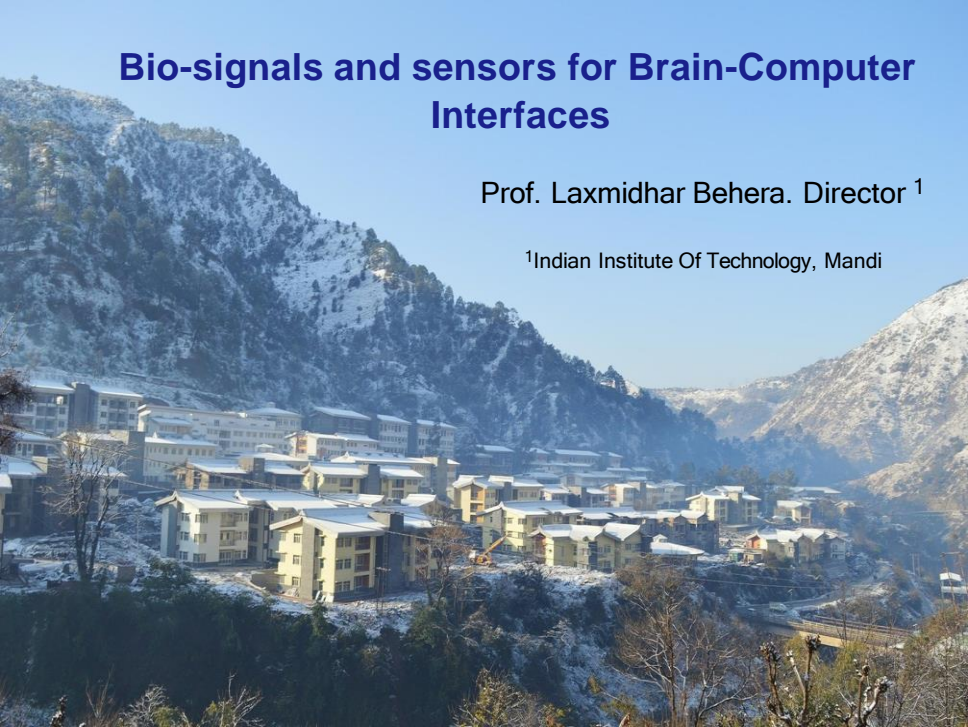


Bio-signals and sensors for Brain-Computer Interfaces

Prof. Laxmidhar Behera. Director ¹

¹Indian Institute Of Technology, Mandi



- Biomedical signals means the bio-signals which are generated in biological systems only.
- Biomedical signals are observations of the physiological activities of organisms, ranging from gene and protein sequences, to neural and cardiac rhythms, to tissue and organ images.
- Examples of biomedical signals
 - ECG (Electrocardiogram)
 - EEG (Electroencephalogram)
 - EMG (Electromyograph)

How Bio-medical signals are generated?



- Biomedical signals are electrical or magnetic signals generated by some biological activity in the human body.
- Human body is composed of living tissues that can be considered as a power station.
- Action of living tissues in terms of bioelectric potentials generate multiple electric signals from two internal sources- muscles and nervous system

1 Introduction to BCI

2 History of BCI

3 BCI closed – loop Flowchart

4 Recording Brain Signal types in BCI

- Brain activity

5 Temporal Resolution and Spatial Resolution

- EEG
- ECoG
- MEG
- CT
- MRI/fMRI
- fNIRS
- PET
- SPECT

6 Trade-off between Temporal and Spatial Resolution

7 Importance of EEG over other methods

8 EEG-based BCI Paradigm

- P300 - Evoked Potential
- Motor Imagery
- VEP : Visual Evoked Potential

9 Other Biomedical signals

- Electrocardiogram (ECG/EKG)
- Electromyography (EMG)
- Electrooculography (EOG)

10 References

- ❑ The system of the brain and the spinal cord collectively known as the Central Nervous System (CNS) is an essential part of the living organism to interact with the world and self. It receives many different sensory inputs(external or internal stimuli) and responds to the outside world or the body itself by producing appropriate motor outputs (hormonal or neuromuscular).
- ❑ A brain-computer interface (BCI) measures CNS activity by monitoring electric or magnetic fields, hemoglobin oxygenation, or other parameters using sensors on the scalp, on the surface of the brain, or within the brain.

- ❑ Different techniques to measure BCI signals are broadly classified into 3 types:
 - ❑ **Non Invasive:** The sensors are placed on the scalp to measure the electrical potentials produced by the Brain.
 - ❑ **Semi Invasive:** The electrode are placed on the exposed surface of the Brain [cereberal cortex].
 - ❑ **Invasive:** The micro-electrode is placed directly into the cortex, measuring the activity of a single neuron.

