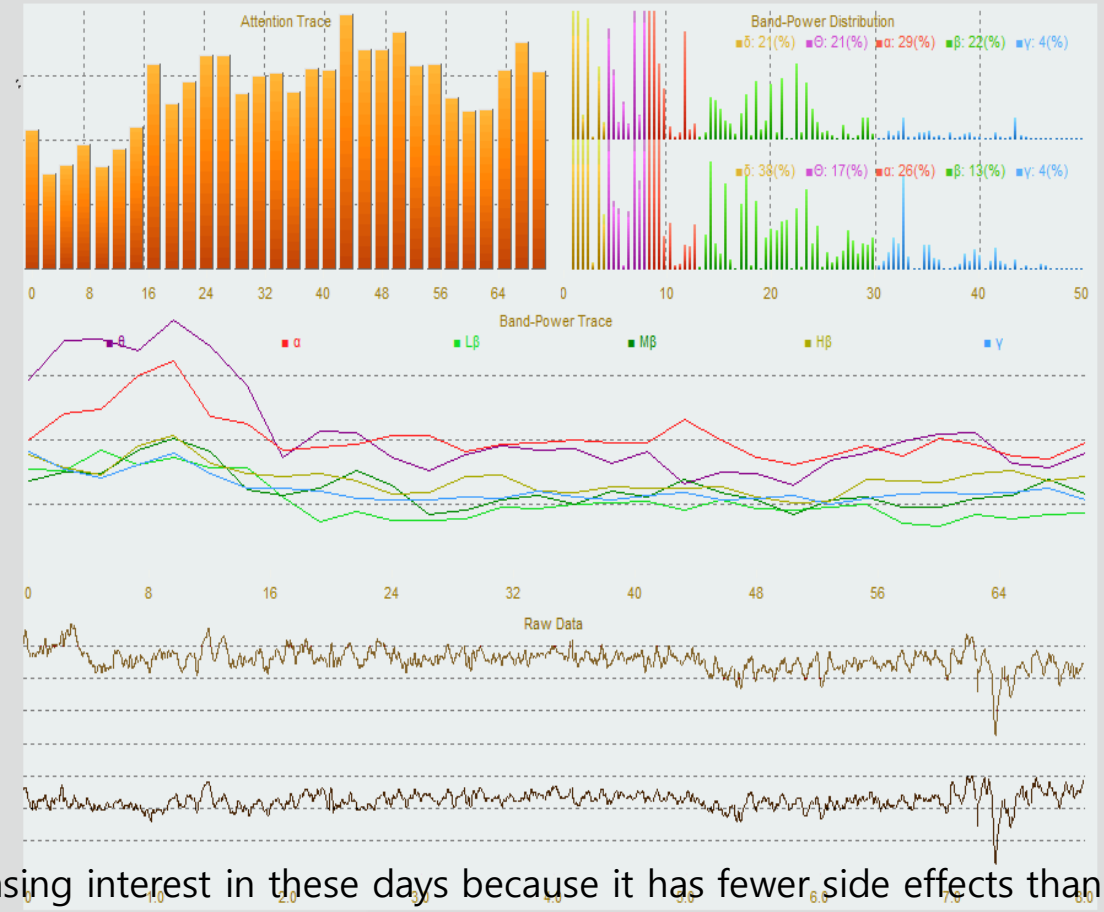


The prefrontal EEG markers are also preferred in the field of digital drug therapy for improving the brain function.

Attention | **Relaxation** | **Balance** | **Coherence** | **Activation**

Neurofeedback training





*The digital drug therapy is an area of increasing interest in these days because it has fewer side effects than conventional drugs.

