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- We conducted a systematic review of EEG studies of mindfulness meditation
- We examined power differentials between mindfulness and a control state
- Mindfulness was associated with enhanced alpha and theta power
- No consistent patterns were observed in terms of beta, delta and gamma
- Elevated alpha and theta may signify a state of relaxed alertness

Title

A systematic review of the neurophysiology of mindfulness on EEG oscillations

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Abstract:

Mindfulness meditation has been purported as a beneficial practice for wellbeing. It would be expected that the neurophysiology of mindfulness would reflect this impact on wellbeing. However, investigations of the effect of mindfulness have generated mixed reports of increases, decreases, as well as no differences in EEG oscillations in comparison with a resting state and a variety of tasks. We have performed systematic review of EEG studies of mindfulness meditation in order to determine any common effects and to identify factors which may impact on the effects. Databases were reviewed from 1966 to August 2015. Eligibility criteria included empirical quantitative analyses of mindfulness meditation practice and EEG measurements acquired in relation to practice. A total of 56 papers met the eligibility criteria and were included in the systematic review, consisting of a total 1,715 subjects: 1,358 healthy individuals and 357 individuals with psychiatric diagnoses. Studies were principally examined for power outcomes in each bandwidth, in particular the power differentials between mindfulness and the control state, as well as outcomes relating to hemispheric asymmetry and event-related potentials. The systematic review revealed that mindfulness was most commonly associated with enhanced alpha and theta power as compared to an eyes closed resting state, although such outcomes were not uniformly reported. No consistent patterns were observed with respect to beta, delta and gamma bandwidths. In summary, mindfulness is associated with increased alpha and theta power in both healthy individuals and in patient groups. This co-presence of elevated alpha and theta may signify a state of relaxed alertness which is conducive to mental health.

Keywords: mindfulness; meditation; neurophysiology; EEG; systematic review.

Introduction

Meditation refers to a diverse range of mental activities which share a common focus on the regulation of attention and awareness (Cahn and Polich, 2006) in order to improve voluntary control of mental processes which is purported to foster general wellbeing (Walsh and Shapiro, 2006). Most world cultures have developed their own forms of meditation; for example, Christianity has a long tradition of contemplative prayer (Egan, 1978). Much of the recent scientific interest in meditation has centred on mindfulness meditation, which is a practice that is believed to have originated with Buddhism around the fifth millennium B.C. although its roots may stretch back further to the third millennium B.C. in Hindu culture (Cousins, 1996).

The most common forms of meditation may be conceptualized as involving either focused attention or an open-monitoring form of processes (Lutz et al., 2008). Focused attention practices may be operationalized into their respective attention networks (Posner and Petersen, 1990; Mirsky et al., 1991): sustained attention (e.g. towards a target, such as the breath), executive attention (e.g. preventing one's focus from 'wandering'), attention switching (e.g. disengaging from distractions), selective attention and attention re-orienting (e.g. redirecting focus back to the breath), and working memory (Lutz et al., 2008; Vago and Silbersweig, 2012). Open-monitoring refers to a broader receptive awareness or capacity to detect events within an unrestricted awareness without a specific focus (Raffone and Srinivasan, 2010), which can include a process of 'meta-awareness' (i.e., awareness of awareness, in which practitioners are able to reflect on the process of consciousness itself).

Mindfulness has been described as the awareness that arises through purposeful attention on the present moment with nonjudgmental experience (Kabat-Zinn, 2003). While mindfulness has been commonly viewed as an example of open-monitoring, it has been proposed to involve an admixture of focused attention and open-monitoring (Lutz et al., 2008; Vago and Silbersweig, 2012) as most mindfulness practices begin with a period of focused attention on a target, such as the breath, in order to focus awareness, followed by the more receptive state of open-monitoring (Cahn and Polich, 2006). In Vago and Silbersweig'smodel (2012), the practice of mindfulness leads to three overarching self-related capacities: meta self-awareness, self-regulation, and self-transcendence**.** These are subserved by numerous subcomponent cognitive components, including motivation (which is crucial in terms of people practicing meditation in the first place), attention regulation (via the development of attention modalities), and de-centring (an ability, defined below, that arises from enhanced attention regulation, and which facilitates self-awareness and transcendence). It is further proposed that these three overarching capacities modulate 'self-specifying and narrative self-networks' through an integrative fronto-parietal control network.

Mindfulness has been applied as a clinical intervention based on the notion that it is a method for training attention and awareness. By developing the ability to observe one's thoughts and feelings, practitioners learn how to perceive them as temporary, objective events in the mind as opposed to reflections of the self that are necessarily true, which has been termed as the ability to "decentre" (Fresco et al., 2007). As a clinical intervention, it involves the process to engage with negative experiences, such as pain or dysphoric emotions, with more dispassion and less reactivity (Shapiro et al., 2005). Mindfulness was initially applied as an intervention for chronic pain with Kabat-Zinn's (1982) Mindfulness-Based Stress Reduction (MBSR) program. The MBSR program has since been applied in the treatment for number of conditions, including cancer (Ledesma & Kumano, 2009) and migraine (Schmidt et al., 2010), and adapted as a treatment to prevent relapse in depression (Mindfulness-Based Cognitive Therapy; Segal et al., 2002) and for the treatment of substance abuse (Mindfulness-Based Relapse Prevention; Bowen et al., 2014, Mindfulness-Oriented Recovery Enhancement; Garland et al., 2014).

The effectiveness of mindfulness has been assessed by measures for depression and quality of life (Hofmann et al., 2010). As mindfulness may be considered to be a method of attention training and emotion regulation, we would expect that the corresponding neurophysiological states should be observable. Electroencephalography (EEG) is a non-invasive technique that analyzes spatiotemporal aspects of underlying brain activity, which provides a measure of the large-scale synchronization of neural networks (Cacioppo et al., 2007). Patterns of EEG activity to particular meditative states have been investigated. A commonly reported feature of meditation has been theta and alpha event-related synchronization (Fell et al., 2010), which are regarded as markers of internally-directed attention processing (Shaw, 1996). Such synchronization has been observed across different meditation practices, including mindfulness, as well as practices such as transcendental meditation, which involves focused attention upon an internally-voiced mantra. However, different types of meditation practice have been associated with unique frequency patterns, reflecting the form of attention (Dunn et al., 1999). For example, mindfulness has been associated with increase alpha power while focused attention has been associated with increased gamma activity and idiosyncratic meditation with decreased alpha and beta (Hinterberger et al., 2014).

Additionally, Event-Related Potentials (ERP) provide a measure of large number of time-locked experimental trials, enabling the analysis of sensory, perceptual, and cognitive processing (Light et al., 2010). Such studies involve the precision analysis of populations of neuronal transients directly manifested via a stimulus/event, which is frequently a stimulus connected to an attention-based task (e.g., listening to an auditory signal) (Schoenberg and Speckens, 2014). The high temporal resolution of this approach, involving millisecond precision, allows the investigation of early information processing stages and subsequent transitions to higher-level cognitive operations. ERP studies have been used to corroborate the idea of mindfulness as a system of attention training. For example, van Leeuwen et al. (2012) examined the impact of mindfulness practice on hierarchical stimulus processing and attentional selection, focusing on differences in early components of the evoked visual response (e.g., P1 and N1 components) in meditators versus matched controls. Meditators exhibited faster attentional disengagement from a dominant global presentation in order to focus in on specific stimuli, suggesting that meditation enhances speed of attention allocation and relocation, thus increasing the depth of information processing.

In the present review, we have focused on mindfulness meditation. We have examined factors which appear to impact upon EEG measures including the experience of the meditator, being a novice or relative expert, as experience has been reported to accentuate amplitude differences between meditation and the resting state (Hinterberger et al., 2014) while the converse has also been observed (Cahn et al., 2010). An additional factor includes the location of the brain activity. For example, increased alpha during mindfulness has been localized to frontal regions (Takahashi et al., 2005) but has also been observed increases in posterior regions (Lagopoulos et al., 2009; Cahn et al., 2010). Furthermore, EEG analysis of meditation may be affected by whether the control task is a resting state or a cognitive task as increased theta amplitude during meditation has been observed in comparison to a resting state baseline, but was comparable in amplitude to an executive attention task, which may be further modulated by the experience of the meditator (Lomas et al., 2014).

We sought to perform a systematic review of patterns of electrophysiological activity associated mindfulness in order to examine the impact on neurophysiology as assessed by EEG bandwidth activation and other measures, including hemispheric asymmetry or event-related potential, and the functional significance of these activities. If mindfulness is expected to impact on functioning attentional networks as well as open-monitoring, then we would expect to observe distinct neural features associated with its practice. We also expected that the experience of the meditator, type of control task, and location of the EEG oscillation would moderate the impact of mindfulness on neurophysiology.

Methods

The literature search was conducted using the MEDLINE and Scopus electronic databases with the criteria: "EEG" (AND) "mindfulness OR meditation", in all fields in MEDLINE and limited to article title, abstract, and keywords in Scopus, with the dates: from 1966 to 1st August 2015. The participants, interventions, comparisons, outcomes and study design (PICOS) characteristics, the key criteria were interventions: mindfulness meditation or functional equivalent; participants: adults; and outcomes: EEG analysis. Studies were required to be published, or a manuscript in press, and to be in English. The review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009). The review protocol was registered with the International Prospective Register of Systematic Reviews (PROSPERO) database on 15th September 2014. Registration number: CRD42014013766 (http://www.crd.york.ac.uk/PROSPERO).

Inclusion criteria were: 1) mindfulness meditation practice or functional equivalent, such as Vipassana or Zen meditation; 2) EEG measurements acquired in relation to mindfulness meditation practice (whether assessment during the practice itself or connected to its practice, e.g., pre- and post-intervention); 3) quantitative analysis supported by appropriate statistical methodology; and exclusion criteria; and 4) adult sample; and exclusion criteria: 1) theoretical articles or commentaries without statistical analyses.