There are many non-invasive techniques out of which EEG is most commonly used because of the cost and hardware probability.

- ❑ In 1968, First attempt to control brain signals on a neuro physiological basis was reported by **Wyrwicka** and **Sterman**.
- ❑ In 1969, First scientific report of volitional control of Human Brain Oscillation was published by **Kamiya**.
- ❑ In 1969, **Fetz** demonstrated that operant conditioning could be used to control the firing of single cortical neurons in monkey.
- ❑ In 1973, BCI term was first proposed by **Jacques Vidal**, when he presented a system that could translate EEG signals into computer control signals.

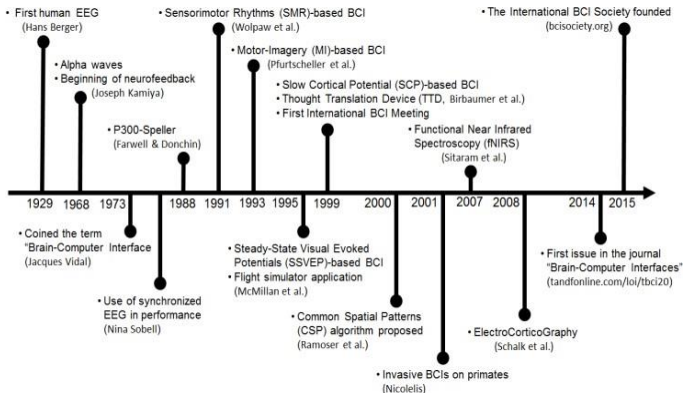


Figure 2: History of BCI [1]

BCI closed – loop Flowchart

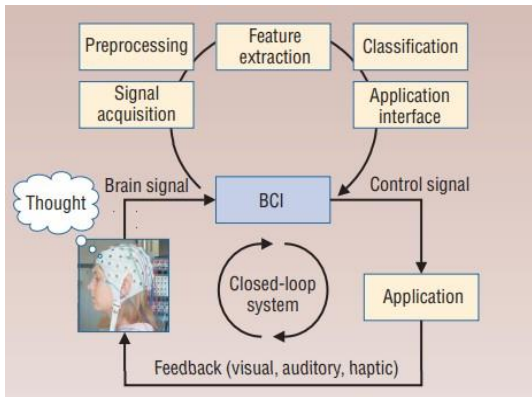


Figure 3: Elements of non invasive closed loop BCI system [\[2\]](#)

Brain signals recorded by a variety of different electrophysiological and metabolic methods can serve as BCI inputs. These signals differ considerably in topographical resolution, frequency content, area of origin, and technical requirements.

There are two ways to monitor brain activity:

Electrophysiological Activity

- Generated due to the Electrochemical transmitters exchanging information between the neurons.
- The neurons generate currents that flow within and across neuronal assemblies.
- Electrophysiological activity is measured by electric and magnetic devices:
 - EEG** - Electroencephalography
 - ECoG** - Electrocoricography
 - MEG** - Magnetoencephalography

□ Hemodynamic Response

- It is a process in which the blood releases glucose to active neurons at greater rate than in the area of inactive neurons.
- The glucose and oxygen delivered through the blood stream results in a surplus of oxyhemoglobin in the veins of the active area. This forms the distinguishable change of local ratio of oxyhemoglobin to deoxyhemoglobin.
- These changes can be quantified by neuroimaging methods requiring electromagnetic fields or radiation such as:
 - **MRI/fMRI** - Functional Magnetic Resonance Imaging
 - **NIRS** - Functional Near Infrared Spectroscopy
 - **CT** - Computerised Tomography
 - **PET** - Positron Emission Tomography
 - **SPECT** - Single-Photon Emission Computed Tomography

BCI types based on Signal capture I

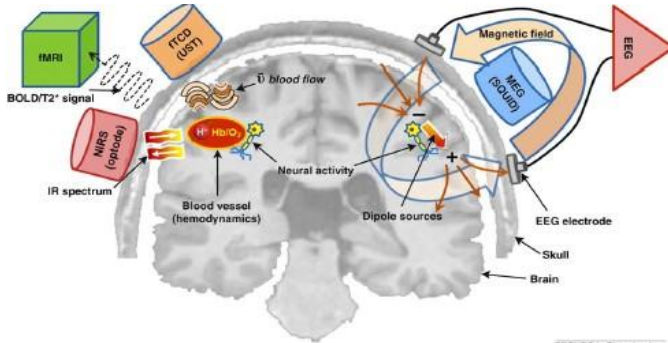


Figure 4: Source: Schematic of brain signal detection mechanisms [3]

