Reliable EEG Neuromarker to discriminate meditative states across practitioners

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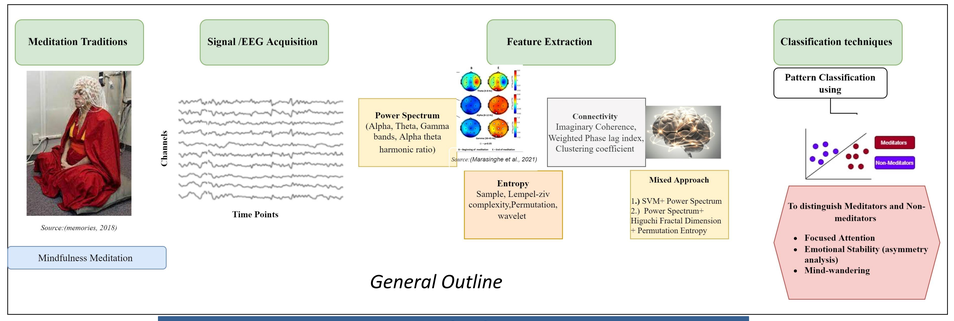
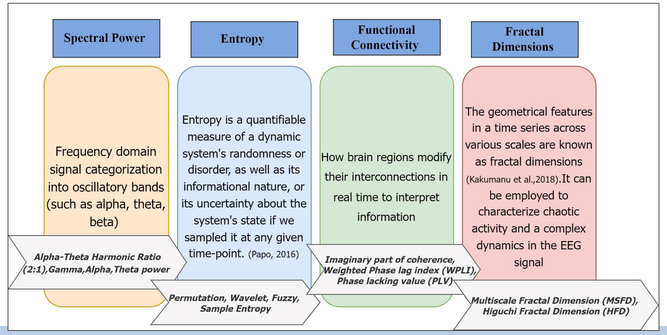
Introduction

Meditation encompasses the **conscious surveillance of attention and emotion**, both of which can be strengthened with routine practice.(Young et al., 2021). In this study, we examined EEG analysis techniques across a variety of meditation traditions in order to **identify reliable metrics** that could be applied in the meditation research, revealing how each tradition interprets EEG signals distinctly. EEG's high temporal resolution may result in misinterpretation or erroneous correlation if the analyzing techniques are unreliable and weak. ***Overall, close examination may provide insights into the complex nature of meditative practice with a steady metric to be utilized in the near future for neurotechnological applications.***



