ORIGINAL ARTICLE

Exploring Meditation Techniques through EEG: A Systematic Review Contrasting Focused Attention and Open Monitoring Practices

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ABSTRACT

Mediation, dating back thousands of years, has evolved into a multifaceted practice, encompassing diverse techniques such as focused attention (FA) and open monitoring (OM). This meta-analysis aims to explore the neural correlates of FA and OM using electroencephalography (EEG) data. The findings provide a prevailing pattern of heightened alpha and theta brain waves in FA and OM. However, this analysis also exposes significant variations across studies. This heterogeneity contributed to the lack of a standardized approach for assessing mediation, disparate participant profiles, and methodological divergences in measuring brain activity. Further investigation must unravel the neural intricacies of FA and OM and more uniform methodologies in future studies.

INTRODUCTION

Meditation is an ancient practice prevalent in multiple cultures. Whether the name goes by contemplative prayer (Christian), Dhikr (Islam), or Vipassana (Hindu), some level of meditation exists in almost all societies. Meditation first seems to appear in the ancient Vedic writings and has proliferated throughout various cultures and faiths since its inception [1]. Mediation techniques were further developed during the modern age, notably through the transcendental meditation techniques developed by Maharishi Mahesh Yogi, a prominent figure in the counterculture and spirituality movement in the 60s. Throughout history, meditation techniques have been created to facilitate self-growth, introspection, and modulated states of awareness numerous types of meditation, including mindfulness meditation, open monitoring meditation, Zen meditation, transcendental meditation, compassion meditation, and vipassana meditation. Each of them has unique attributes that separate them from the others.

Starting in the 1960s, the emergence of the Electroencephalogram (EEG) proliferated and grew significantly. The ability of EEGs to record temporal data, which is imaging that coincides with reality. While many studies aim to find the neural structures associated with meditation, such studies utilize imaging tools that do not show the relationship between meditation and the time-related changes it induces. MRI, fMRI, PET scans, and others identify various regions of the brain (that correspond to different meditation techniques). However, only EEG allows us to have insight into the cortical activity of the brain in real-time [1]. The meditation techniques rely on attenuating or increasing different brain regions, a time-related process that is only valuable when captured by tools that can record such temporal data. EEG is the most suitable candidate for capturing fleeting and transient data for our purposes.

Meditation states range wildly. Each meditation state can indicate the culture it originates from and reflects neural processes that emphasize certain aspects over others. A key component of all these meditations is the modulation of attention. Every form of meditation exists along a spectrum of attention, whether it is concentrating the attentional resources or dispersing them instead. For this review, we turn our attention towards open-monitoring (OM) and focused attention (FA) meditation, two broad categories that encompass multiple components of meditation based on an "attention-holding" or the "attention-releasing" duality. Dunn and colleagues first differentiated These two categories in the literature in 1999. The complementary practices have since been explored alongside each other, with more standardized descriptions provided by Lutz et al. in 2008 and 2015 [2]. It is important to note that there is no strict duality. Meditation heavily relies on the nature of consciousness, which itself falls on a spectrum that is mediated by attention and awareness.

METHODS

We used PubMed as our primary search database. Our search included the terms "Meditation" AND "EEG" AND a distinguishing term for the targeted meditation state/practice: "Focused Attention" or "Concentration," "Open Monitoring," or "Mindfulness," for a total of four combined searches. The terms concentration or concentrative meditation are sometimes interchangeable for focused attention practices; likewise, mindfulness is often used as a generalized term fitting with open monitoring practices- albeit with a breadth often beyond meditation.

We further limited our search to original research articles published in English within the previous ten years. Additional inclusion criteria included healthy adult participants, noted documentation of participant meditation experience, and primary outcome measures as EEG analyses of meditation states that could be readily compared between studies (primarily spectral analysis, synchrony measures, and event-related potentials (ERPs).

Operational Definitions of Meditation

Papers were screened to align with operational definitions of the focused attention and open monitoring categories of meditation provided by Lutz et al. (2004) [2]. Focused attention (FA) meditation was defined as "voluntary focusing attention on a chosen object in a sustained fashion," where any deviation of focus is to be acknowledged, and attention is subsequently redirected to the object of focus. Open monitoring (OM) meditation was defined as "non-reactively monitoring the content of experience from moment to moment" without explicit focus, executive guidance, or rumination on passing observations. Notably, these definitions are not mutually exclusive or exhaustive of meditation practices more broadly. Meditation practices that utilize both approaches within the same session or are regularly taught using both techniques, such as Mindfulness-Based Stress Reduction (MBSR), were included separately as additional supporting evidence for trends of meditation more generally without having the power to distinguish the two approaches.