MRI/fMRI - Functional Magnetic Resonance Imaging

ECoG - Electrocorticography

MEG - Magnetoencephalography

NIRS - Functional Near Infrared Spectroscopy

CT - Computerised Tomography

PET - Positron Emission Tomography

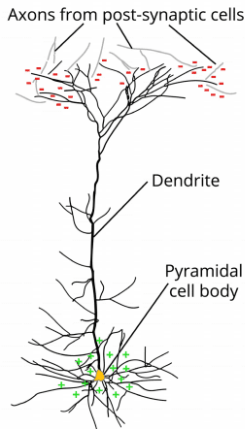
SPECT - Single-Photon Emission Computed Tomography

Temporal and Spatial Resolution

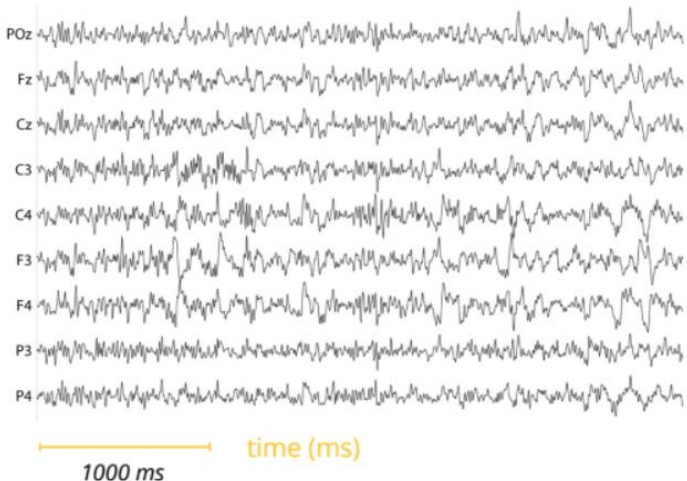


- ❑ Brain activity is distributed in 3-dimensional space and evolves in time.
- ❑ **Temporal Resolution** refers to how closely the measured activity corresponds to the timing of the actual neuronal activity [4].
- ❑ **Spatial Resolution** refers to how accurately the measured activity is localized within the brain [4].
- ❑ High **Spatial** and **Temporal** resolution imaging modalities needed.

- ❑ To record electrical activity generated by the brain, simply record the electrical data from sensors (electrodes) placed at the scalp surface.
- ❑ EEG measures electric brain activity either during an event or to measure spontaneous brain activity. Activity associated with events is called event-related potentials (ERPs).
- ❑ EEG measures postsynaptic potential (not action potential) which is a change in postsynaptic membrane potential when synaptic impulse from the axon of the presynaptic neuron releases neurotransmitters to receptive dendrites at the postsynaptic resting neuron.



Electroencephalography(EEG) I



- As brain cells communicate they produce electric waves α , β , γ , δ , θ of different frequencies, amplitude, and shape. Brain wave analysis is useful for the conscious (awakened state), unconscious (dream and sleep pattern, REM sleep) states, coma state, circadian rhythms and other brain disorders.

What our brain waves are and what they do:



- Delta (<4Hz): Delta is characteristic of deep sleep. The brains of meditators, intuitive, and healers have much more delta than normal.
- Theta (4-8Hz): Theta is characteristic of light sleep rapid eye movement (REM) sleep.
- Alpha (8-12Hz) : is an optimal state of relaxed alertness. It is responsible for enhanced cognitive-information processing.
- Beta (12-40Hz) :
 - Higher beta (25 to 40 Hz) is the signature brain wave of people with anxiety, people experiencing frustration, and people under stress.
 - Low beta (12 to 25 Hz) is the band that synchronizes our bodies' automatic functions. Its also called the sensorimotor rhythm frequency. Relaxed, yet focused, integrated.
- Gamma (>40Hz) : It is associated with enhanced binding of the information into an episodes (Episodic memory). Meditators have a high gamma burst. Also associated with integrated thoughts.

❑ Advantage :

- ❑ fast, low-cost, and noninvasive imaging method
- ❑ high temporal resolution, can measure changes occurring in milliseconds.
- ❑ Diagnosis of Brain tumors, brain damage from head injury, stroke, inflammation of the brain

❑ Disadvantage:

- ❑ poor spatial resolution as it measures electrical activity when a large group of neurons is activated at the same time.
- ❑ limited ability to accurately record from structures deeper than the cortex.