EEG and Cognitive performance

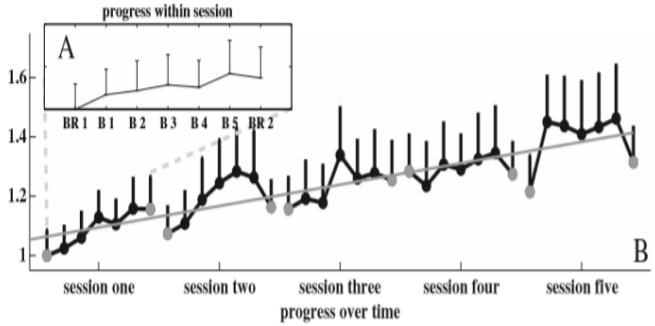


Fig. 1. (A) Experimental design within each of the five sessions. BR1, BR2: base rates; B1–B5: training blocks. (B) Average UA amplitudes across all responders according to the temporal course of the study, normalized with respect to the first base rate of the first session. The straight line results from a linear regression and indicates a linear long-term increase. Note, that the second base rate within each session usually lies above the first one (both in grey), and that the first base rate in the last session is significantly higher than in the first session, both reflecting trainability. The bars indicate standard errors of the mean, depicted one-tailed due to the directional hypothesis of a temporal increase of UA.

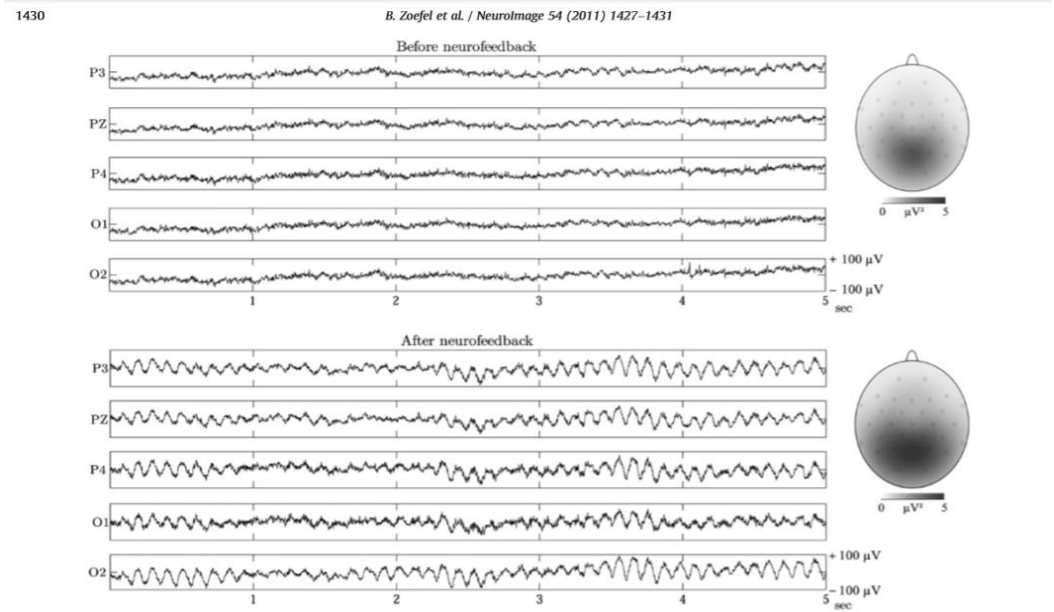


Fig. 3. Reflection of the UA enhancement in the raw EEG data. In the left column parts of the EEG of a selected responder are shown, recorded within the first (top) and last (bottom) session. Only within the last session, the pronounced alpha rhythm is visible. In the right column the topographical maps of the UA are shown as averaged across all responders.

Cognitive performance

On average, 18 ± 2.8 items were presented in the control group with an average presentation time for a single item of 56.6 ± 33.7. In the NFT group, 16.7 ± 3.5 items were presented, each for approximately 66.9 ± 23.1 (difference to control group n.s.). The performance measures of the control group for the two mental rotation tests were 108.8 ± 11.38 and 114.7 ± 19.08. The performance measures of the NFT group were 116.9 ± 11.50 and 129.7 ± 11.63.

The mean increase of mental rotation test performance in the control group was 5.9 ± 11.48. In the NFT group the mean increase was 12.8 ± 7.98. The performance was significantly increased for the NFT group ($t(16) = 2.21$, $p = .029$), but not the control group (n.s.).

For the control group, the UA before the second cognitive test was not significantly different from the UA before the first cognitive test. For the NFT group, as it was already mentioned, there was a significantly higher UA amplitude in the first base rate of the last session (before the second cognitive test) than in the first base rate of the first session (before the first cognitive test). Thus, the NFT group, who did show UA enhancement, also showed better cognitive performance, while the control group lacked both UA enhancement and pronounced differences in cognitive performance.