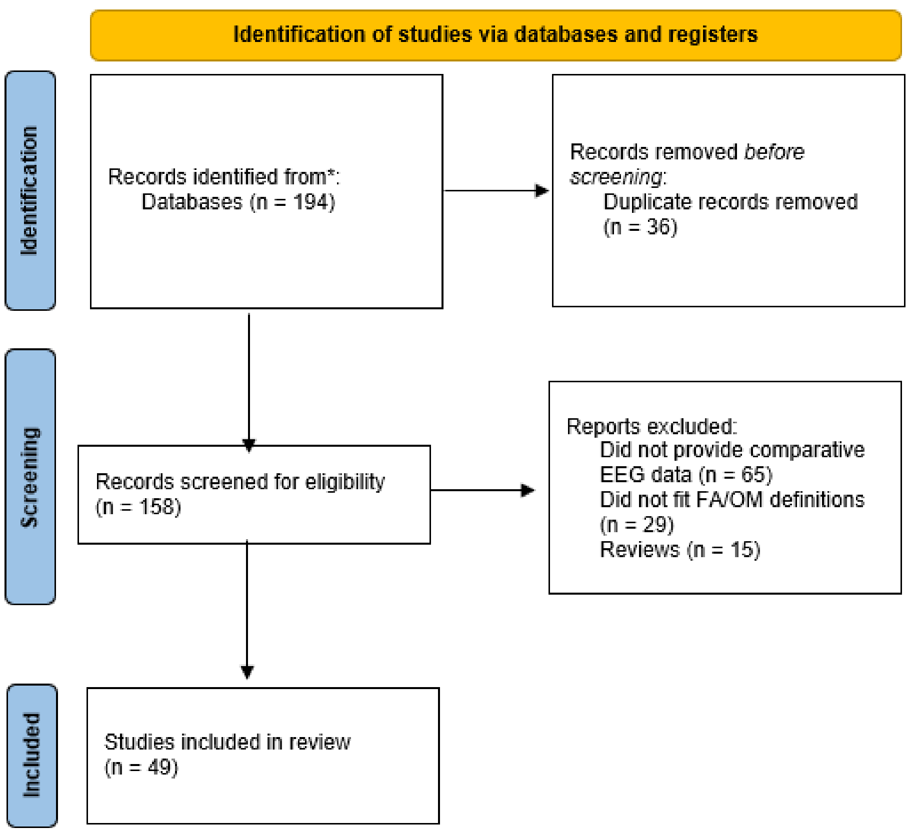

Figure 1. The screening process adapted from the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [3].

Screening

Our combined searches yielded 158 entries after removing duplicates. From this set, 65 papers were excluded due to various restrictions for comparison. Single-subject case studies, use of commercial EEG headbands with restricted recording sites and data specification, non-EEG outcome measures, or confounding factors in the study design were reasons for exclusion. An additional 29 studies were excluded for not fitting our FA and OM operational definitions. Notable exclusions included transcendental or non-dual meditation, yoga, walking, other movement-based, and app-based, guided meditation practices. An additional 15 reviews were also removed from consideration. A flowchart of our paper search can be found in Figure 1.

RESULTS

Fourt nine (49) papers were included in our aggregated analysis. Our initial strict inclusion only yielded five papers for consideration: two FA, two OM, and one comparing both. Therefore, we relaxed our inclusion criteria to allow outcome measures secondary to the meditative state (such as using meditation as an intervention for mind wandering or emotion regulation), contributing an additional 27 papers for inclusion. Our analysis included 10 FA, 16 OM, and six comparative papers, which examined both FA and OM as separate approaches. Additionally, allowing meditation practices that combined FA and OM approaches, such as MBSR, contributed to 17 more papers for generalized support of trending results (seen as light grey text in Table 1).

Aggregate Results

Table 1 displays the aggregated results of our included studies. Results were generalized as appropriate to fit into broad categories for comparison. Most results reported were specific to each study, restricting comparison and replication, and thus are not shown in full detail. Primary trends are presented in grey boxes, with total supporting studies tallied to the side. Below is a more detailed breakdown- including contradictory results- each primary result. See supplementary Table 2 for a more detailed attribution of each study with the ID Codes used in Table 1 above.