- ❑ EEG recording system consists of electrodes, an amplifier, an A/D converter, and a recording device whose functions are discussed as follows:
 - ❑ **Electrodes** : They acquire signals from the scalp.
 - ❑ **Amplifier** : They process the analog signal to enlarge the amplitude of the EEG signals.
 - ❑ **A/D Converter** : This setup digitizes the analog signals to avoid noise.
 - ❑ **Recording Device** : It may be the personal computer or similar that stores and displays the data.

Electroencephalography(EEG) V

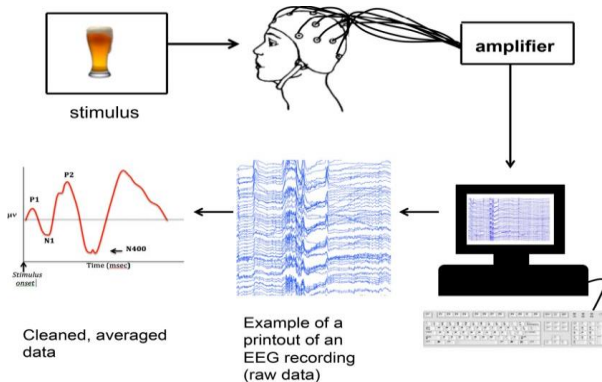


Figure 5: EEG Block diagram [\[5\]](#)

Source : A. M. Beres, "Time is of the essence: A review of electroencephalography (EEG) and event-related brain potentials(ERPs) in language research," Applied psychophysiology and biofeedback, vol. 42, no. 4, pp. 247-255, 2017.

Electroencephalography(EEG) VI

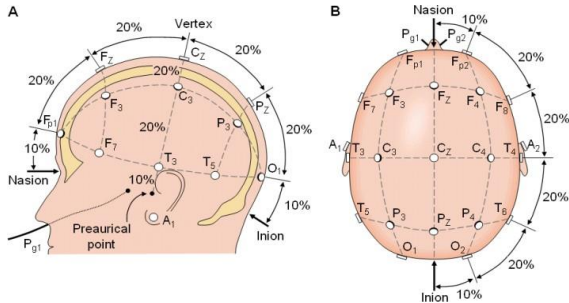
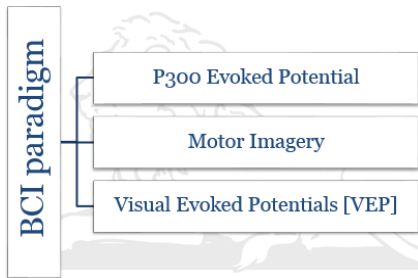


Figure 6: The international 10-20 system seen from (A) left and (B) above the head for EEG setup [6]

Source : S. E. P. Nomenclature, "American electroencephalographic society guidelines for," Journal of clinical Neurophysiology, vol. 8, no. 2, pp.200-2, 1991.

- ❑ The purpose of BCI is to interpret user intention by means of monitoring cerebral activity.
- ❑ Brain signals involve numerous of simultaneous phenomenon related to the cognitive task as a result origin of the signals remain unknown.
- ❑ Physiological phenomenon of some brain signals have been decoded in the form EEG based BCI paradigm.



- ❑ **P300 Evoked Potentials** are the positive peaks in the EEG due to the infrequent auditory, visual or somatosensory stimuli.
- ❑ The P300 responses are elicited about 300ms after the odd stimuli among several frequent stimuli.
- ❑ BCI based on visual P300 evoked potential comprises of letters, numbers or other symbols or commands.

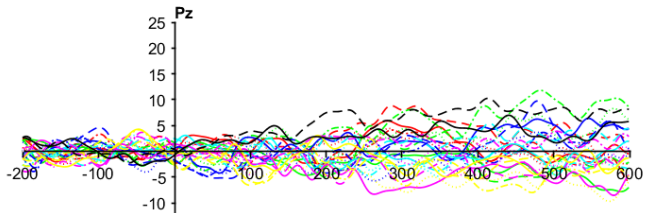
- ❑ The row or column of matrix are flashed at random while the EEG is monitored.
- ❑ The user keeps an eye on the desired symbol and count how many times the row or column containing the desired choice flashes.
- ❑ **Disadvantage** : Performance is reduced because the user gets used to the infrequent stimulus and consequently P300 amplitude is **decreased**.