NeuroImage, 2011, Vol.54

Realtime human emotion monitoring engine based on the prefrontal EEG and HRV-markers

In the era of the fourth industrial revolution,
the wearable EEG, HRV applications are expanding very much.

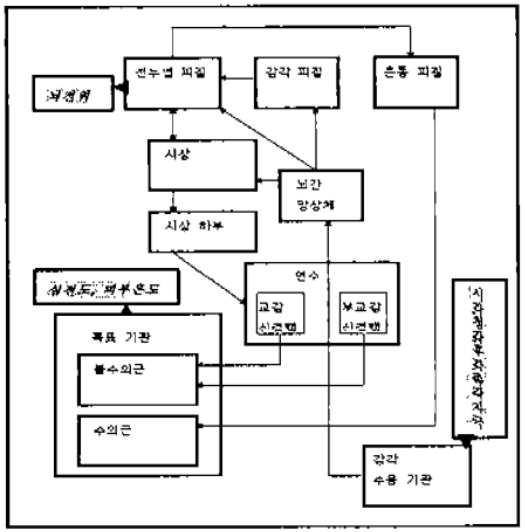
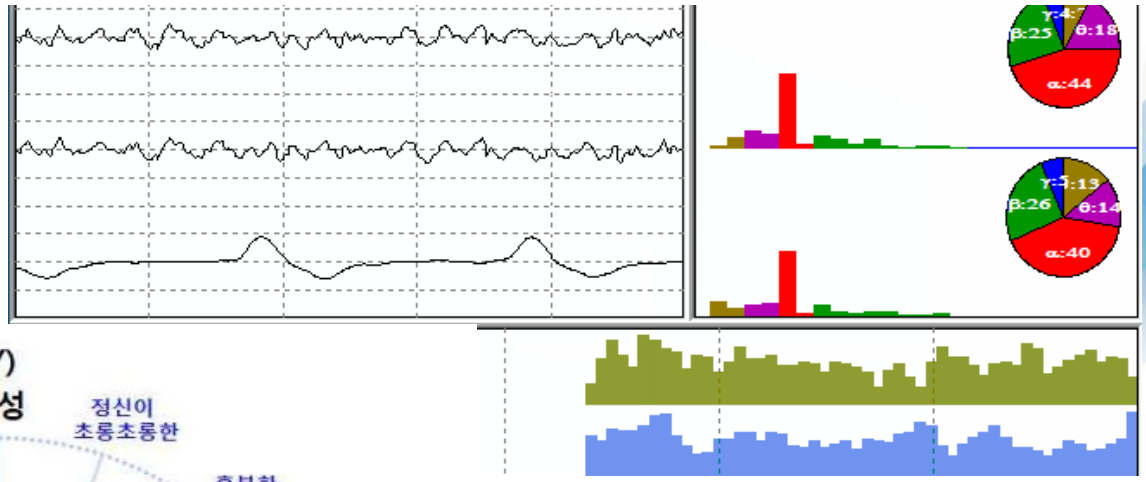
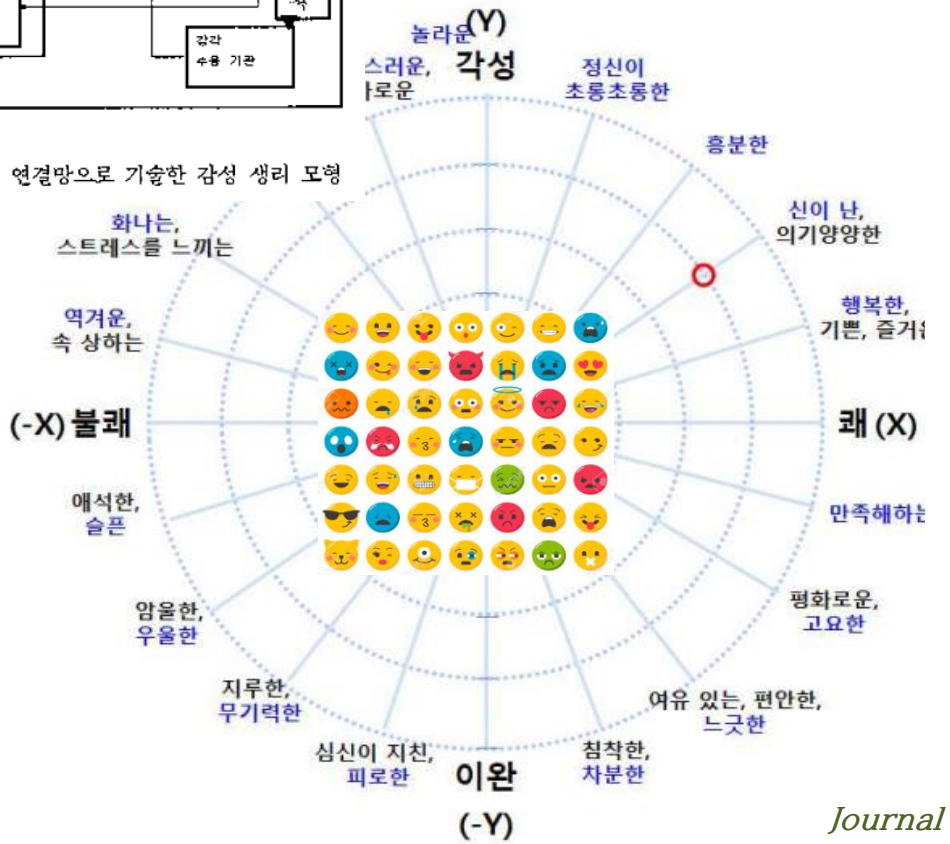