Studies that directly compared FA and OM meditation practices did not find significant differences in EEG measures [4-7]. Furthermore, most results were replicated individually and in mixed practice approaches for both meditative practices. Two of the comparative studies by Brown et al.(2022) and Yordanova et al. (2020) noted asymmetrical differences [8-9], but these differences had limited replication [1,10].

Analysis Method	Result	FA = Focused Attention OM = Open Monitoring BC = Both Comparative BI = Both Integrative (e.g. MBSR)									
Studies directly comparing FA and OM	No FA/OM Difference	BC1	BC2	BC3	BC6						
		BC4 and BC5 show inconsistent differences in hemispheric asymmetry									
	Increase alpha power	FA3	FA4	FA7	OM2	OM3	OM9	OM11	BC1	BC3	
		BC4	BC5	BI4	BI8	BI9	BI10	BI12	BI14	BI17	
	Low alpha	FA4	FA7	FA9	OM2	BC1					
	Frontal alpha	FA7	OM9	BC4 (FA only)		BI4	BI8	BI16			
	Posterior (Centro-parietal/Parieto-occipital) alpha	FA1	FA3	FA7	OM9	BC5					
	Right lateralized alpha	OM2	BC5								
	Left lateralized alpha	OM11	BC4 (FA only)								
	Decrease alpha	OM2	OM10	BI1							
	Increase theta power	FA1	FA2	FA3	FA7	FA8	OM3	OM9	BC1		
		BI7	BI10	BI13	BI17 (Smaller increase in theta in expert than in novice)						
	Frontal/Frontal-midline	FA1	FA2	FA3	FA7	FA8	OM9	OM16	BI7	BI10	BI13
	Posterior/Parietal	FA2	OM3	BI7	BI13						
	Decrease theta	OM10									
	Increase gamma power	FA1	OM12	OM13	BC1	BC2					
	Decrease gamma	FA2	OM7								
	Decrease beta power	FA2	OM2	OM8	BI11						
Spectral Analysis	Decrease in alpha, theta	OM10	BI11								
	Increase fronto-parietal coherence	FA1	FA11	OM5	OM13						
	Increase alpha coherence	OM3	OM4	OM14	BC5						
	Increase theta coherence	OM3	OM15	BI17							
Synchrony/Coherence	Decrease phase synchrony	OM4	BI4	BI15							
	Increased P3 response amplitude	FA1	FA6	BC6	BI5						
	Decreased P3 response amplitude	OM6									
	Decreased latency in P3 response	BC6 (OM only)									
	More frontal distribution of P3 response	FA6	OM1								
	Increased N2 response amplitude	FA5	BI2	BI3	BI6						
ERP	No N2 difference between exp/nov	OM1	BI5								

Table 1. Aggregate results organized to show which type of study/meditation practice produced similar results. A key for study IDs can be found at the top of the table; numbers were assigned in order of review. Supplementary Table 2 shows IDs and respective study details. Integrative studies (shown in light grey) used both FA and OM practices, indicating the effects of meditation generally while unable to distinguish between the attentional approaches.

The most consistently prominent result between meditation studies of any type was an increase in alpha power- typically low alpha in frontal and parietal areas when specified [1,10-11]. Even still, a few OM studies noted decreased alpha power. An increase in theta power was also found across many studies, again in frontal and parietal areas. Notably, the trend of increased theta in the frontal-midline was typically found as a trait effect in experts compared to novices, regardless of active meditation during the EEG recording. Several studies also reported increases in gamma power and decrease in beta power, though with less consistency. Fronto-parietal connections were further supported by evidence of synchrony in alpha and theta bands. However, a decrease in synchrony was also shown to be a meditation marker.

Most studies examining evoked potentials and event-related potentials relied upon passive auditory oddball or active response inhibition paradigms. Separate studies, each assessing specific task demands, found increased P3 response amplitudes and increased N2 response amplitudes.

Trait vs. State and Study Design

Few studies determined whether the results should be considered trait or state effects. The basis for comparison varied widely between studies. Many studies compared experts to novices or naïve meditators, presenting trait differences from long-term practice. These studies also often bled into state effects without clearly distinguishing differences due to efficacy in reaching targeted meditation state. As such, results presented here consider effortful novice state induction alongside relatively effortless expert induction. One such study by Tanaka et al. (2014) noted an increase in theta in both novices and experts as a state effect, but experts exhibited a lesser increase than novices [12]. While this result follows normalization within subjects, not all studies carefully report such details. Other studies compared experts' baseline rest to active and post-meditation. Few attempted to compare meditation to active, non-meditative control groups. Still more attempted months-long, longitudinal studies of novice meditators with comparisons pre- and post-training. See Supplementary Figures 1a-c for more details on comparing study designs.