P300 based Goal Selection

- **P300 (P3)** wave is an [event-related potential](#) (ERP) component elicited in the process of decision making
- 35 goals can be selected from this GUI
- By mentally focusing on the desired goal and counting the number of flashes on it .. either by a row flash or column flash

A	B	C	D	E	F
G	H	I	J	K	L
M	N	O	P	Q	R
S	T	U	V	W	X
Y	Z	1	2	3	4
5	6	7	8	9	—

An example plot



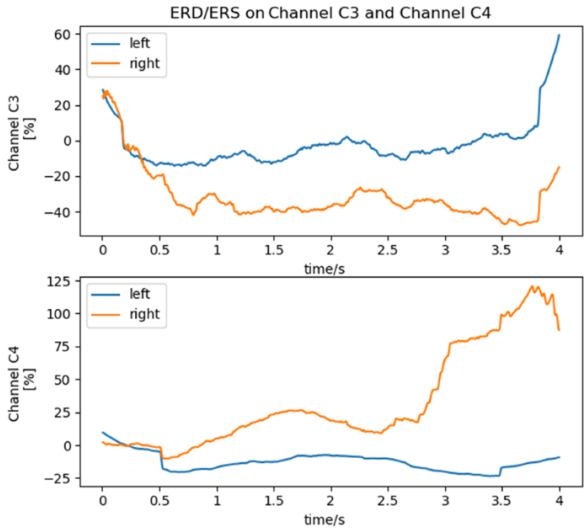
- BIN53: a
- - - BIN54: b
- ... BIN55: c
- · - · BIN56: d
- BIN57: e
- - - BIN58: f
- ... BIN59: g
- · - · BIN60: h
- BIN61: i
- - - BIN62: j
- ... BIN63: k
- · - · BIN64: l
- BIN65: rr
- - - BIN66: n
- ... BIN67: o
- · - · BIN68: p
- BIN69: q
- - - BIN70: r
- ... BIN71: s
- · - · BIN72: t
- BIN73: u
- - - BIN74: v
- ... BIN75: w
- · - · BIN76: x
- BIN77: y
- - - BIN78: z

- ❑ In **Motor Imagery**, participants are asked to imagine visual images of related real movements.
- ❑ The above is not sufficient for a BCI system because the pattern of these sensorimotor rhythms differ from actual Motor Imagery.
- ❑ Sensorimotor Rhythm comprise of μ and rhythms, which are oscillations in the brain activity localized in the μ band (7Hz-13Hz) and the band (13Hz-30Hz) respectively.

- ❑ Self Control of sensorimotor rhythms is not easy as a result most people have difficulties with motor imagery.
- ❑ Motor Imagery training is traditionally based on Visual or Auditory feedback.
- ❑ In this training, users are asked to perform a certain motor imagery task and then the sensorimotor rhythms are extracted and classified by comparing them with a reference.

- ❑ The latest advances shows that it is possible to predict human voluntary movement before they occur based on the modulation in sensorimotor rhythms.
- ❑ Sensorimotor Rhythm can endure two kinds of amplitude modulation which are as follows:
 - ❑ **ERD** : Event Related Desynchronization involves an amplitude suppression of a rhythm.
 - ❑ **ERS** : Event Related Synchronization involves an amplitude enhancement of a rhythm.

Motor imagery



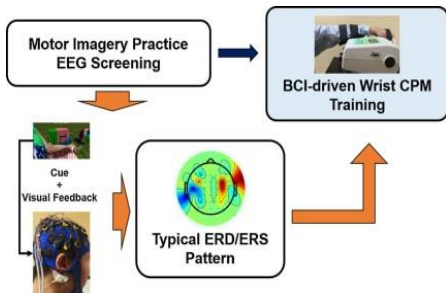


Figure 15: Motor imagery based brain-computer interface control [\[8\]](#)

Source : Rong-Rong Lu, et al."Motor imagery based brain-computer interface control of continuous passive motion for wrist extension recovery in chronic stroke patients", Neuroscience Letters, Jan'2020.

- ❑ Visual Evoked Potential are brain activity modulations that occur in the visual cortex after receiving visual stimuli.
- ❑ VEPs are classified according to the three different criteria :-
 1. **By the morphology of the optical stimuli** : VEPs may be caused by using flash stimulation or using graphic patterns such as checkerboard lattice(changes checks from black to white and from white to black), gate and random-dot map.

- 2. By the frequency of the visual stimulation :** In this type VEPs are further divided into two types:
 - TVEPs - Transient Visual Evoked Potential** occur when the frequency of visual stimulation is below 6Hz.
 - SSVEPs - Steady State Visual Evoked Potential** occur in a reaction to stimuli of higher frequency.
- 3. By the field stimulation :** In this the graphics are displayed halfly or partly to the screen and the person is asked to look at the center of the screen. Depending on this above is categorized either in **Half Field VEPs** or **Part Field VEPs**.