The following variables were extracted from each paper: experimental protocol (control condition, meditation condition, and/or experimental task), experience of participants (novice or expert), sample features (clinical or non-clinical), outcomes for each individual bandwidth (alpha, beta, theta, delta, and gamma), hemispheric asymmetry, and any event-related potential outcomes.

The primary summary measures were differences in levels of power in each of the bandwidths. Neural activity generates electrical potentials which can be analyzed in terms of parameters of amplitude, frequency, coherence and synchrony. Amplitude, or power, which is the square of the amplitude, reflects the magnitude of the electrical signal, representing the level of synchronized activity in the underlying tissue, i.e. neurons discharging simultaneously. Frequency is the number of oscillatory cycles per second and is divided into the following bandwidths: Delta (1-4 Hz); Theta (4-8 Hz); Alpha (8-13 Hz); Beta (13–30 Hz); and Gamma (36-44 Hz) (Cacioppo et al., 2007). EEG connectivity is the functional integration of spatially distributed neural populations which can be assessed in terms of synchrony, the degree of leading or lagging in the relationship between signals from electrode pairs, and coherence, the stability of that phase relationship.

The primary summary variable was principally the difference in power between a meditation condition and a resting state condition. Secondary power differentials included longitudinal pre- and post- differences, such as, in meditation and/or resting state and/or task conditions before and after an intervention. If applicable, outcomes relating to coherence, synchrony, asymmetry and event-related potentials were also noted.

Of note, there was considerable diversity in how the experience of the participant was defined. In terms of years meditating, the range for which papers rated participants as being 'experienced' varied from 1 year (Kasamatsu and Hirai, 1966) to 9 years (Lagopoulos et al., 2009). Likewise, in terms of hours meditating, the range for which papers rated participants as being 'experienced' varied from 40 hours (Hinterberger et al., 2011) to 1740 hours (Berkovich-Ohana et al., 2012). In the present systematic review, we have applied the lowest of these cutoffs, such that an 'experienced' (i.e., non-novice) meditator was considered to have been meditating for longer than 1 year or have completed more than 40 hours of meditation.

The Quality Assessment Tool for Quantitative Studies (QATQS; National Collaborating Centre for Methods and Tools, 2008) was used to assess the quality of the studies. QATQS assesses methodological rigor in six areas: (a) selection bias; (b) design; (c) confounders; (d) blinding; (e) data collection method; and (f) withdrawals and drop-outs. Each area is assessed on a quality score of 1 to 3 (1 = strong; 2 = moderate; 3 = weak). Scores for each area were collated, and a global score was assigned to each study. If there are no weak ratings, the study is given a score of 1 (judged as strong); one weak rating leads to a score of 2 (moderate); and two or more weak ratings generates a score of 3 (weak) (Supplementary Materials). QATQS scoring was conducted (II) and checked independently (TL). Any discrepancies were resolved by discussion with agreement reached in all cases.

The first authors of each paper were contacted for additional information as needed (Amihai and Kozhevnikov, 2014; Arita, 2012; Cahn et al., 2010; Cahn et al., 2013; Hinterberger et al., 2011; Hinterberger et al., Walach, 2014; Howells et al., 2012; Huang and Lo, 2009; Lagopoulos et al., 2009; Lehmann et al., 2012; Lo et al., 2003; Milz et al., 2014; Murata et al., 2004; Saggar et al., 2012; Stinson and Arthur, 2013; Tang et al., 2009; Xue et al., 2014). Data were extracted (TL) and reviewed (II) with guidance and review (CF).

Results

Search results

Following removal of duplicate citations, 284 potentially relevant papers were identified (302 articles from Scopus, 291 articles from MEDLINE, and 12 from the reference lists of articles). From the abstract review, 120 papers were excluded. From the full text reviews of 164 papers, 108 papers were excluded. Thus, a total of 56 papers were included in the systematic analysis. Ten of these papers were identified as reporting on overlapping samples: (Berkovich-Ohana et al., 2012; Berkovich-Ohana et al., 2013); (Cahn et al., 2010; Cahn et al., 2013); (Slagter et al., 2007; Slagter et al., 2009); (Hinterberger et al., 2011; Hinterberger et al., 2014); (Schoenberg and Speckens, 2014; Schoenberg and Speckens, 2015). As such, the 56 papers included in the systematic analysis represented results from 51 independent participant samples (n = 1,715 subjects; age range = 19-72 years) (Figure 1). 46 papers focused on healthy participants, representing results from 42 independent samples (*n* = 1,358 subjects; age range = 18-72 years)(Table 1), and 10 papers included participants with a psychiatric disorder, representing results from 9 independent samples (*n* = 357 subjects; age range = 22-64 years): 3 studies on depressed patients in remission (*n* = 157), 1 study of patients with suicidal depression (*n* = 22),1 study involving patients diagnosed with major depressive disorder, reported across 2 papers (Schoenberg and Speckens, 2014, 2015) (*n* = 51), 1 study of patients with bipolar disorder (*n* = 21), 1 study of patients with chronic pain (*n* = 27), 1 study of patients with chronic pain with risk of opioid abuse (*n* = 29), and 1 study of patients with attention-deficit/hyperactivity disorder (ADHD) (*n* = 50) (Table 2).

The findings fall into two main types: (a) studies examining the effects of mindfulness in comparison with a resting state; and (b) studies examining longitudinal changes in EEG patterns relating to practicing mindfulness (Table 3, Supplementary Tables 3-9).

Effects of mindfulness on neurophysiology

Twenty-one studies examined the alpha bandwidth, reporting greater amplitude during mindfulness in comparison with an eyes-closed resting state (*n* = 12), lower amplitude (*n* = 1), and no significant differences (*n* = 3) (Table 3). Most of the studies involved experienced meditators; novice participants were involved in4 of the reports of greater amplitude and 1 of the reports of no significant differences. Coherence was examined in 2 papers, with mixed results, and more complex analyses in another 2 papers.

The beta bandwidth was examined in 12 studies which compared mindfulness with a resting state, reporting greater amplitude during mindfulness (*n* = 3; including *n* = 1 with novice meditators), lower amplitude (*n* = 1), and no significant differences (*n* = 5, including *n* = 2 novices). Coherence (*n* = 1, with no difference found), asynchrony (*n* = 1, finding higher synchrony with meditation) and more complex analyses (*n* = 1) were also examined.

The theta bandwidth was examined in 19 studies, reporting greater amplitude during mindfulness (*n* = 11; including *n* = 3 with novices), lower amplitude (*n* = 3; including *n* = 2 with novices), and no significant differences (*n* = 2; *n* = 1 with novices). Coherence (*n* = 2, with no difference found), and more complex analyses (*n* = 1) were also examined.

The delta bandwidth was examined in 5 studies, reporting greater amplitude during mindfulness (*n* = 1, with novices, limited to frontal regions) as well as no significant differences (*n* =3; *n* = 1 with novices). More complex analyses (*n* = 1) were also examined.

The gamma bandwidth was examined in 7 studies, reporting greater amplitude during mindfulness (*n* = 3) and no significant differences (*n* = 2; *n* = 1 with novices). Gamma amplitude during mindfulness also correlated with train mindfulness and years of practice (*n* = 1). Coherence (*n* = 1, with no difference found) and asymmetry (*n* = 3, finding greater left-sided activation (*n* = 2) and no differences (*n* = 1)) were also examined.

Event-related potentials were examined in 15 studies, with mindfulness found to have an impact on attention processing measures including P300 (*n* = 5; *n* = 2 on P3b specifically), Late Positive Potential (*n* = 2), Feedback Related Negativity (*n* = 1), Error Related Negativity (*n* = 1), Readiness Potential (*n* = 1), pain-evoked ERPs (*n* = 2), Late Contingent Negative Variation (*n* = 1), and a Go/NoGo task (*n* = 2).

Longitudinal neurophysiological changes associated with mindfulness practice

In healthy individuals, learning mindfulness was associated with decreased alpha amplitude (*n* = 2 studies), increased (*n* = 1) as well as decreased (*n* = 1) theta amplitude, and changes in asymmetry with an increase relative left-sided activation (*n* = 1).

In participants with chronic pain, a course of mindfulness was associated with a decrease in beta amplitude (*n* = 1). In patients with depression and suicidal ideation, a relative increase in left-sided activation following mindfulness training was observed, while the inverse pattern with a relative decrease in left-sided activation was reported in patients in remission from depression.

Discussion

The main finding to emerge from the systematic review is an increase in alpha power associated with mindfulness relative to a resting state. Additional effects have been reported in the oscillation bandwidths, including a majority trend towards increased theta power during meditation compared to resting state. The patterns of increased alpha and theta amplitude associated with meditation were observed in both experienced and novice meditators. Clinical studies of mindfulness-based interventions revealed a shift towards greater relative left-sided activation which may be associated with increased positive affect. However, these findings have been mixed with reports of increases, decreases as well as no differences, particularly in other bandwidths, but also in alpha and theta bandwidths.

Alpha synchronization has been regarded as one of the 'signatures' of meditation as it has been consistently observed across a range of different meditation practices relatively independent of both technique and degree of practice (Fell et al., 2010). In the present review, increased alpha synchronization during meditation as compared to a resting state was reported 65% of papers that analyzed this outcome (12 out of 18), all of which involved healthy participants, including both novice (Lo et al., 2003; Milz et al., 2014; Takahashiet al., 2005; Yu et al., 2011) and experienced meditators (Ahani et al., 2014; Arita, 2012; Cahn et al., 2013; Dunn et al., 1999; Hinterberger et al., 2014; Huang and Lo, 2009; Kasamatsu and Hirai, 1966; Lagopoulos et al., 2009). Most of the studies had examined participants during mindfulness in comparison to a resting state with eyes closed with a few exceptions (ex. Takahashiet al., 2005). However, the findings have not been wholly consistent as a few studies found no differences with mindfulness in novice (Kubota et al., 2001) or experienced (Cahn et al., 2010; Lehmann et al., 2012) participants, as well as decreased alpha power during mindfulness (Amihai and Kozhevnikov, 2014). It is of note that none of the studies involving clinical populations had analyzed or reported findings on alpha power. Comparisons of mindfulness with performance on attention tasks reported no differences in alpha power with eyes closed while attending to auditory clicks (Becker and Shapiro, 1981);

with a time production task (Berkovich-Ohana et al., 2013); and with an eyes-open session watching a video about neurofeedback (Stinson and Arthur, 2013), although Ren et al. (2011) found lower levels of alpha compared to a problem-solving task.