General Outline

Methods



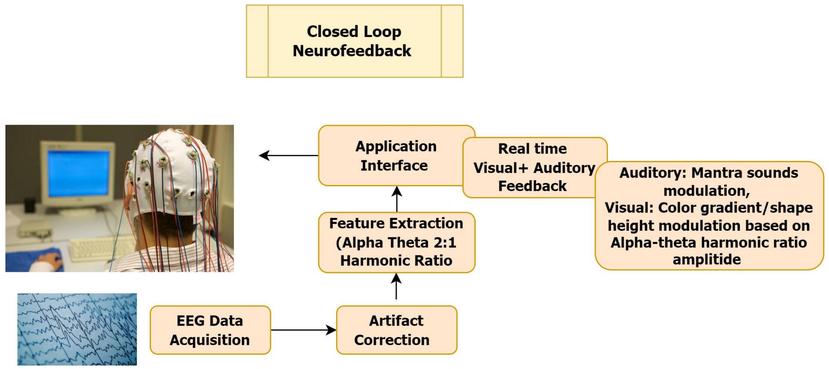
Results

Metric	Specific Analysis technique	Main Observations	Meditation Type	Reference
Power Spectrum	Alpha+Theta	i.) Expert Practioners: Increased **frontal midline theta** and **somatosensory alpha rhythms** during meditation as compared to mind wandering, greater depth and frequency of **sustained meditation,** (meditative absorption) ii.)Non-expert practitioners-greater depth and frequency of **mind wandering** episodes.	**Himalayan Yoga Tradition** (Moderate level of experience (non-expert), Advance in the practice (expert))	Brandmeyer et al., 2018
	Alpha- Theta cross frequency dynmics, Harmonicity	i.)During meditation, **diminished 3:1 harmonicity and cross-frequency phase synchrony between alpha and theta rhythms** were substantially correlated with mindfulness training compliance	36 participants (nurses) underwent an 8-week mindfulness training program based on the **mindfulness-based stress reduction** (MBSR)	Rodriguez et al., 2020
	Gamma	**i.) Increase Parieto- occipital Gamma (60-110Hz) among all the 3 meditators (HYT,VIP,ISY) in comparison to controls**	**Himalayan (HYT-16), vipassana (VIP)-16, Isha shoonya (ISY-16)**	Braboszcz et al., 2017
	Alpha-Theta Harmonic Ratio	i.)From a meditative to an active cognitive processing state, **transient alpha-theta 2:1 harmonic linkages increased linearly (arithmetic tasks)** ii.)The rise in harmonic locking during rest vs. meditation was more noticeable in **central and left temporo-parietal electrodes,** whereas the increase in arithmetic vs. rest had a **frontal distribution**	43 experienced Meditators (from 3 different Meditation traditions**15 QiGong, 14 Sahaja Yoga, 14 Ananda Marga Yoga)**	Rodriguez et al., 2020
Entropy	Sample Entropy	**i.) Higher alpha and gamma power sample envelope entropy for Vipassana meditation** vs. controls, both when comparing meditation vs. focus on breathing and instructed mind wandering in the group of matched controls.	**Himalayan** (16), **vipassana** (16) , **Isha shoonya meditation** (16)	Vivot et al., 2020
	Lempel-Ziv complexity	i)**Lower amounts of entropy (lempel ziv complexity) during meditation** compared with mind wandering state. ii.) According to the study, **meditation reduces brain complexity independent of meditation practise**.	28 participants from six meditation styles (7shamatha (sensation of breath, 6vipassana (sensation of full body), 6zazen, 5dzogchen, 1tonglen (imagined imagery and emotion), and 3 visualization (imagined imagery)	(Young et al., 2021)
	Time domain Fuzzy based entropy	i.) The modified fuzzy entropy analysis revealed **higher irregularities (elevated time domain fuzzy entropy) during meditative states (Peace and angelic meditation) in the frontal regions** than nonmeditative states, suggesting that signal complexity increases during meditation.	15 Rajayoga meditators (Peace and Angelic Meditation)	(G et al., 2020)
Fractal Dimension	Higuchi Fractal Dimension	i.) The Higuchi Fractal Dimension (HFD) of the meditator group in every lobe (frontal, parietal, temporal, and occipital) is **lower** in the post-EEG recording condition than in the pre-EEG recording condition. ii.) **After mindfulness intervention, a decline in fractal dimension shows an efficient way in managing cognitive load.**	**Focused Attention Mindfulness** 40 participants (20 participants in the mindfulness meditation training group and 20 controls)	(Gupta et al., 2021)
	Higuchi Fractal Dimension (Time-domain)	i.)The reduction in HFD (Averaged Higuchi Fractal dimension AHFD) in participants demonstrates that the **EEG signal complexity decreases following OM chanting,** leaving out one of the subjects	10 subjects performed **OM mantra meditation**	(P Harne, 2014)
Functional Connectivity	Phase Synchrony Estimation method Phase locking value (PLV), Improved Phase Locking Value (IPLV)	i.) During meditation, **the meditative signal demsontrated improved phase synchronisation (Improved Phase Locking Value) in the alpha frequency, with enhanced functional integration**. ii.) The **synchronisation of anterior and posterior channels** was the most noticeable topographical change	Kriya Yoga (23 experienced meditators)	(Shaw & Routray, 2016)
	Network analysis a.)average path length b.) clustering coefficient	i.) IBMT group- **smaller average path length and larger clustering coefficient of the entire network** and two midline electrode nodes (Fz and Pz) after training, indicating **enhanced capacity of local specialization and global information integration in the brain**	**Integrated Body-Mind Training (IBMT)** 24 Subjects in IBMT group and 21 in control group (IBMT group were provided with 1 week -30 minutes per session (total of 3.5 hours of training)	(Xue et al., 2014)
Classification	Power Spectral Density, Linear discriminant analysis classifier	i.) The lowest impact on the classifi cation accuracy was given by the low-frequency lateralization measures (delta, theta, and alpha bands). The highest predictability was provided by the **gamma bands, especially the lateralization of the gamma2 band**. ii.) Both **low and high gamma bands with 78 % and 79 % offer higher classifi cation** rates than using all bands and features	49 meditation practitioners with varying meditation experiences were part of the study.Example: **Zen- Buddhism, Qi-Gong, Sahaja Yoga, Western contemplative methods, Spiritist/ mediumistic practioners.**	(Hinterberger et al., 2011)
	Permutation Entropy , SVM classification	i.)Advanced yogis and Non-meditators achieved average offline **classification accuracies of 74.31% and 62.16%** respectively. ii.) Classification of meditation states using **PE (Permutation Entropy) features are better than EEG spectral features**. iii.) It may since advanced meditators have a sufficient **degree of attentional control due to long-term meditation training**	**20 advanced yogis** with above 3 years yoga experience and 20 nonmeditators	(Han et al., 2020)

Discussion & Future Directions

•The generation of a neurophysiological marker that is reliable when a person is progressing from one level of meditation to another is still in its infancy.

•Depending on how different meditation styles are studied and analyzed there might be **both similarities and differences in the results as observed,** but rigorous scrutiny (preprocessing, experimental design, meditation type, feature extraction, etc.) will provide **a better insight into generalizations.**



Here, we propose using a closed loop neurofeedback to learn meditation which is truly cutting-edge technology, as we may be able to discover precise strategies to quickly learn and achieve deeper states of meditation by receiving real-time feedback, with alpha-theta harmonic ratio of 2:1 as its features

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