Heart rate variability

Biological Basis

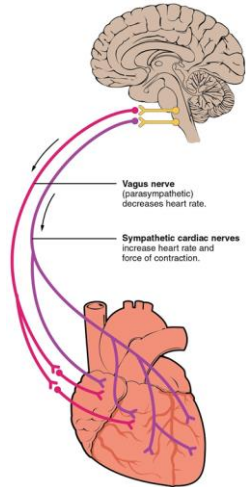
Heart rate is controlled by the two branches of the autonomic nervous system.

- The sympathetic nervous system (SNS) - accelerates the heart rate

- The parasympathetic nervous system (PNS). - decelerates the heart rate

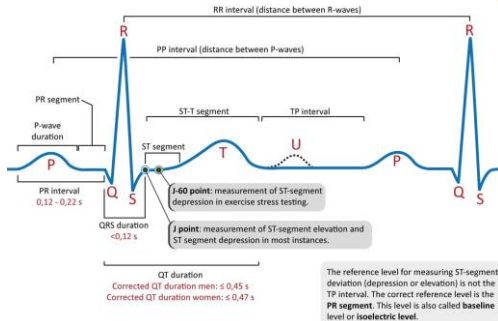
- As you exercise more strenuously, the sympathetic system “kicks in” to accelerate your heart rate even more

- While Meditating or taking slow, deep breaths, the parasympathetic nervous system help to slow your heart rate



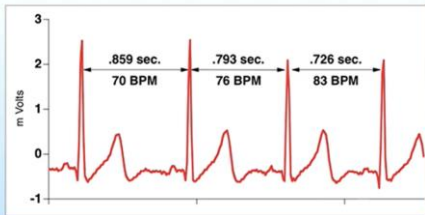
Electrocardiography ECG

- ❑ An electrocardiogram (ECG/EKG) uses temporary electrodes on your chest and limbs to monitor, track and document your heart's electrical activity for diagnostic purposes
- ❑ ECG waveform is a composition of P, Q, R, S, and T waves, which interprets the polarization and depolarisation of ventricular and atrial chambers of the heart.



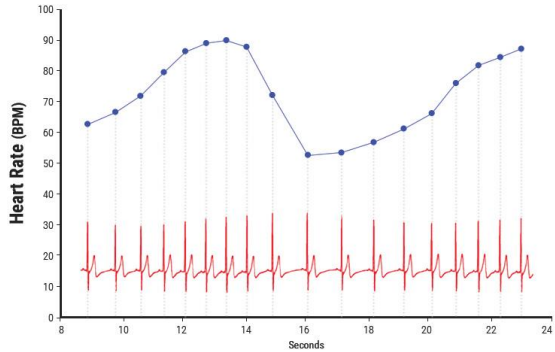
HRV

Heart Rate Variability (HRV)



- Physiological variation of the interval between consecutive heartbeats is known as the heart rate variability (HRV)

HRV



Heart rate variability

- Scientists and physicians consider HRV to be an important indicator of health and fitness.
- As a marker of physiological resilience and behavioral flexibility,
 - it reflects our ability to adapt effectively to stress and environmental demands.
 - A simple analogy helps to illustrate this point: just as the shifting stance of a tennis player about to receive a serve may facilitate swift adaptation, in healthy individuals the heart remains similarly responsive and resilient, primed and ready to react when needed.



Heart Rate Variability and Physical Health

- We have the most HRV when we are young and it steadily declines as we age.
- Below-normal HRV for your age is a strong and independent predictor of future health problems, including all-cause mortality.
- Low HRV reflects the effects of depletion on the autonomic nervous system and is associated with: inflammation, congestive heart failure, diabetes, hypertension, weight gain, and Metabolic Syndrome.