Fig.1 신경계의 연결망으로 기술한 감성 생리 모형





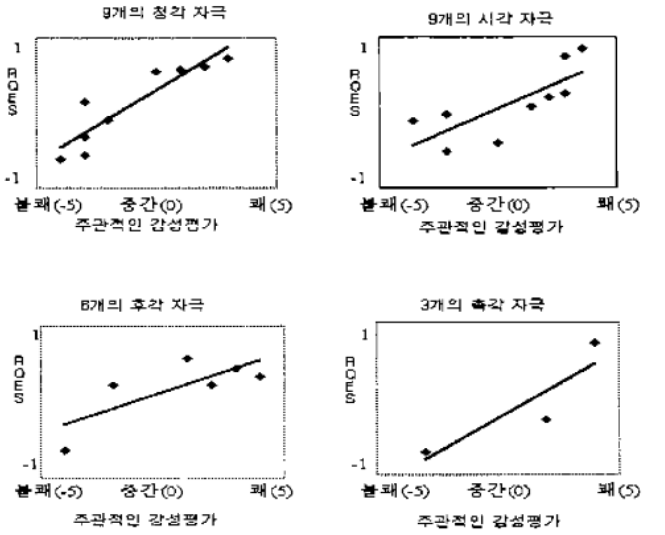
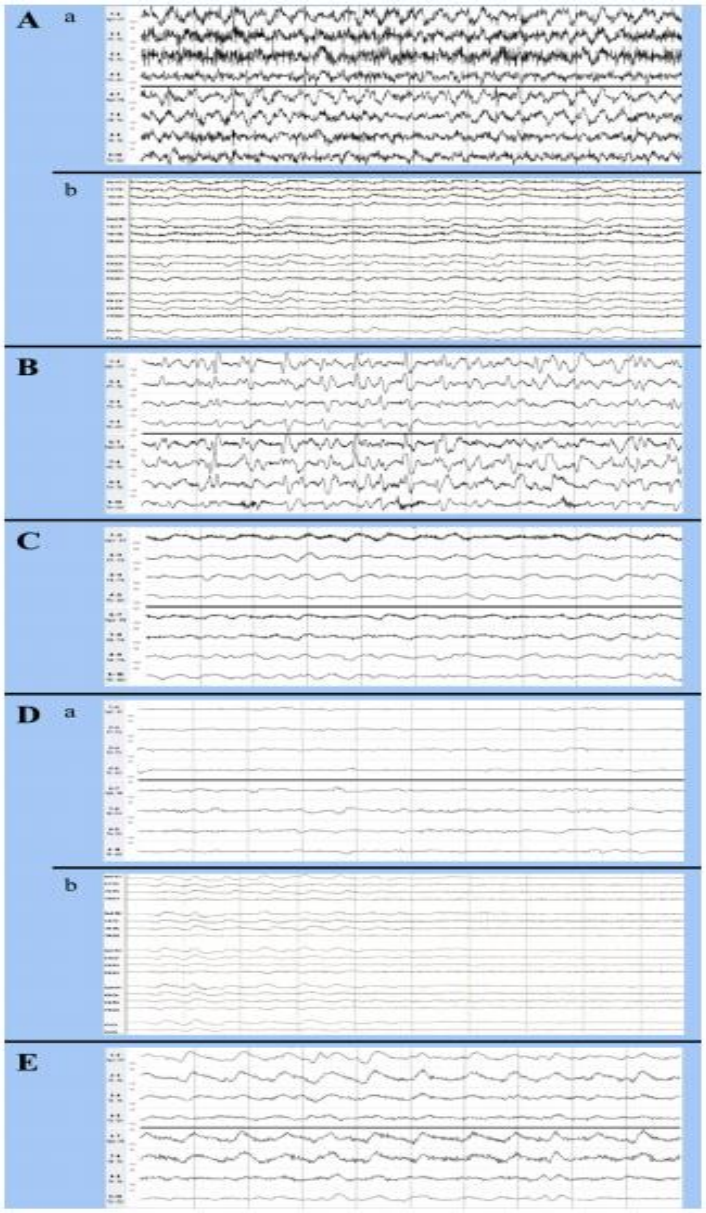