The functional significance of alpha has been much debated. Alpha synchronization has been understood as reflecting the 'de-activation' of cortical areas as a signifier of the brain 'idling' since it occurs during relaxed eyes closed wakefulness (Shaw, 1996; Pfurtscheller et al., 1996). The increase in alpha synchronization with mindfulness as compared to an eyes closed rest may indicate even greater levels of synchronization associated with mindfulness. According to the 'brain idling' hypothesis, the effect suggests that meditation generates greater cortical de-activation than during an eyes closed resting state. However, Shaw (1996) proposes that there is a paradoxical response which distinguishes between 'outer-directed' and 'inner-directed' attention. While 'outer-directed' attention is associated with alpha desynchronisation, 'inner-directed' attention, which is also referred to as 'intention,' is associated with increases in alpha power. In support, tasks requiring memory (Jensen et al., 2002) and imagination (Cooper et al., 2006) lead to increases in alpha power. Mindfulness improves the training and development of various attention networks (sustained, executive, executive, selective, and re-orienting) in terms of its focused-attention aspects and awareness in terms of its open-monitoring aspects (Lutz et al., 2008; Vago and Silbersweig, 2012). As such, it is possible to infer that increased alpha power associated with mindfulness is evidence that alpha synchronization is indeed a signifier of increased processing in these various attention modalities (e.g., as per Vago and Silbersweig's (2012) model) with respect to internally generated stimuli.

With regards to beta oscillations, of the 12 studies which compared beta activity in meditation with eyes closed rest in healthy individuals, only 3 studies reported that beta amplitude was higher in meditation, involving experienced meditators (Ahani et al., 2014; Cahn et al., 2013) and novices (Dunn et al., 1999). Five studies found no significant differences in experienced practitioners (Cahn et al., 2010; Lagopoulos et al., 2009;

Lehmann et al., 2012) and in novices (Milz et al., 2014; Yu et al., 2011), while one study observed lower beta amplitude in meditation in experienced practitioners (Amihai and Kozhevnikov, 2014), and 5 studies found no significant differences (Cahn et al., 2010; Lagopoulos et al., 2009; Lehmann et al., 2012; Milz et al., 2014; Yu et al., 2011). A comparison of mindfulness with task performance, an eyes open session watching a video about neurofeedback, reported lower amplitude in meditation relative to the task (Stinson and Arthur, 2013). Only one paper reported on beta power in clinical populations, observing pre-post longitudinal decreases in beta power during the resting state which was linked to the practice of mindfulness (Howells et al., 2012).

Interpretations of the significance of beta are mixed because it has been proposed to reflect a reduction in cortical activity as it is associated with barbiturates and benzodiazepines use (Herning et al., 1994), but beta activity has also been attenuated with increasing cognitive task demands (Ray and Cole, 1985) while around 20% of patients with deficit hyperactivity disorder exhibit ‘excessive’ beta activity, which is associated with elevated behavioural problems (Clarke et al., 2001).

Increased theta power has been considered to be another key feature of meditation (Josipovic, 2010; Fell et al., 2010). This pattern was to some extent borne out in the present review and was observed in both novice and experienced meditators, although there did appear to be a slight weighting towards this effect being more prevalent in experienced practitioners. Of the 19 studies that that compared theta activity in meditation with eyes closed rest, a majority (*n* = 11) reported that theta power was higher in mindfulness, including 8 with experienced practitioners (Ahani et al., 2014; Arita, 2012; Cahn et al., 2010; Chan et al., 2008; Kasamatsu and Hirai, 1966; Lagopoulos et al., 2009; Lomas et al., 2014), but only 2 with novices (Kubota et al., 2001; Takahashiet al., 2005), plus also Tanaka et al. (2014), who found this effect with both novice and experienced practitioners. Against this, 3 studies reported that theta was lower during mindfulness compared to eyes-closed rest, 2 of which involved novices (Dunn et al., 1999; Yu et al., 2011) and 1 involving experienced practitioners (Huang and Lo, 2009). Moreover, 2 studies found no significant differences in experienced (Amihai and Kozhevnikov, 2014) and novice practitioners (Milz et al., 2014). An additional 2 longitudinal studies also observed pre-post decreases in theta power during the resting state which was linked to the practice of mindfulness (Saggar et al., 2012; Tang et al., 2009). Only one paper reported on theta power in clinical populations, observing pre-post longitudinal increases in theta power (during the resting state) linked to the practice of mindfulness (Howells et al., 2012).

The presence of theta along with alpha synchronization during mindfulness lends support to the hypothesis that increased alpha power during signifies internalized attention rather than the brain 'idling' because theta synchronization is widely viewed as a marker of executive functioning. Theta activity has been linked to various types of cognitive activity, including switching and orienting attention (Dietl et al., 1999), processing of new information (Grunwald et al., 1999), and memory in episodic encoding and retrieval (Klimesch et al., 1997), and theta power increases as task demands increase (Klimesch et al., 1997). Taken together, the finding suggests that mindfulness constitutes a state of enhanced internally-directed attention. Theta oscillations during wakefulness generally occur maximally in the frontal-midline regions of the brain, particularly in the prefrontal cortex (Asada et al., 1999) and may be localized to the anterior cingulate cortex (Onton et al., 2005), in contrast to theta activity during REM sleep, which is generated mainly by the hippocampus (Cantero et al., 2003). These regions are centrally involved in the executive control of attention, as well as other higher-level cognitive activities such as volition and planning (Posner and Dehaene, 1994; Miller and Cohen, 2001), and have been proposed as central to the development of attention and awareness in meditation (Newberg and Iversen, 2003).

This interpretation is strengthened by the differences observed between experienced and novice practitioners, in which the former were more reliably found across the studies to exhibit higher levels of theta activation during meditation in comparison to a resting state, suggesting that enhanced theta activation during meditation is to some extent a function of training and practice in meditation by learning to maintain an inner-directed attention. Furthermore, it has been suggested that the co-presence of theta and alpha in mindfulness indicates a state of 'relaxed alertness' (Britton et al., 2014), which is corroborated by qualitative self-reports of their experiences in mindfulness (Cahn and Polich, 2006).

Fewer studies have reported delta and gamma activity with mixed findings and have all been limited to healthy individuals. Slow wave delta band activity is more commonly associated with sleep, particularly during deep non-REM stages (Hofle et al., 1997). It has been suggested though that an increase in delta activity during wakefulness reflects attention to internal processing during the performance of cognitive tasks, such as difficult arithmetical calculation tasks (Harmony et al., 1996). The reports of delta activity have generally found no differences (Lagopoulos et al., 2009; Amihai and Kozhevnikov, 2014; Milz et al., 2014), although reduced (Dunn et al., 1999) as well as increased amplitudes, which were localized to frontal regions (Cahn et al., 2010), have been described in comparison to an eyes closed resting state in novice (Dunn et al., 1999; Milz et al., 2014) and experienced (Lagopoulos et al., 2009; Cahn et al., 2010; Amihai and Kozhevnikov, 2014) meditators. Stinson and Arthur (2013) also found lower amplitude during meditation compared a control task of watching a neurofeedback video.

Gamma synchronization is purported to reflect activity in the default mode network (Berkovich-Ohana et al., 2012) which refers to the self-referential and reflective thoughts that occur in the absence of requirements to respond to external stimuli (Buckner, Andrews-Hanna, and Schacter, 2008). With mindfulness, gamma power has been reported as increased (Berkovich-Ohana et al., 2012; Cahn et al., 2010; Lehmann et al., 2012) as well as showing no differences (Amihai and Kozhevnikov, 2014; Milz et al., 2014) in comparison with an eyes closed resting state. Of interest, increased gamma activity was observed in experienced meditators (Berkovich-Ohana et al., 2012; Cahn et al., 2010; Lehmann et al., 2012), although no differences were also found in both experienced (Amihai and Kozhevnikov, 2014) and novice (Milz et al., 2014) meditators. In comparison with a control task, lower amplitude was reported during mindfulness as compared to a neurofeedback video task (Stinson and Arthur, 2013). In addition, studying experienced Zen meditators, Hauswald et al. (2015) found that gamma power during meditation correlated both with levels of trait mindfulness and years of meditation practice. Ferrarelli et al. (2013) also reported a correlation between meditation experience and gamma power during non-REM sleep, but Berkovich-Ohana et al. (2012) found no difference in coherence between meditation and rest. Gamma oscillations have also been implicated in theories of consciousness, in which the fast rhythmic synchronization of neural discharges provide the necessary spatial and temporal links to bind processing across different brain areas, thereby integrating disparate experiential qualia into a coherent state of moment-to-moment awareness (Singer, 1993; Tallon-Baudry and Bertrand, 1999). Increased gamma power during mindfulness thus might indicate a more unified and coherent mental state.

In addition to analysis of specific bandwidths, patterns of asymmetric brain activation have been examined in which left prefrontal activity has been associated with positive affect and 'approach-related' behavior, and right prefrontal activity with negative affect and 'withdrawal-related' behavior (Davidson, 1992). If mindfulness is associated with enhanced subjective wellbeing, then its practice should be linked to greater left prefrontal activity. Such an asymmetry has been observed during mindfulness in experienced meditators relative to an eyes closed resting state (Amihai and Kozhevnikov, 2014; Chan et al., 2008). Following mindfulness training, similar changes have been reported in novice participants who were healthy volunteers (Davidson et al., 2003) as well as with a history of suicidal ideation (Barnhofer et al., 2007). In novice participants with a history of depression, there have been reports of no differences (Milz et al., 2014), increased (Barnhofer et al., 2010) and decreased (Keune et al., 2011) left-sided activation.