Heart Rate Variability and Psychological Health

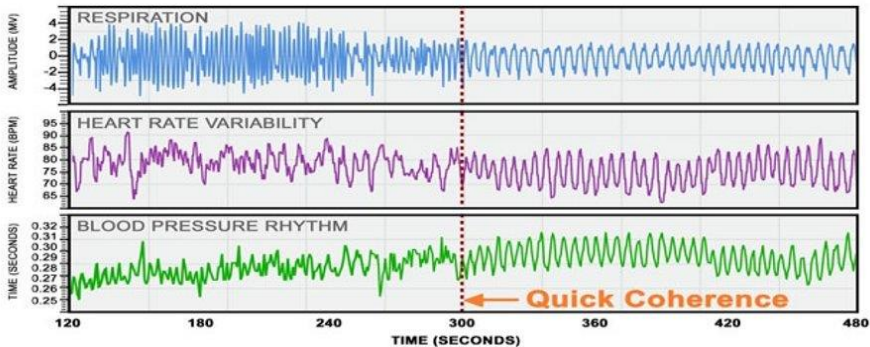
- HRV is an important indicator of psychological resiliency and ability to handle stress.
- Higher levels of HRV are associated with superior mental performance on tasks requiring executive functions.
- Reduced HRV is associated with anxiety, depression and self-regulatory capacity
- Low HRV is associated with: Behavior problems and difficulties with emotion regulation, depression and generalized anxiety.
- HRV coherence: used for optimal state training to support leaning of the self-regulation tools and improved mental functions.

Coherence as a measure

The HeartMath Institute has defined coherence as a state of sustained positive emotions which facilitates a body-wide shift to a specific, scientifically measurable state.

Research shows that when we activate this state, our physiological systems function more efficiently, we experience greater emotional stability, and we also have increased mental clarity and improved cognitive function. Simply stated, our body and brain work better, we feel better, and we perform better.

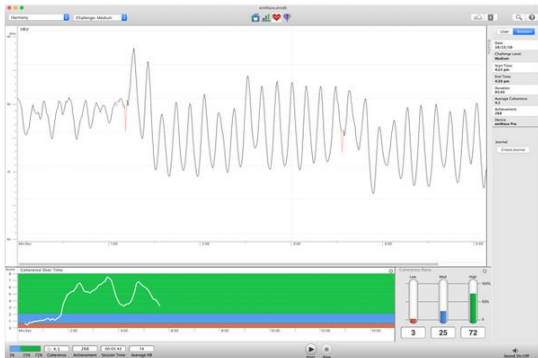
The Coherent State



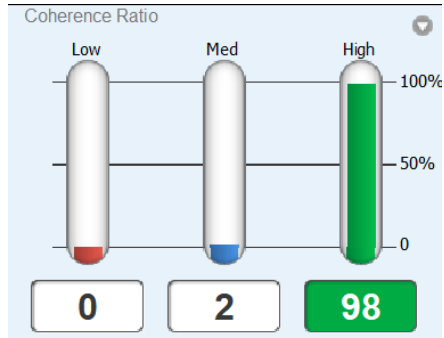
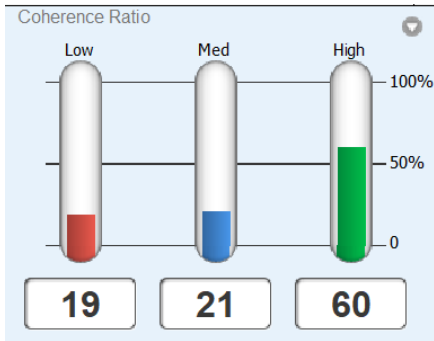
Pre-intervention

Post-intervention

An
example
reading



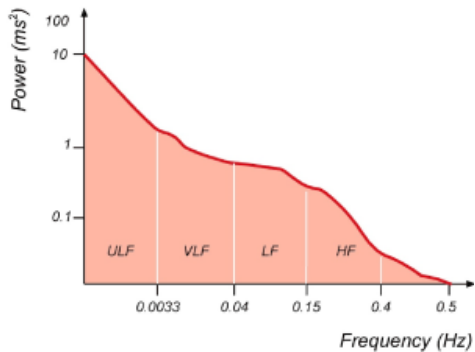
Baseline vs Staircase climbing



Time domain measurement definitions of heart rate variability

VARIABLE (Unit)	Explanation
NN (ms)	The cycle length between two beats (normal-to-normal (NN) intervals or the instantaneous heart rate)
SDNN (ms)	It is the standard deviation of all normal RR intervals . The standard deviation of NN (SDNN) reflects the parasympathetic component of the autonomic function. It reflects the decrease in SDNN, decreased vagal activity and increased sympathetic activity of the sinus node.
SDANN (ms)	It is the standard deviation of the average NN intervals calculated over short periods, usually 5 minutes, which is an estimate of the alterations in heart rate due to cycles longer than 5 minutes.
RMSSD(root mean square of successive differences)(ms)	It is the square root value of the total squared differences of successive NN intervals . It is considered as an important indicator of parasympathetic activity.
SDSD (ms)	It is the standard deviation of differences between successive normal cycles.
NN50 Number	It is the number of NN intervals between which the difference occurs greater than 50 msec throughout the entire record