Furthermore, specific study designs presented bias about which aspects of meditation were being assessed. For example, focused attention studies were likelier to use within-subjects comparisons than open monitoring. Despite the inconsistency in study design, we identified a trend whereby novices with training over several weeks to months exhibited state effects similar to experts with many years of training (an expected average would be at least 30 years across studies) rather than naïve counterparts attempting meditation for the first time.

DISCUSSION

In line with open-monitoring and focused attention, studies analyzing focused attention describe techniques equivalent to concentrative meditation, whereas studies analyzing open-monitoring meditation techniques are akin to mindfulness. In concentrative meditation, the goal is for affective and cognitive phenomena to be barely. Either form of meditation is sufficient to stand in as cognitive prototypes of open monitoring and focused attention, though the terms will be used interchangeably. Our intention with this meta-analysis is to find the EEG data that corresponds to these binary states and associate the data with possible neural mechanisms that underlie the functioning of the meditation states.

Prior literature on the subject has focused on mindfulness meditation, and a large body of the discourse in the field is dedicated to uncovering the link between the EEG data and the subsequent techniques and their benefits. There is also a solid base of knowledge about focused attention meditation, with similar intentions towards the neural underpinnings and the resulting techniques and benefits. However, we discovered no articles comparing the two techniques according to the dimension of attention. Attention is vital to either subject, but it is not held as a reference point to compare the two juxtaposed states; it is only about one technique, or the other. Our study aims to investigate how EEG data collected from studies of both techniques may reveal the neural underpinnings of the attentional duality found in the two contrasting meditative states.

Our findings have uncovered more problems and areas of remediation than conclusive findings. Overwhelmingly, the results of the articles we selected for mindfulness and open monitoring show a trend whereby the alpha and theta waves decrease in amplitude and increase in power. , there are massive discrepancies between various articles and researchers, who have found contradictory regions of the brain that pertain to these spectral ranges corresponding to mindfulness. While we expected to see evidence for prominent theta activity in the frontal midline, experiments in our review provide little evidence supporting this relationship. There is no definitive consensus on whether the associated spectral ranges are localized or generalized other than the alpha and theta power increase. We initially hypothesized that the role of focused attention would increase beta activity, but we ceased to find any precise, definitive results that show up.

Many issues arose with the analysis of the articles. For example, the definition of meditation varies wildly, more so than we were expecting. What one researcher can assess as mindfulness can differ from another researcher's assessment. Indeed, we found multiple cases where mindfulness and concentrative meditation were used interchangeably, despite the clear distinction between the two based on previous work on meditative states [1-2, 6]. This discrepancy issue makes much of the data overlap too much to find any significance. Multiple articles that compare the two in a binary classification found comparable results. Alpha and theta power increases and amplitude decreases. In keeping with the operationalization issues, the ways of assessing the meditation states had little to no standard. The techniques used to induce mindfulness or concentrative attention overlapped so much that the results overlapped. In numerous articles compared to control conditions, both concentrative meditation and mindfulness meditation showed, once again, an increase in alpha and theta ranges. That is the only authentic, consistent finding, which may be a result of the poor operational definitions put forth by the researchers. Lastly, the selection of participants negated any usefulness of the experiment. We aimed to restrict the spectral ranges for our analysis to the alpha-theta-beta range for the specific reason of accommodating the participant's experience. This did not help. The massive issue prevailing in these studies is that though there are control participants, novice participants, and expert participants, there are never all three. We found two out of three in almost every article, which further adds to the issue of whether there is a difference in the meditation states. We could not find a difference between the meditation states, and it is unclear whether it is due to the nature of meditation or experiments.

From our analysis, it is very difficult to decide whether there exists an attentional spectrum of mediation or if there is even a difference in meditative states. Though we used just concentrative and mindfulness meditation, we could not see any difference in meta-analysis, review, or experiment articles. Our only factual finding is that the spectral ranges of alpha and theta show an increase in power. We want to make a very pressing statement that the experiment results are not squarely on the heads of the researchers.