Using event-related potentials, reduced P3b in response to distractor stimuli (Slagter et al., 2007) and faster attentional disengagement from a dominant global presentation in order to focus in on specific stimuli (van Leeuwen et al., 2012) was observed in experienced meditators. Likewise, Delgado et al. (2013) found that experienced Vipassana meditators demonstrated larger P3b amplitudes to a *target* tone after meditation than before meditation, findings, which are interpreted as reflecting increased attentional engagement following meditation, given that P3b is interpreted as reflecting allocation of attentional resources to incoming stimulation to facilitate information processing, thus corroborating the notion of mindfulness as a system of attention training. Moreover, anticipatory and pain-evoked ERPs to acute pain were reduced in participants who received mindfulness training but not in controls (Brown and Jones, 2013). Sobolewski et al. (2011) explored the impact of meditation practice on late positive potential (LPP), the amplitude of which tends to be greater in ERPs evoked by emotionally arousing images, particularly ones that are negatively valenced. While control participants with no meditation experience showed an increase in LPP amplitude in response to negative stimuli, no such increases were observed in meditators, suggesting that the latter were less affected by negative emotional load than control participants; in contrast, both groups responded equally to positively-valenced stimuli. Teper and Inzlicht (2014) explored participants' neuroaffective reaction to rewarding, aversive and neutral feedback, as gauged by feedback-related negativity (FRN), a brain response that differentiates positive from negative feedback, reporting that trait levels of mindfulness in novice meditators predicted less differentiation of reward from neutral feedback. Lakey et al. (2011) explored the impact of brief mindfulness training on performance of a P300-based brain-compute interface task. Compared to non-meditating control participants, the experimental subjects produced significantly larger P300 amplitudes and were also more accurate at the task which was understood as suggesting that the experimental participants were better able to harness present-moment attentional resources.

Working with patients with ADHD, Schoenberg et al. (2014) explored the impact of Mindfulness-Based Cognitive Therapy (MBCT) on error processing (ERN, Pe), conflict monitoring (NoGo-N2), and inhibitory control (NoGo-P3) in relation to a continuous performance task (CPT-X). Compared to matched controls, MBCT was linked to increased

Pe and NoGo-P3 amplitudes, which coincided with reduced 'hyperactivity/impulsivity' and 'inattention' symptomatology. In a trial involving patients currently diagnosed with major depressive disorder, Schoenberg and Speckens (2014) found that an MBCT intervention had a modulating effect on evoked FM-theta power during a Go/NoGo task: enhanced event-related synchronization (ERS) in the late temporal window was observed pre-to-post for the experimental group, with the reverse pattern found in control participants. It was suggested that these findings were reflective of optimized allocation of attentional resources as a result of the intervention. Moreover, these modulated ERS dynamics were also found to correlate with ameliorated depressive and rumination symptoms in the MBCT group. Studying patients with chronic pain at risk of opioid abuse, Garland et al. (2015) found that a Mindfulness-Oriented Recovery Enhancement intervention was able to enhance natural reward processing. In particular, the intervention was associated with increases in LPP in response to natural reward stimuli relative to neutral stimuli, which also correlated with reduced opioid craving from pre- to post-treatment. Jo et al. (2014) explored the Readiness Potential correlates of the intentional binding effect, and found that early neural activity correlates with the participants' reports of initiating a voluntary action; however, there were no differences between experienced Zen meditators and matched controls in this regard.

A significant limitation of the present systematic review has been the variability of the measures which were acquired and reported such that a meta-analysis was not feasible for any of the measures because there were no more than 3 studies which used the same measure at the same site. The quality was assessed for each of the studies using the Quality Assessment Tool for Quantitative Studies (National Collaborating Centre for Methods and Tools, 2008), revealing considerable variation. Clinical studies were generally of higher quality as they tended to keep track of withdrawal and attrition rates and used standardized meditation protocols. Furthermore, a key issue was limited reporting on participants' prior level of meditation experience. Some studies reported this in terms of years, some in terms of total number of hours, and a few omitted to specify this. Moreover, there was variation in the criteria for which studies rated participants as ‘experienced’; in terms of years, this ranged from 1 year (Kasamatsu and Hirai, 1966) to 9 years (Lagopoulos et al., 2009), while in terms of hours this ranged from 40 hours (Hinterberger et al., 2011) to 1740 hours (Berkovich-Ohana et al., 2012). We applied the lowest of these cutoffs such that an ‘experienced’ (i.e., non-novice) meditator was considered to have been meditating for longer than 1 year or have completed more than 40 hours of meditation. Arguably hours would be a better metric than years since it better reflects a person’s general amount of practice; however, it is recommended that future studies report both hours and years which would provide some indication of the ‘intensity’ of participants’ practice. Another issue was key poor and/or inconsistent reporting on the nature of participants’ meditation practice. Although all the studies included in the review featured mindfulness specifically (or a functional equivalent), even this is a somewhat generic label, with nuances and differences among practices that can be classified as such mindfulness prior level of meditation experience. Many studies had not described in detail the form and type of mindfulness practice engaged in by participants.

In conclusion, the burgeoning literature on EEG investigations of mindfulness is beginning to highlight some consistent trends, most notably with respect to increased amplitude in the alpha and theta bandwidths. The co-presence of elevated alpha and theta waves may reflect a state of ‘relaxed alertness as alpha and theta can both be interpreted as signifiers of increased attention with alpha specifically representing internalized attention and both have also been identified as indexing states of relaxation. Further work will be needed to explore the nuances of brain states associated with mindfulness, particularly with respect to the other bandwidths and measures such as ERP and asymmetry, to elucidate the differences between mindfulness and other meditation practices, and to further explore the impact of factors such as degree of meditation practice.

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Figure Legends

Figure 1. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Flow Diagram

Figure 1.

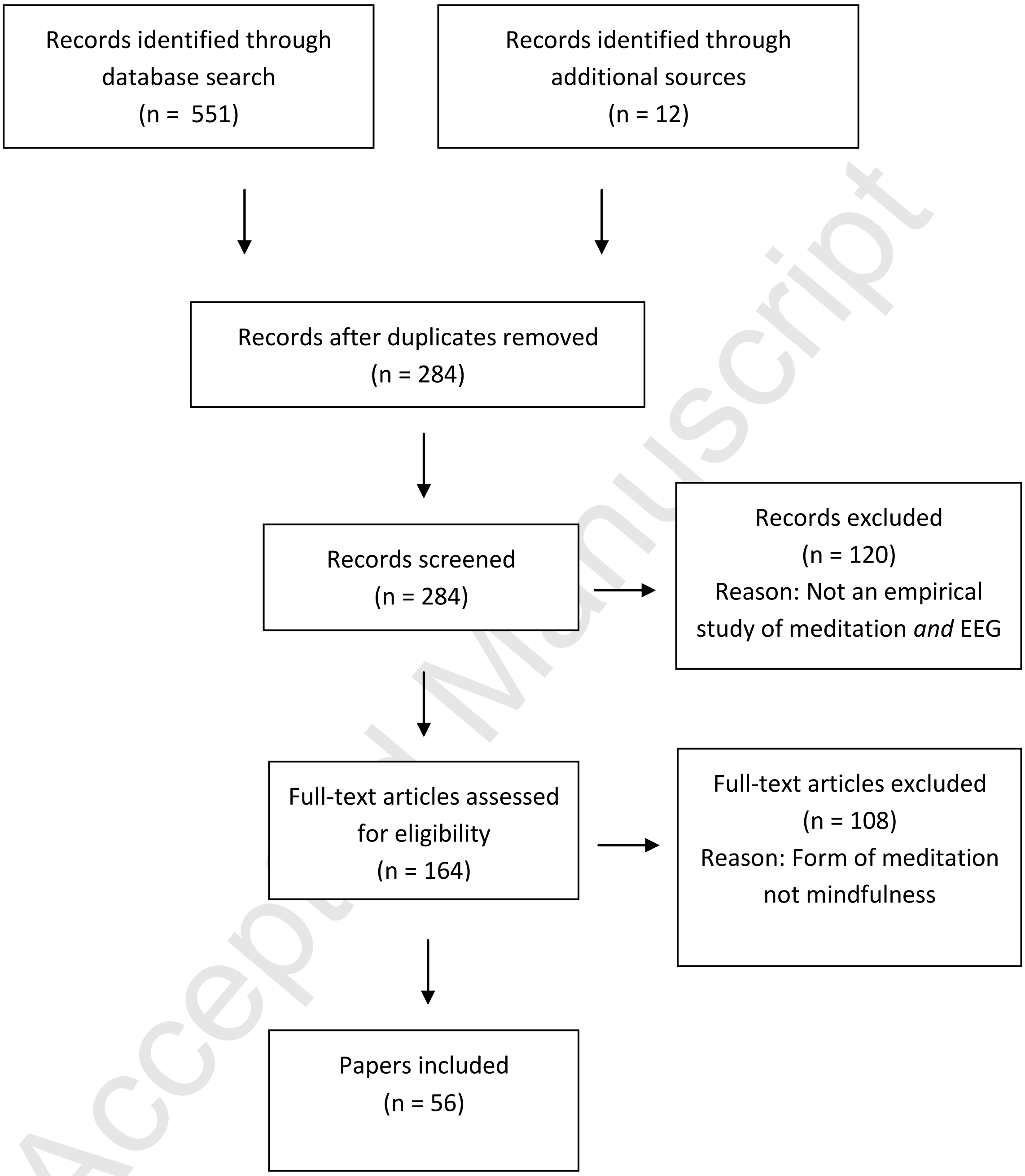
Records identified through database search (n = 551)
Records identified through additional sources (n = 12)
Records after duplicates removed (n = 284)
Records screened (n = 284)
Records excluded (n = 120) Reason: Not an empirical study of meditation *and* EEG
Full-text articles assessed for eligibility (n = 164)
Full-text articles excluded (n = 108) Reason: Form of meditation not mindfulness
Papers included (n = 56)