Frequency Domain



The normal ranges of some of used time domain and frequency domain measurements

INDEX (Unit)	NORMAL RANGE
SDNN (ms^2)	141±39
SDANN (ms^2)	127±35
RMSSD(ms^2)	27±12
SDSD (ms^2)	141±39
pNN50 (%)	20±16
Spectral measurements in 5-min recordings	
Total Power (ms^2)	3466±1018
VLF(ms^2)	627±215
LF(ms^2)	1170±416
HF(ms^2)	975±203
LF/HF ratio (ms^2)	1.5-2.0

Effect of different activities on HRV

Smoking:

Alyan Ö, et al. I- LF and LF/HF ratio was significantly higher in smokers; and that they found significantly lower SDNN, SDANN, RMSSD and HF values, and that smoking disrupts sympathovagal balance in healthy subjects.

Hypertension:

Thayer JF, et al. reported that modifiable (such as work stress) and unmodifiable (such as hypertension, obesity, family history) risk factors for cardiovascular disease were linked to decreased heart rate variability parameters [42].

Obstructive Sleep Apnea:

Sarıkaya S, et al. reported that they found lower SDNN values in the sleep apnea syndrome group compared to the healthy group, and higher LF and LF/HF values of frequency-based values in patients with sleep apnea syndrome compared to the control group, and lower HF values in sleep apnea syndrome patients compared to the control group, and that patients should be assessed carefully in terms of cardiac arrhythmias [44].

Exercise:

It has been reported that SDNN values, RMSSD values and triangular index values from time-domain parameters respectively increased with exercise [46].

<https://oatext.com/pdf/JIC-4-258.pdf>

Effect of Mantra meditation on HRV

Damerla et. Al. conducted a study -

- Experimental Group – chanted Hare Krishna mantra for weeks
- Control Group – chanted Sham mantra for 4 weeks and then shifted to Hare Krishna mantra

1. The experimental group participants' post-test measures of Heart Rate Variability increased to a statistically significant degree in all measures namely vLF, HF and LF which indicates vagal upregulation

2. In the control group, chanting of the *Hare Krishna Mantra* also increased the heart rate variability measures of vLF and HF to statistically significant degree after the participants switched from the concocted Sanskrit sound without spiritual significance for 4 weeks. Indicating sounds with a prayer have specific beneficial effects

Other self-reported changes reported by the participants

In comparison to before entering the Mantra meditation study, my feeling of selfless caring for others has

7 responses



- Increased
- decreased
- Neither increased or decreased

Maha-mantra



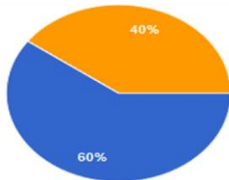
In comparison to before entering the Mantra meditation study, during worship or at other times when connecting with God/others, my feeling joy, which lifts me out of daily concerns has

6 responses

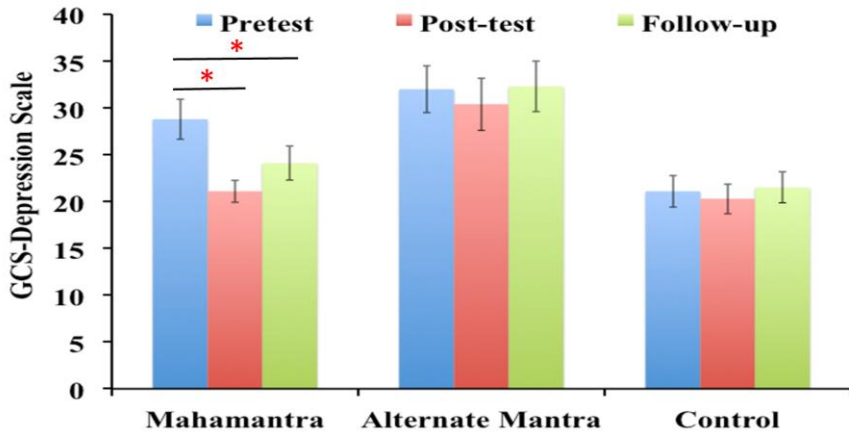


- increased
- decreased
- neither increased or decreased

Mahamantra



sham-sound



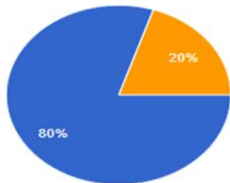
In comparison to before entering the Mantra meditation study, my feeling thankful for my blessings has

7 responses



- Increased
- decreased
- Neither increased or decreased

Maha-mantra



Sham sound

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Thanks.