Though we lambast the results and methods presented, the researchers echoed those exact concerts. They state numerous times in their discussion about the inconsistency of prior results, the difficulty in operationalizing the nuanced nature of meditation, and the issues of trying to establish an experiment that portrays a cohesive and thorough portrayal of meditation, either concentrative or mindfulness. Despite our frustration with this analysis's results, we applaud the efforts of the various authors who tried to find some standard to gauge meditation. It is our understanding, however, that the current literature on meditation is not in a state of agreeance with science and that the nature of operationalization may strip away all the nuances associated with meditation until you only find the most bare-bones findings: increased power in alpha and theta ranges.

FUTURE DIRECTIONS

To those reading, it may seem that our inconclusive findings would be a disappointment. We argue otherwise. Our insight into meditation research is not groundbreaking; several researchers have attempted to find a generalized under, including Lomas et al. (2015) [13]. We believe that a better understanding of meditation is required before attempting operationalization. Namely, meditation needs to be differentiated from attention, and tasks that require attention should be relevant to meditation. Several papers that attempt to experiment on the attentional aspects of meditation seem to have little to do with meditation and instead seemed like meditation was a mediating factor, not the primary focus to consider. Additionally, the field needs to reach a clear consensus on the standardization of meditation research. Conflicting results appear primarily from the participants utilized. There is no clear-cut approach with the participants, as several experiments utilized novices, experienced practitioners, or participants without prior knowledge. The effects of meditation range wildly based on the level of experience, and several recordings in the spectral bands reflect that level of experience. To have conclusive findings, one must use conclusive samples and subjects. Mere experimentation, with a cookie-cutter approach (control vs expert), is not genuinely comprehensive of the overall nature of meditation and usually does not reflect the dynamic aspect of mindfulness or concentrative meditation. Our firm belief is that researchers with personal experience with meditation will be required to investigate meditation. Anything less will result in a reductionistic perspective on a strikingly dynamic and nonlinear phenomenon, a concept that cannot be broken down into its constituent parts. We hope future researchers will meditate upon our findings as we have meditated on them ourselves.

SUPPLEMENTAL TABLES

	Trait Effects of Long-term Meditators Expert vs Novice/Naive			
	Trait Alone At Baseline/Rest	*Trait-State Group differences during Meditation*	*On task performance Pre or Post Meditation*	*Other correlated group attributes*
Both	Higher Complexity for Teachers	Long term practice enabled further low-alpha power increases and lesser beta and gamma power increases during meditation widespread high-theta differences between Nov and Tea in all the conditions	No difference for auditory oddball MMN	
	Higher proportional low alpha and low gamma with experience	Increase gamma for FA and OM for experts		
		Lower frontal theta overall compared to novice (both groups state increase)		
Focused Attention	Alpha increased in all levels of depth compared to baseline	Decreased central gamma and beta in deeper states	Auditory oddball mismatch negativity increased in experts	
		Increased theta frontal midline and temporo-parietal in deeper states in meditators	More frontal distribution of P300 neural activity following WM stimuli	
Open Monitoring	Experts show less frontal beta	Experts show less frontal beta	Auditory oddball late frontal negativity increased in experts	Left gamma coherence negatively correlated with expertise
	Novice increased frontal beta to enter meditation stage, no change for Expert	Novice increased frontal beta to enter meditation stage, no change for Expert	More frontal distribution of P3 for go and no go conditions in meditators	Mindfulness (MAAS Scores) correlated with (high) gamma power
	Increased theta-alpha in wake (peaking at 8 and 15 Hz) over prefrontal and left centro-parietal for experts	Expert increased frontal beta from meditation to post-meditation rest period	Increased positivity over the right parietal cortex prior to visual information reaching the occipital cortex in meditators	
	Greater frontoparietal EEG coherence in gamma for experts	Novice changes mostly occurred in left (frontal), whereas Expert were more bilateral	Meditators showed increased MFC-Central region synchrony on incongruent trials, more in time to response than stimulus with some specificity to lateralization for handedness (No meditation conducted during study)	
	Right hippocampal connectedness in theta band	Greater frontoparietal EEG coherence in gamma for experts	No N2 difference between groups	
		Higher synchrony across network		

Table 1a A comparison of different trait effect study designs is shown with representative results.