Table 1.Demographics of healthy participants

First author	Year	Meditators	Meditators (male)	Controls	Mean age meditators	Mean years meditating	Meditation type	Study type
Davidson	2003	25 (from 32)	6	16	36	0	MBCT	Pre-post
Dunn	1999	9 (from 10)	NR	-	NR	0	FA& MM	Pre-post
Kerr	2011	12 (from 16)	1	6	31	0	MBCT	Pre-post
Lomas	2014	30	30	-	42.3	10.1	Various (inc. MM)	Pre-post
Moore	2012	12 (from 19)	NR	16 (from 23)	36.9	0	MM	Pre-post
Saggar	2012	22 (from 30)	12	22 (from 30)	49.5	Experienced (yrs NR)	MM (retreat)	Pre-post
Slagter	2007	17	17	23	NR	Experienced (yrs NR)	Vipassana (retreat)	Pre-post
Slagter	2009	17	17	23	NR	Experienced (yrs NR)	Vipassana (retreat)	Pre-post
Tang	2009	40	NR	40	NR	0	Mind-body training	Pre-post
Xue	2014	45	29	24	22.9	0	Mind-body training	Pre-post
Ahani	2014	34	6	-	61	0 (6 weeks training)	MM	Non pre-post
Amihai	2014	19	16	-	44.4	7.7	Vipassana	Non pre-post
Arita	2012	15	NA	-	NA	NA	Zen	Non pre-post
Becker	1981	30 (10 Zen)	17 (Zen=8)	10	32.7 (Zen=37.8)	6.5 (Zen=7.5)	Zen, TM & Yoga	Non pre-post
Berkovich-Ohana	2012	36	NR	12	41.7	3,673 (hrs)	MM	Non pre-post
Berkovich-Ohana	2013	36	NR	12	41.7	3,673 (hrs)	MM	Non pre-post
Brown	2010	12	6	15	34	NR	Various (inc. MM)	Non pre-post
Cahn	2010	16	11	-	45.5	20	Vipassana	Non pre-post
Cahn	2013	16	11	-	45.5	20	Vipassana	Non pre-post
Chan	2008	19	8	-	19-22 (range)	NR	Triarchic	Non pre-post
Delgado	2013	10	10	0	20-61 (range)	7.5	Vipassana	Non pre-post
Ferrarelli	2013	29	14	29	50.7	15.6	MM	Non pre-post
Hauswald	2015	11	5	-	50	12	Zen	Non pre-post
Hinterberger	2011	49	33	-	45	40-1000 (hrs; range)	Various (inc. MM)	Non pre-post
Hinterberger	2014	49	33	-	45	40-1000 (hrs; range)	Various (inc. MM)	Non pre-post
Huang	2009	23	16	23	31.5	8.4	Zen	Non pre-post
Jo	2014	20	7	19 (from 20)	40.7	3 (minimum)	Zen	Non pre-post
Kasamatsu	1966	48	48	18	24-72 (range)	1-20 (range)	Zen	Non pre-post
Kubota	2001	25	11	-	23.1	0	Zen	Non pre-post
Lakey	2011	18	7	-	18-33 (range)	0	MM	Non pre-post
Lagopoulos	2009	18	13	-	52	9-14 (range)	Acem	Non pre-post
Lehmann	2012	71 (15 Zen)	NR	-	41.4 (Zen=42)	11.3 (Zen=12.3)	Various (inc. Zen)	Non pre-post
Lo	2003	20	NR	10	NR	NR	Zen	Non pre-post
Lo	2013	10	7	10	28	5.8	Zen	Non pre-post
Milz	2014	23	23	2	23.2	0	MM	Non pre-post
Murata	2004	22	22	-	23.3	0	Su-soku	Non pre-post
Pasquini	2015	17	9	14	44.6	2 (minimum)	Zen	Non pre-post
Ren	2011	32	23	16	23.3	0	Su-soku	Non pre-post
Sobolewski	2011	13	7	13	38.7	5 (minimum)	MM	Non pre-post
Stinson	2013	13	NR	-	NR	0	Neurofeedback	Non pre-post
Takahashi	2005	20	20	-	28.6	0	Zen	Non pre-post
Tanaka	2014	10	4	10	49.2	11.6	MM	Non pre-post
Teper	2013	20	9	18	33	3.19	MM	Non pre-post

Teper	2014	45 (from 47)	27	-	19.26	0	Trait mindfulness	Non pre-post
van Leeuwen	2012	8	5	8	29	5	MM	Non pre-post
Yu	2011	15	14	-	38	0	Zen	Non pre-post

Note: MBCT = mindfulness-based cognitive therapy; MM = mindfulness meditation; NCC = neural correlates of consciousness; NR = not recorded; RCT = randomized controlled trial; TM = transcendental meditation; Number of meditators is presented in column headed by Meditators.

Table 2.Demographics of participants with a clinical history

First author	Year	*n* meditators	*n* males meditators	*n* controls	Mean age meditators	Meditation type	Psychiatric Disorder
Barnhofer	2007	10 (from 16)	5	12 (from 18)	48	MBCT	Suicidal depression
Barnhofer	2010	8	1	8	31.6	MM	Previously depressed
Bostanov	2012	32 (from 45)	9	32 (from 46)	50.9	MBCT	Depressed (remission)
Brown	2013	12	NA	15	NA	MM pain manage.	Chronic pain
Garland	2015	11	NA	18	NA	MORE	Chronic pain
Howells	2012	12	2	9	37	MBCT	Bipolar disorder
Keune	2013	40 (from 53)	10	37 (from 50)	48.9	MBCT	Depressed (remission)
Schoenberg (et al.)	2014	26 (from 32)	NA	24 (from 29)	NA	MBCT	ADHD
Schoenberg (& S.)	2014	26	6	25	47.8	MBCT	Depression (current)
Schoenberg (& S.)	2015	26	6	25	47.8	MBCT	Depression (current)

Note: MBCT = mindfulness-based cognitive therapy; MM = mindfulness meditation; MORE = mindfulness-oriented recovery enhancement. All studies featured pre-post designs, and all except Howells were RCTs. All subjects participating had no previous experience with meditation.

Table 3. Results synthesis of papers according to principle findings and according to bandwidth or asymmetry

Outcome	MED > RS	MED = RS	MED < RS	Pre < post (linked to MED)	Pre > post (linked to MED)
Alpha power	**Ahani (2014);** Arita (2012); Cahn (2013); ***Dunn (1999);*** Hinterberger (2014); Huang (2009); Kasamatsu (1966); Lagopoulos (2009); (2003); ***Milz (2014);*** Murata (2004; coherence); ***Takahashi (2005); Yu (2011)***	Berkovich-Ohana (2013; coherence); Cahn (2010); ***Kubota (2001);*** Lehmann (2012)	Amihai (2014)		Saggar (2012)
Beta power	**Ahani (2014);** Cahn (2013); ***Dunn (1999);*** Lo (2003; synchrony)	Cahn (2010); Lagopoulos (2009); Lehmann (2012); ***Milz (2014);*** Murata (2004; coherence); ***Yu (2011)***	Amihai (2014)	***Howells (2012)***	Saggar (2012)
Theta power	**Ahani (2014);** Arita (2012); Cahn (2010); Chan (2008); Kasamatsu (1966); ***Kubota (2001);*** Lagopoulos (2009); Lehmann (2012); Lomas (2014); ***Takahashi (2005); Tanaka (2014)***	Amihai (2014); Berkovich-Ohana (2013; coherence); ***Milz (2014);*** Murata (2004; coherence)	***Dunn (1999);*** Huang (2009); ***Yu (2011)***	***Howells (2012); Xue (2014)***	Saggar(2012; in RS); ***Tang (2009)***
Delta power	Cahn (2010; at frontal brain regions)	Amihai (2014); Cahn (2010; at central and parietal brain regions); Lagopoulos (2009); ***Milz (2014)***	***Dunn (1999)***		
Gamma power	Berkovich-Ohana (2012); Cahn (2010); Hauswald (2015); Lehmann (2012)	Amihai (2014); Berkovich-Ohana (2012; coherence); ***Milz (2014)***			
Greater relative left-sided activation	Amihai (2014); Chan (2008)	***Milz et al. (2014)***		***Barnhofer (2007); Barnhofer (2010);Davidson (2003)***	***Keune (2011;*** CNT also decreased)

Note:> = significantly greater than; < =significantly lower than; = = no significant differences; CNT = control group; MED = meditation; RS = resting state. Studies featuring novice participants are indicated by the author/year being italicized in bold. All findings refer to amplitude, unless stated otherwise (e.g., coherence).