Fig.6 주관적인 감성평가값과 뇌전위의 RQES 변수 사이의 양의 비례관계를 청각, 시각, 촉각, 후각 자극에 대해 나타낸 그림

Journal of the Science of Emotion & Sensibility, 1998

Covie-19 and EEG abnormalities : Impaired Consciousness



Seizure: European Journal of Epilepsy, 2020 (vol.81)

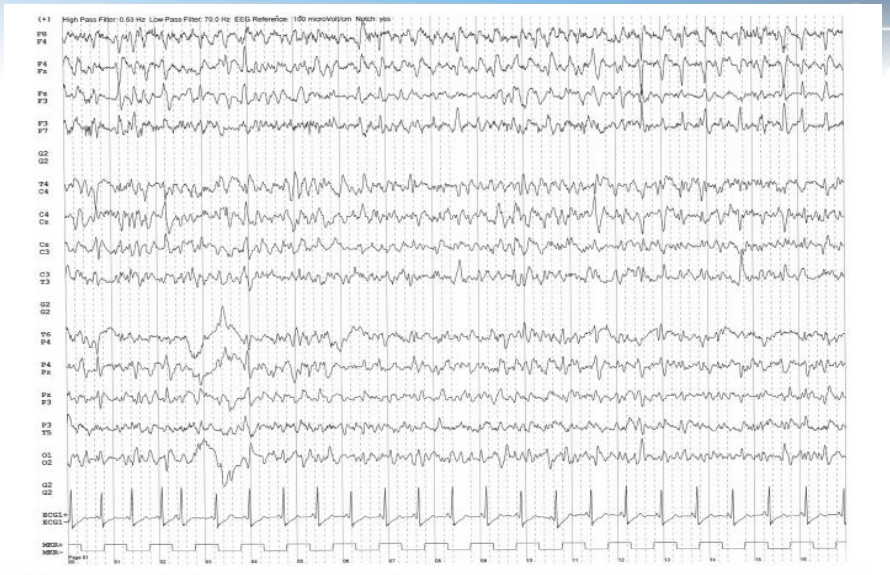


Fig. 1a. EEG recording on day 6 after admission. Transverse bipolar montage. Bandpass: 0.53–70 Hz. 50-Hz notch filter. Sensitivity 10 μV/mm. Note the repetitive epileptiform discharges mostly in the bilateral frontal areas, over a slowing of the background activity.

Fig. 1b. EEG recording on day 21 after admission. Transverse bipolar montage. Bandpass: 0.53–70 Hz. 50-Hz notch filter. Sensitivity 10 μV/mm. Note the periodic triphasic waves with short periods (1–1.5 s) over a worsened background activity.

Clinical Neurophysiology, 2020 (vol.131)

Thank you