	State Effects Measurement during Meditation	
	Within Subject *vs. Baseline*	*Between Subjects* *vs. (Active) Control*
Both	Increase power in all bands	Increase in alpha power
	Most spectral power in alpha bands during rest and meditation	
	Broadly distributed delta networks	
	Left-hemispheric theta networks with a local integrating posterior focus	
	Right-hemispheric alpha networks, with a local integrating parieto-occipital focus	
	Increase in P300 peak amplitude	
Focused Attention	increased high beta in right hemisphere	
	Increased Pz alpha	
	Increased frontal midline theta and somatosensory alpha rhythms during meditation compared to mindwandering	
	Increase low alpha in frontal and parieto-occipital regions during meditation	
	Increase low alpha during breath focus	
	Delta coherence increase for frontal, parietal, and occipital regions	
Open Monitoring	Increased Frontal Theta	decrease in phase synchrony across all bands (exp vs control)
	Increased high beta in left hemisphere	reduction in right theta coherence; reduction in left alpha and gamma coherence
	Increase in alpha coherence (in experts)	decreased PCC gamma corresponded with effortless awareness
	increased alpha-1 and alpha-2 frequency activity in an exclusively right-lateralized cluster extending from prefrontal areas including the insula to parts of the somatosensory and motor cortices and temporal areas	decreases in the theta (4–8 Hz) and alpha ranges (8–13 Hz)
	decreased alpha and beta-2 activity in the left angular gyrus	Increase alpha power in left-anterior relative to right
	decreased beta-1 and beta-2 activity in a large bilateral posterior cluster comprising the visual cortex, the posterior cingulate cortex and the parietal cortex	
	Decrease latency of P300 auditory oddball response	

Table 1b. A comparison of different state effect study designs is shown with representative results.

	Short-term Trait Effects Longitudinal Novice Training	
# Weeks Training Training Method	*Within Subject* *Pre vs Post Training*	*Between Subjects* *(Waitlist, Active Control, etc.)*
FA 8 weeks A	increased left frontal alpha asymmetry	
FA 8 weeks B	Higher P3 amplitude on task	
	Increased synchrony F4-Pz correlate with P3 amplitude Decreased synchrony of F4-Oz correlate with P3 amplitude (auditory task	
	Trending increase of frontal theta with longterm FA practice	
	Increaed (frequency-PCA) Delta-Theta-Alpha, Low Alpha, High Alpha, and Alpha-Beta during meditation	
FA 4 weeks	Increased low alpha at baseline rest	
FA 3 weeks	increased N2 response in anterior and central regions, and faster reaction time	
OM 8 weeks	Null difference	
OM 6 weeks		Increased global beta
		Increased theta most in occipital, temporal; not significant in frontal
		Slight increased alpha occipital, right temporal
		Phase coherence higher in meditation group in beta, alpha, theta

Table 1c. A comparison of different longitudinal novice training study designs is shown with representative results.