Supplementary Table 1. Quality rating of papers with healthy participant samples

First author	Year	Selection bias	Design	Confounders	Blinding	Data collection	Attrition	Global
Ahani	2014	1	1	3	3	1	1	1
Amihai	2014	1	2	2	2	1	2	2
Arita	2012	NA	NA	NA	NA	NA	NA	NA
Becker	1981	1	3	3	3	2	3	3
Berkovich-Ohana	2012	1	1	1	1	1	2	1
Berkovich-Ohana	2013	1	1	1	1	1	2	1
Brown	2010	2	1	3	2	1	2	2
Cahn	2010	1	3	3	3	1	3	3
Cahn	2013	1	3	3	3	1	3	3
Chan	2008	3	3	3	3	1	3	3
Davidson	2003	1	1	1	2	1	1	1
Delgado	2013	2	2	2	3	1	2	2
Dunn	1999	2	3	2	2	3	3	3
Ferrarelli	2013	1	1	1	2	1	2	1
Hauswald	2015	2	2	2	2	1	2	2
Hinterberger	2011	1	2	2	2	1	2	2
Hinterberger	2014	1	2	2	2	1	2	2
Huang	2009	1	1	2	2	1	2	2
Jo	2014	2	1	2	2	1	1	1
Kasamatsu	1966	1	2	2	2	2	2	2
Kerr	2011	1	1	1	2	1	1	1
Kubota	2001	2	2	2	2	1	2	2
Lakey	2011	1	2	2	2	1	2	2
Lagopoulos	2009	1	1	1	2	2	1	1
Lehmann	2012	2	1	2	2	1	2	2
Lo	2003	2	3	3	2	1	2	3
Lo	2013	1	2	2	2	2	2	2
Lomas	2014	1	2	2	2	1	2	2
Milz	2014	1	1	1	2	1	2	1
Moore	2012	1	1	1	1	1	1	1
Murata	2004	1	2	2	2	1	2	2
Pasquini	2015	2	1	2	2	1	2	2
Ren	2011	1	1	2	2	2	2	2
Saggar	2012	1	1	1	2	1	1	1
Slagter	2007	3	3	3	2	1	2	3
Slagter	2009	2	1	1	1	1	2	1
Sobolewski	2011	1	1	1	2	1	2	1
Stinson	2013	2	3	3	1	1	2	3
Takahashi	2005	2	2	2	2	1	2	2
Tanaka	2014	1	1	2	2	1	1	1
Tang	2009	1	1	2	2	1	1	1
Teper	2013	1	1	1	2	1	1	1
Teper	2014	1	2	1	1	1	1	1

van Leeuwen	2012	1	1	1	2	1	2	1
Xue	2014	1	1	2	2	1	2	2
Yu	2011	2	3	2	3	2	2	3

Note: NA = full pdf not available. Studies featuring novice participants are indicated by the author being italicized in bold.

Supplementary Table 2. Quality rating of papers with clinical samples

First author	Year	Selection bias	Design	Confounders	Blinding	Data collection	Attrition	Global
Barnhofer	2007	1	1	2	1	1	1	1
Barnhofer	2010	1	1	1	1	1	1	1
Bostanov	2012	1	2	2	2	1	2	2
Brown	2013	NA	NA	NA	NA	NA	NA	NA
Garland	2015	1	1	1	1	1	2	1
Howells	2012	1	1	1	2	1	2	1
Keune	2013	1	1	1	1	1	1	1
Schoenberg (et al.)	2014	1	1	2	1	1	1	1
Schoenberg (& S.)	2014	1	1	1	1	1	1	1
Schoenberg (& S.)	2015	1	1	1	1	1	1	1

Note: NA = not available. Studies featuring novice participants are indicated by the author being italicized in bold.

Supplementary Table 3. Alpha bandwidth

Author	Year	Meditation	Protocol: Resting	Findings
			Meditation vs resting state	
Higher amplitude during meditation				
Ahani	2014	15 mins MM (E-C)	15 mins audio listening (E-C)	ME > CNT **(F(1,33) = 10.58, *p* ≤ 0.0011)**
Arita	2012	NA	NA	MED > RS (stats NA)
Cahn	2013	21 mins (Vipassana)	21 mins (E-C)	MED > RS ($F(1, 15) = 6.64$, $p < .05$)
Dunn	1999	15 mins (FA) then 15 mins (MM)	15 mins (E-C)	MED (MM) > RS & FA. Stats NR
Hinterberger	2014	15 mins (self-chosen), 2 mins (MM), 2 mins (thoughtless emptiness), 2 mins (FA on 'third eye'), 2 mins (FA on body axis)	5 mins (E-O), 5 mins (E-C), 5 mins (reading)	MED (MM) > RS ($t = 2.7$, $p < .05$)
Huang	2009	40 mins (Zen) (vs 40 mins rest for CNT)		EXP (MED) > CNT (rest) ($F(1, 45) = 31.57$, $P < .0001$)
Kasamatsu	1966	Time NR (Zen)	Time NR (E-C)	MED > RS. Stats NR.
Lagopoulos	2009	20 mins (Acem)	20 mins (E-C)	MED > RS ($F(1, 17) = 7.19$, $p = .02$)
Lo	2003	40 mins (Zen)	15 mins (E-C)	MED > RS. Stats NR.
Milz	2014	2 x 5 mins (breath counting)	3 x 5 mins (E-C)	Power: MED > RS ($t = 3.02$, $p = .036$); Coherence: MED =RS ($t(22)= 1.29$, $p = .20$);
Murata	2004	15 mins (Su-soku; E-O)	15 mins (E-O)	MED > RS (coherence) ($t = 3.03$, $p< .01$)
Takahashi	2005	15 mins (Su-soku)	15 mins (E-O)	MED > RS ($F(1, 19) = 29.47$, $p < .001$)
Yu	2011	20 mins (Zen: tanden breathing)	2 mins (E-C)	MED > RS ($F = 9.31$, $p < .001$)
Lower amplitude during meditation				
Amihai	2014	Therevada = 15 mins(Samatha) & 15 mins (Vipassna); V=Vajrayana = 15 mins (deity) & 15 mins (Rig-pa)	10 mins (E-C)	MED (Therevada) < RS ($F(2,18) = 6.84$, p < 0.01); MED (Vajrayana) = RS (p > 0.8)
No significant differences (or no clear reportable patterns)				
Berkovich-Ohana	2013	15 mins (MM)	2.5 mins (E-C) + 2.5 mins (E-O)	MED = RS (coherence); Stats NR. RS: EXP = CNT (coherence); Stats NR.
Cahn	2010	21 mins (Vipassana)	21 mins (E-C)	MED = RS ($F(1, 15) = 0.096$, $p = .76$)
Hinterberger	2011	15 mins (self-chosen), 2 mins (MM), 2 mins (thoughtless emptiness), 2 mins (FA on 'third eye'), 2 mins (FA on body axis)	5 mins (E-O), 5 mins (E-C), 5 mins (reading)	Complex analyses. Stats NU.
Kubota	2001	25 mins (Su-soku)	2.5 mins (cued-breathing)	MED = RS ($t = 0.68$, p NR)
Lehmann	2012	60 mins (self-chosen)	4 mins (20 sec E-O, 40 sec E-C; x 4)	MED (Zen) = RS. $T = 1.81$, $p = 0.09$
Lo	2013	40 mins (Zen)	15 mins (E-C)	Complex analyses. Stats NU
Pre-post changes				
Saggar	2012	12 mins (MM: pre, mid, & post retreat)		Group x time interaction: ($F(2,41) = 23.26$, $p < .001$): pre-post decrease for EXP ($t(21) = 6.59$, $p<.001$), not CNT

Author	Year	Meditation	Protocol: task	Findings
			Meditation vs task	
Becker	1981	30 mins (self-chosen MED: Zen, TM or Yoga), then 30 mins (self-chosen MED) concurrent with task	Auditory clicks (30 mins)	Task: EXP = CNT (alpha suppression). Stats NR
Berkovich-Ohana	2013	15 mins (MM)	Time-production task (2-3 mins)	EXP = CNT (coherence); Stats NR
Kerr	2011		Cued attention-detection runs	EXP (vs CNT): Enhanced alpha modulation in early (600-800ms period) (Mann-Whitney, $p < .01$)
Pasquini	2015		Focused attention task	EXP in task: Negative correlation between alpha powerand both meditation practice time ($r = -0.52$, $p = .003$) and meditation weekly frequency ($r = -0.41$, $p = .021$).

Ren	2011	Time NR (Su-soku)	Problem solving (Time NR)	EXP (MED) < CNT (cognitive task) ($F(2, 45) = 4.14$, $p = .05$)
Schoenberg (& S.)	2015		Go/NoGo task	Task: pre-post power increase for negative stimuli ($t(24) = 2.58$, $p = .02$) for CNT only (EXT: no significant increase).
Stinson	2013	Time NR (relaxation – 'Alpha brain state exercise')	Neurofeedback video (Time NR)	MED = task. Stats NR.

Note: > = significantly greater than; < =significantly lower than; = = no significant differences; CNT = control group; E-C = eyes-closed; E-O =eyes-open; EXP =experimental group; FA= focussed-attention (concentrative) meditation; (from …) = initial number of participants in a pre-post study; MED = meditation; MM = Mindfulness meditation; NA = not available; NR = not reported; NU = not usable (here); NCC = neural correlates of consciousness (i.e., EEG measurement during MED vs RS); ROI = region of interest; RS = resting state. All bandwidth outcomes pertain to power, unless otherwise stated in parentheses (e.g., coherence). Most entries are comparing the experimental group (EXT; i.e., meditators) under different conditions (e.g., RS vs MED): significantly higher power levels during meditation are written as MED > RS; significantly lower levels as MED < RS; and no significant differences as MED = RS. Some entries are comparing two groups (i.e., EXP vs CNT) on a particular condition (e.g., RS): this will be indicated as RS: EXT >/=/< CNT. Studies featuring novice participants are indicated by the author being italicized in bold.

Supplementary Table 4. Beta bandwidth

Author	Year	Meditation	Protocol: Resting	Findings
		Meditation vs resting state		
Higher amplitude during meditation				
Ahani	2014	15 mins MM (E-C)	15 mins audio listening (E-C)	ME > CNT ($F(1,33) = 142.03$, $p \leq 0.004$)
Cahn	2013	21 mins (Vipassana)	21 mins (E-C)	MED > RS (synchrony) ($F(1, 15) = 9.01$, $p < .01$)
Dunn	1999	15 mins (FA) then 15 mins (MM)	15 mins (E-C)	MM > RS & FA. Stats NR
Lo	2003	40 mins (Zen)	15 mins (E-C)	MED > RS. Stats NR.
Lower amplitude during meditation				
Amihai	2014	Therevada = 15 mins(Samatha) & 15 mins (Vipassna); V=Vajrayana = 15 mins (deity) & 15 mins (Rig-pa)	10 mins (E-C)	MED (Therevada) < RS ($F(2,18) = 3.68$, $p < 0.05$); MED (Vajrayana)< RS ($F(2,18) = 8.42$, $p < 0.01$)
No significant differences (or no clear reportable patterns)				
Cahn	2010	21 mins (Vipassana)	21 mins (E-C)	MED = RS ($F(1, 15) = 0.62$, $p = .44$)
Hinterberger	2011	15 mins (self-chosen), 2 mins (MM), 2 mins (thoughtless emptiness), 2 mins (FA on 'third eye'), 2 mins (FA on body axis)	5 mins (E-O), 5 mins (E-C), 5 mins (reading)	Complex analyses. Stats NU.
Lagopoulos	2009	20 mins (Acem)	20 mins (E-C)	MED = RS ($F(1, 17) = 0.57$, $p = .46$)
Lehmann	2012	60 mins (self-chosen)	4 mins (20 sec E-O, 40 sec E-C; x 4)	MED (Zen) = RS. $T = 0.48$, $p = 0.63$
Milz	2014	2 x 5 mins (breath counting)	3 x 5 mins (E-C)	Power: MED = RS; Stats NR. Coherence: MED =RS ($t(22)= 0.11$, $p = .91$)
Murata	2004	15 mins (Su-soku; E-O)	15 mins (E-O)	EXP: MED = RS (coherence). Stats NR.
Yu	2011	20 mins (Zen: tanden breathing)	2 mins (E-C)	MED = RS ($F = 0.96$, $p = .44$)
Pre-post changes				
Saggar	2012	12 mins (MM: pre, mid, & post retreat)		Group x time interaction: ($F(2,41) = 7.11$, $p < .01$): pre-post decrease for EXP ($t(21) = 8.65$, $p<.001$), not CNT
Howells	2012		3 mins (E-O), 3 mins (E-C),	RS (EXP only): post < pre ($t = 2.23$, $p < .05$)
		Meditation vs task		
Author	Year	Meditation	Protocol: task	Findings
Stinson	2013	Time NR (relaxation – 'Alpha brain state exercise')	Neurofeedback video (Time NR)	MED < task. Stats NR.

Note: > = significantly greater than; < =significantly lower than; = = no significant differences; CNT = control group; E-C = eyes-closed; E-O =eyes-open; EXP =experimental group; FA= focussed-attention (concentrative) meditation; (from …) = initial number of participants in a pre-post study; MED = meditation; MM = Mindfulness meditation; NA = not available; NR = not reported; NU = not usable (here); NCC = neural correlates of consciousness (i.e., EEG measurement during MED vs RS); ROI = region of interest; RS = resting state. All bandwidth outcomes pertain to power, unless otherwise stated in parentheses (e.g., coherence). Most entries are comparing the experimental group (EXT; i.e., meditators) under different conditions (e.g., RS vs MED): significantly higher power levels during meditation are written as MED > RS; significantly lower levels as MED < RS; and no significant differences as MED = RS. Some entries are comparing two groups (i.e., EXP vs CNT) on a particular condition (e.g., RS): this will be indicated as RS: EXT >/=/< CNT. Studies featuring novice participants are indicated by the author being italicized in bold.

Supplementary Table 5. Theta bandwidth

Author	Year	Meditation	Protocol: Resting	Findings
			Meditation vs resting state	
Author	Year	Meditation	Protocol: Resting	Findings
Higher amplitude during meditation				
Ahani	2014	15 mins MM (E-C)	15 mins audio listening (E-C)	ME > CNT (F(1,33) = 118.79, $p \leq 0.001$)
Arita	2012	NA	NA	MED > RS (stats NA)
Cahn	2010	21 mins (Vipassana)	21 mins (E-C)	MED > RS (condition x ROI interaction – only at specific sites ($F(2, 30) = 7.75$, $p = .002$). Increase in MED at Fz ($p= .006$), but not Cz ($p= .99$) or Pz ($p=.85$)
Chan	2008	12 mins(Triarchic Body Relaxation Technique)	5 mins (E-C)	MED > RS (a range of t-tests; t = -3.73 - -4.82, $p < .02$.
Kasamatsu	1966	Time NR (Zen)	Time NR (E-C)	MED > RS. Stats NR.
Kubota	2001	25 mins (Su-soku)	2.5 mins (cued-breathing)	MED > RS ($t = 6.14$, $p< .0001$)
Lagopoulos	2009	20 mins (Acem)	20 mins (E-C)	MED > RS ($F(1, 17) = 4.99$, $p = .04$)
Lehmann	2012	60 mins (self-chosen)	4 mins (20 sec E-O, 40 sec E-C; x 4)	MED (Zen) > RS. $T = 4.95$, $p < 0.001$.
Takahashi	2005	15 mins (Su-soku)	15 mins (E-O)	MED > RS ($F(1, 19) = 5.5$, $p = .031$)
Tanaka	2014	40 mins (MM)	8 mins (E-C)	EXP: MED > RS (stats NA). MED: EXP > CNT ($p < .0001$). RS: EXP < CNT ($p < .0001$).
Lower amplitude during meditation				
Dunn	1999	15 mins (FA) then 15 mins (MM)	15 mins (E-C)	MM < RS; Stats NR; MM > FA; Stats NR
Huang	2009	40 mins (Zen) (vs 40 mins rest for CNT)		EXP (MED) < CNT (rest) ($F(1, 45) = 28.68$, $P < .0001$)
Yu	2011	20 mins (Zen: tanden breathing)	2 mins (E-C)	MED < RS ($F = 9.85$, $p < .001$)
No significant differences (or no clear reportable patterns)				
Amihai	2014	Therevada = 15 mins (Samatha) & 15 mins (Vipassna); Vajrayana = 15 mins (deity) & 15 mins (Rig-pa)	10 mins (E-C)	MED (Therevada) = RS ($F(2,18) = 1.11$, p>0.3); MED (Vajrayana) = RS ($F(2,16) = 2.5$, p>0.1)
Berkovich-Ohana	2013	15 mins (MM)	2.5 mins (E-C) + 2.5 mins (E-O)	MED = RS (coherence); Stats NR. RS: EXP = CNT (coherence); Stats NR.
Hinterberger	2011	15 mins (self-chosen), 2 mins (MM), 2 mins (thoughtless emptiness), 2 mins (FA on 'third eye'), 2 mins (FA on body axis)	5 mins (E-O), 5 mins (E-C), 5 mins (reading)	Complex analyses. Stats NU.
Milz	2014	2 x 5 mins (breath counting)	3 x 5 mins (E-C)	Power: MED = RS; Stats NR. Coherence: MED =RS ($t(22) = 0.62$, $p = .53$)
Murata	2004	15 mins (Su-soku; E-O)	15 mins (E-O)	EXP: MED = RS (coherence). Stats NR.
Pre-post changes				
Lomas	2014	10 mins (MM)	5 mins (E-C)	Pre: MED > RS ($F(1, 27) = 7.14$, $p = .013$); Post: MED > RS ($F(1, 27) = 5.74$, $p = .024$)
Tang	2009		Time NR (E-C)	Group x time interaction ($F(1, 32) = 4.92$, $p < .05$): pre-post decrease for EXP ($p < .05$), not CNT
Xue	2014		5 mins (E-C)	Group x time interaction (in connectivity) (F(1,43) = 2.93; $p = 0.09$). Pre: EXP = CNT ($p > .05$). Post: decreased path-length in EXP ($t(23) = 3.72$, $p = .001$), not CNT.
			Meditation vs task	
Author	Year	Meditation	Protocol: task	Findings
Berkovich-Ohana	2013	15 mins (MM)	Time-production task (2-3 mins)	EXP = CNT (coherence); Stats NR
Howells	2012	Resting state: 3 mins (E-O), 3 mins (E-C)	Sustained attention (visual A-	RS (EXP only): post < pre ($t = 2.29$, $p < .05$)

			X continuous performance) (10 mins)	
Pasquini	2015		Focused attention task	EXP in task: Correlation between theta power and meditation weekly frequency (r = 0.42, p = .02).
Slagter	2009		Attentional blink (time NR)	Group x time interaction: MED-related changes in the phase of target induced EEG responses. Stats NU
Stinson	2013	Time NR (relaxation – 'Alpha brain state exercise')	Watching video – explaining neurofeedback (Time NR)	MED < task. Stats NR.

Note: > = significantly greater than; < =significantly lower than; = = no significant differences; CNT = control group; E-C = eyes-closed; E-O =eyes-open; EXP =experimental group; FA= focussed-attention (concentrative) meditation; (from …) = initial number of participants in a pre-post study; MED = meditation; MM = Mindfulness meditation; NA = not available; NR = not reported; NU = not usable (here); NCC = neural correlates of consciousness (i.e., EEG measurement during MED vs RS); ROI = region of interest; RS = resting state. All bandwidth outcomes pertain to power, unless otherwise stated in parentheses (e.g., coherence). Most entries are comparing the experimental group (EXT; i.e., meditators) under different conditions (e.g., RS vs MED): significantly higher power levels during meditation are written as MED > RS; significantly lower levels as MED < RS; and no significant differences as MED = RS. Some entries are comparing two groups (i.e., EXP vs CNT) on a particular condition (e.g., RS): this will be indicated as RS: EXT >/=/< CNT. Studies featuring novice participants are indicated by the author being italicized in bold.

Supplementary Table 6. Delta bandwidth

		Meditation vs resting state		
Author	Year	Meditation	Protocol: Resting	Findings
Higher amplitude during meditation				
Cahn	2013	21 mins (Vipassana)	21 mins (E-C)	Expertise x state x ROI interaction(synchrony) (F(2, 2, 28) = 5.83, p < .01): long- term EXP higher synchrony during MED (vs RS) at frontal sites, but not central or parietal sites; for short term meds, MED = RS
Lower amplitude during meditation				
Dunn	1999	15 mins (FA) then 15 mins (MM)	15 mins (E-C)	MM < RS; Stats NR
No significant differences (or no clear reportable patterns)				
Amihai	2014	Therevada = 15 mins (Samatha) & 15 mins (Vipassna); Vajrayana = 15 mins (deity) & 15 mins (Rig-pa)	10 mins (E-C)	Med < RS (F(2,18) = 8.37, p < 0.01). Post-hoc: no diff between– RS and Therevada MED (only Vajrayana MED)
Cahn	2010	21 mins (Vipassana)	21 mins (E-C)	MED = RS (F(1, 15) = 1.85, p = .19)
Hinterberger	2011	15 mins (self-chosen), 2 mins (MM), 2 mins (thoughtless emptiness), 2 mins (FA on 'third eye'), 2 mins (FA on body axis)	5 mins (E-O), 5 mins (E-C), 5 mins (reading)	Complex analyses. Stats NU.
Lagopoulos	2009	20 mins (Acem)	20 mins (E-C)	MED = RS (F(1, 17) = 0.99, p = .34)
Milz	2014	2 x 5 mins (breath counting)	3 x 5 mins (E-C)	Power: MED = RS. Stats NR
		Meditation vs task		
Author	Year	Meditation	Protocol: task	Findings
Stinson	2013	Time NR (relaxation – 'Alpha brain state exercise')	Watching video – explaining neurofeedback (Time NR)	MED < task. Stats NR.