ID Code	Title	First Author	Year	Attentional Approach	Analysis Method	Expertise Design
BC1	Dissociating meditation proficiency and experience dependent EEG changes during traditional Vipassana meditation practice	Kakumanu RJ	2018	Both (Comparative)	Spectral Analysis	Expert vs Novice
BC2	Differential effects of non-dual and focused attention meditations on the formation of automatic perceptual habits in expert practitioners	Fucci E	2018	Both (Comparative)	ERP (auditory oddball)	Expert vs Novice
BC3	No effect of focused attention and open monitoring meditation on EEG auditory mismatch negativity in expert and novice practitioners	Fucci E	2022	Both (Comparative)	ERP (auditory oddball)	Expert and Novice vs active control
BC4	Comparing impacts of meditation training in focused attention, open monitoring, and mindfulness-based cognitive therapy on emotion reactivity and regulation: Neural and subjective evidence from a dismantling study	Brown KW	2022	Both (Comparative)	ERP (emotional reactivity)	Novice only (Trained 8 weeks FA or OM)
BC5	Common and distinct lateralised patterns of neural coupling during focused attention, open monitoring and loving kindness meditation	Yordanova J	2020	Both (Comparative)	Synchrony	Expert only (vs Baseline)
BC6	P300 and Heart Rate Variability Recorded Simultaneously in Meditation	Telles S	2019	Both (Comparative)	ERP (auditory oddball)	Novice (untrained)
FA1	Focused attention meditation training modifies neural activity and attention: longitudinal EEG data in non-meditators	Yoshida K	2020	Focused Attention	ERP (auditory oddball) Synchrony	Novice (8 week training)
FA2	Electroencephalographic correlates of states of concentrative meditation	DeLosAngeles D	2016	Focused Attention	Spectral Analysis	Expert vs Novice
FA3	Reduced mind wandering in experienced meditators and associated EEG correlates	Brandmeyer T	2018	Concentration	Spectral Analysis	Expert vs novice
FA4	The Effects of Concentrative Meditation on the Electroencephalogram in Novice Meditators	Duda AT	2023	Concentration	Spectral Analysis (PCA)	Novice (1 month training) pre vs post
FA5	Focused-attention meditation increases cognitive control during motor sequence performance: Evidence from the N2 cortical evoked potential	Chan RW	2020	Focused Attention	ERP (Serial reaction time)	Novice (21 day training vs 1 session vs control)
FA6	Mindfulness meditation alters neural activity underpinning working memory during tactile distraction	Wang MY	2020	Focused Attention	ERP (tactile distraction, working memory task)	Expert vs Control
FA7	Alterations of regional cerebral glucose metabolism using(18)F-fluorodeoxyglucose positron-emission tomography/computed tomography and electroencephalography analysis during mindfulness breathing in Anapanasati meditation: A preliminary analysis	Chotipanich C	2020	Focused Attention	Spectral Analysis (+glucose metabolism PET)	Expert
FA8	Closed-Loop Frontal Midlineθ Neurofeedback: A Novel Approach for Training Focused-Attention Meditation	Brandmeyer T	2020	Focused Attention	Spectral Analysis (FMtheta neurofeedback)	Novice (neurofeedbac k app)
FA9	EEG alpha-theta dynamics during mind wandering in the context of breath focus meditation: An experience sampling approach with novice meditation practitioners	Rodriguez-Larios J	2021	Focused Attention	Spectral Analysis, Synchrony	Novice (single session)
FA10	Comparison between human awake, meditation and drowsiness EEG activities based on directed transfer function and MVDR coherence methods	Dissanayaka C	2015	Focused Attention	Synchrony	Expert (vs baseline just prior)
OM1	Mindfulness meditators show altered distributions of early and late neural activity markers of attention in a response inhibition task	Bailey NW	2019	Mindfulness	ERP (Response Inhibition)	Expert vs Novice
OM2	Zazen meditation and no-task resting EEG compared with LORETA intracortical source localization	Faber PL	2015	Open Monitoring	Spectral Analysis (Source Analysis)	Expert (vs baseline)
OM3	Quantitative change of EEG and respiration signals during mindfulness meditation	Ahani A	2014	Mindfulness	Spectral Analysis	Novice (6 week training; older, stressed
OM4	Studying the default mode and its mindfulness-induced changes using EEG functional connectivity	Berkovich-Ohana A	2014	Mindfulness	Synchrony	Experts vs task control
OM5	Frontal Theta Dynamics during Response Conflict in Long-Term Mindfulness Meditators	Jo HG	2017	Mindfulness	ERP (conflict response)	Expert vs Novice
OM6	Effects of a brief mindfulness-meditation intervention on neural measures of response inhibition in cigarette smokers	Andreu CI	2018	Mindfulness	ERP (response inhibition)	Novice
OM7	Source-space EEG neurofeedback links subjective experience with brain activity during effortless awareness meditation	van Lutterveld R	2017	Mindfulness	Spectral Analysis Neurofeedback (PCC gamma)	Experts and Novices
OM8	Effortless Attention as a Biomarker for Experienced Mindfulness Practitioners	Tanaka GK	2015	Mindfulness	Spectral Analysis	Expert vs Novice
OM9	Acute effects of meditation training on the waking and sleeping brain: Is it all about homeostasis?	Dentico D	2018	Mindfulness	Spectral Analysis	Expert vs Novice (vs Baseline)
OM10	Brain activity during meditation in first-time meditators	Śliwowski M	2023	Mindfulness	Spectral Analysis	Novice (1st time meditators)
OM11	Asymmetric activation of the anterior cerebral cortex in recipients of IRECA: preliminary evidence for the energetic effects of an intention-based biofield treatment modality on human neurophysiology	Pike C	2014	Mindfulness	Spectral Analysis (Asymmetry)	Novice

OM12	What it means to be Zen: marked modulations of local and interareal synchronization during open monitoring meditation	Hauswald A	2015	Mindfulness	Spectral Analysis, Graph Network	Expert vs baseline
OM13	Open monitoring meditation alters the EEG gamma coherence in experts meditators: The expert practice exhibit greater right intra-hemispheric functional coupling	Ken Tanaka G	2022	Mindfulness	Synchrony	Expert vs Novice
OM14	Meditation is associated with increased brain network integration	van Lutterveld R	2017	Mindfulness	Synchrony (Network Analysis)	Experts vs Novices
OM15	Mindfulness Meditation Is Related to Long-Lasting Changes in Hippocampal Functional Topology during Resting State: A Magnetoencephalography Study	Lardone A	2018	Mindfulness	Synchrony (Network Analysis)	Expert vs Novice
OM16	Lower trait frontal theta activity in mindfulness meditators	Tanaka GK	2014	Open Monitoring	Spectral Analysis	Expert vs Novice
BI1	Shifting Baselines: Longitudinal Reductions in EEG Beta Band Power Characterize Resting Brain Activity with Intensive Meditation	Skwara AC	2022	Both (Buddhist FA/OM)	Spectral Analysis (Trait Effect)	Already experienced, but then trained in mixed FA/OM Buddhist practice over 3 months
BI2	Mindful Aging: The Effects of Regular Brief Mindfulness Practice on Electrophysiological Markers of Cognitive and Affective Processing in Older Adults	Malinowski P	2017	Both (M-BAT)	ERP (emotional response, conflict response)	Novice
BI3	Short-term mindful breath awareness training improves inhibitory control and response monitoring	Pozuelos JP	2019	Both (M-BAT)	ERP (response Inhibition)	Novice (3 week training)
BI4	Frontolimbic alpha activity tracks intentional rest BCI control improvement through mindfulness meditation	Jiang H	2021	Both (M-BAT)	Spectral Analysis	Novice (trained, unclear details)
BI5	The effects of an internet-based mindfulness meditation intervention on electrophysiological markers of attention	Klee D	2020	Both (MBSR)	ERP (auditory oddball)	Novice
BI6	Respond, don't react: The influence of mindfulness training on performance monitoring in older adults	Smart CM	2017	Both (MBSR)	ERP (conflict response)	Novice
BI7	Combining Behavior and EEG to Study the Effects of Mindfulness Meditation on Episodic Memory	Nyhus E	2020	Both (MBSR)	Spectral Analysis	Novice (4 weeks MBSR)
BI8	Electrophysiological effects of mindfulness meditation in a concentration test	Morais P	2021	Both (MBSR)	Spectral Analysis	Novice (8 week training, longitudinal measures)
BI9	Mindfulness Improves Brain-Computer Interface Performance by Increasing Control Over Neural Activity in the Alpha Band	Stieger JR	2021	Both (MBSR)	Spectral Analysis	Novice
BI10	Interoception Underlies Therapeutic Effects of Mindfulness Meditation for Posttraumatic Stress Disorder: A Randomized Clinical Trial	Kang SS	2022	Both (MBSR)	Spectral Analysis	Novice
BI11	Change in Brain Oscillations as a Mechanism of Mindfulness-Meditation, Cognitive Therapy, and Mindfulness-Based Cognitive Therapy for Chronic Low Back Pain	Day MA	2021	Both (MBSR)	Spectral Analysis	Novice
BI12	Intermediate effects of mindfulness practice on the brain activity of college students: An EEG study	Do H	2023	Both (MBSR)	Spectral Analysis Complexity Synchrony	Novice (vs. active control)
BI13	Increases in Theta Oscillatory Activity During Episodic Memory Retrieval Following Mindfulness Meditation Training	Nyhus E	2019	Both (MBSR)	Spectral Analysis (Memory Task)	Novice (4 week training)
BI14	Entrainment of chaotic activities in brain and heart during MBSR mindfulness training	Gao J	2016	Both (MBSR)	Spectral Analysis (wavelets)	Novice (MBSR trained 8 weeks)
BI15	Phase synchrony in slow cortical potentials is decreased in both expert and trained novice meditators	Jo HG	2019	Both (MBSR)	Synchrony	Expert vs Novice
BI16	Increased neurocardiological interplay after mindfulness meditation: a brain oscillation-based approach	Gao J	2023	Both (MBSR)	Synchrony (with ECG)	Novice (8 week MBSR)
BI17	Spectral power and functional connectivity changes during mindfulness meditation with eyes open: A magnetoencephalography (MEG) study in long-term meditators	Wong WP	2015	Both (Mixed background)	Spectral Analysis, Synchrony (MEG)	Expert vs Novice

Supplementary Table 2. Included studies code IDs and study design details are shown [4,6,7-9,14-57].

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