Note: > = significantly greater than; < =significantly lower than; = = no significant differences; CNT = control group; E-C = eyes-closed; E-O =eyes-open; EXP =experimental group; FA= focussed-attention (concentrative) meditation; (from …) = initial number of participants in a pre-post study; MED = meditation; MM = Mindfulness meditation; NA = not available; NR = not reported; NU = not usable (here); NCC = neural correlates of consciousness (i.e., EEG measurement during MED vs RS); ROI = region of interest; RS = resting state. All bandwidth outcomes pertain to power, unless otherwise stated in parentheses (e.g., coherence). Most entries are comparing the experimental group (EXT; i.e., meditators) under different conditions (e.g., RS vs MED): significantly higher power levels during meditation are written as MED > RS; significantly lower levels as MED < RS; and no significant differences as MED = RS. Some entries are comparing two groups (i.e., EXP vs CNT) on a particular condition (e.g., RS): this will be indicated as RS: EXT >/=/< CNT. Studies featuring novice participants are indicated by the author being italicized in bold.

Supplementary Table 7. Gamma bandwidth

Author	Year	Meditation	Protocol: Resting	Findings
			Meditation vs resting state	
Higher amplitude during meditation				
Berkovich-Ohana	2012	15 mins (MM)	2.5 mins (E-C) + 2.5 mins (E-O)	MED > RS (F(1, 34)= 17.00, p < 0.0001).
Cahn	2010	21 mins (Vipassana)	21 mins (E-C)	MED > RS (F(1, 15) = 9.32, p = .008).
Hauswald	2015	20 mins (Zen, E-O)	5 mins (E-O)	Increased gamma power in MED correlated both with trait mindfulness (p = .015) and years of practice (p = .036).
Lehmann	2012	60 mins (self-chosen)	4 mins (20 sec E-O, 40 sec E-C; x 4)	MED (Zen) > RS. T = 2.66, p = 0.019.
No significant differences (or no clear reportable patterns)				
Amihai	2014	Therevada = 15 mins (Samatha) & 15 mins (Vipassna); Vajrayana = 15 mins (deity) & 15 mins (Rig-pa)	10 mins (E-C)	MED (Therevada) = RS; Stats NR. MED (Vajrayana) < RS (F(2,16) = 6.16, p>0.01)
Berkovich-Ohana	2013	15 mins (MM)	2.5 mins (E-C) + 2.5 mins (E-O)	MED = RS (coherence); Stats NR. RS: EXP = CNT (coherence); Stats NR.
Hinterberger	2011	15 mins (self-chosen), 2 mins (MM), 2 mins (thoughtless emptiness), 2 mins (FA on 'third eye'), 2 mins (FA on body axis)	5 mins (E-O), 5 mins (E-C), 5 mins (reading)	Complex analyses. Stats NU.
Milz	2014	2 x 5 mins (breath counting)	3 x 5 mins (E-C)	Power; MED = RS. Stats NR
			Meditation vs task	
Author	Year	Meditation	Protocol: task	Findings
Berkovich-Ohana	2013	15 mins (MM)	Time-production task (2-3 mins)	EXP = CNT (coherence); Stats NR
Ferarelli	2013		Sleep	Correlation: MED experience & NREM gamma (r = 0.47, p =.017). No correlation with REM gamma
Schoenberg (& S.)	2015		Go/NoGo task	Task: Interaction (time x group x site x epoch) (F(1, 47) = 4.12, p = .05) – pre-post power increase for CNT only (EXT: no increase).
Stinson	2013	Time NR (relaxation – 'Alpha brain state exercise')	Watching video – explaining neurofeedback (Time NR)	MED < task. Stats NR.

Note: > = significantly greater than; < =significantly lower than; = = no significant differences; CNT = control group; E-C = eyes-closed; E-O =eyes-open; EXP =experimental group; FA= focussed-attention (concentrative) meditation; (from …) = initial number of participants in a pre-post study; MED = meditation; MM = Mindfulness meditation; NA = not available; NR = not reported; NU = not usable (here); NCC = neural correlates of consciousness (i.e., EEG measurement during MED vs RS); ROI = region of interest; RS = resting state. All bandwidth outcomes pertain to power, unless otherwise stated in parentheses (e.g., coherence). Most entries are comparing the experimental group (EXT; i.e., meditators) under different conditions (e.g., RS vs MED): significantly higher power levels during meditation are written as MED > RS; significantly lower levels as MED < RS; and no significant differences as MED = RS. Some entries are comparing two groups (i.e., EXP vs CNT) on a particular condition (e.g., RS): this will be indicated as RS: EXT >/=/< CNT. Studies featuring novice participants are indicated by the author being italicized in bold.

Supplementary Table 8. Asymmetry Findings

Author	Year	Meditation	Protocol	Findings
			Meditation vs resting state	
Increase in relative left-frontal activation linked to meditation				
Amihai	2014	Therevada = 15 mins (Samatha) & 15 mins (Vipassna); Vajrayana = 15 mins (deity) & 15 mins (Rig-pa)	10 mins resting state (E-C)	MED (Therevada): Condition x location interaction (F(4,36) = 3.09, p<0.05). MED (Vipassana) > RS at left location (p<0.05), but not right or center (p>0.2)
Barnhofer	2007	8 x 1min (4 = E-O, 4 = E-C)	8 x 1min (4 = E-O, 4 = E-C)	Group x time interaction ($F(2, 19) = 3.7$, $p = .044$): pre-post decreases in relative left prefrontal asymmetry for CNT ($p = .003$), but not EXP ($p = .918$)
Barnhofer	2010	EXP = 15 mins (MM); CNT = 15 mins (LKM)	2 mins (E-C): EEG assessed pre and post MED	Pre-post increase (EXP & CNT) in relative left prefrontal activation ($F(1, 13) = 5.06$, $p = .04$)
Chan	2008	Triarchic Body Relaxation Technique (12 mins) 5 mins (E-C)	5 mins resting state (E-C	MED > RS (left-sided activation; $F(1, 18) = 5.42$, $p = .032$)
Davidson	2003	8 x 1min (4 = E-O, 4 = E-C)	Writing about experiences (EEG recorded 1 min before & 3 mins after)	Group x time interaction in RS ($F(1, 37) = 5.14$, $p < .05$): pre-post increase in relative left- activation for EXP (not CNT)
Decrease in relative left-frontal activation linked to meditation				
Keune	2011		Sad mood induction (sad music, and neg. experience recall). Time NR.	Pre-post decrease (EXP & CNT) in relative left prefrontal activation ($F(4, 64) = 3.38$, $p < .05$)
No change in relative left-frontal activation linked to meditation				
Milz	2014	2 x 5 mins (breath counting)	3 x 5 mins resting state (E-C)	Power: MED = RS. Stats NR

Note: > = significantly greater than; < =significantly lower than; = = no significant differences; CNT = control group; E-C = eyes-closed; E-O =eyes-open; EXP =experimental group; FA= focussed-attention (concentrative) meditation; (from …) = initial number of participants in a pre-post study; MED = meditation; MM = Mindfulness meditation; NA = not available; NR = not reported; NU = not usable (here); NCC = neural correlates of consciousness (i.e., EEG measurement during MED vs RS); ROI = region of interest; RS = resting state. All bandwidth outcomes pertain to power, unless otherwise stated in parentheses (e.g., coherence). Most entries are comparing the experimental group (EXT; i.e., meditators) under different conditions (e.g., RS vs MED): significantly higher power levels during meditation are written as MED > RS; significantly lower levels as MED < RS; and no significant differences as MED = RS. Some entries are comparing two groups (i.e., EXP vs CNT) on a particular condition (e.g., RS): this will be indicated as RS: EXT >/=/< CNT. Studies featuring novice participants are indicated by the author being italicized in bold.

Supplementary Table 9. ERP Findings

Author	Year	Meditation	*Meditation vs task* Protocol: task	Findings
Bostanov	2012	20 mins (MM)	Auditory stimuli during MM	Increased pre-post 'Late contingent negative variation for EXP. but not CNT (F = 7.7, p < .01)
Brown	2010		Stimulation of pain (5 mins)	Lower activation for EXP than CNT in S2 and insula during pain stimulus, t = 2.51, p < .05
Brown	2013	-	Anticipation and simulation of pain (time NR)	Anticipatory and pain-evoked ERPs to acute pain reduced in EXP but not CNT (stats NA)
Delgado	2013		Auditory oddball task	Two-way P3b interaction (task × oddball order): significant effects of meditation after the meditation/control task (p = 0.01).
Garland	2015		Event-related affective picture viewing task	Tim x group x cue interaction (F(1, 25) = 4.99, p = ..035). EXP group (vs CNT) = pre-post increases in LPP activation to natural reward cues across 400 – 1000 ms window.
Jo	2014		Performing voluntary finger movement (time NR)	MED = CNT (Readiness Potential amplitude prior to voluntary action) (p = .26).
Lakey	2011	EXP = 6 mins (MM); CNT = 6 mins (non-MM-task)	P300-based brain–computer interface (BCI) task	Task: EXP > CNT (P300 amplitude peaks) (t(16) = 2.10, P < .05)
Moore	2012		Stroop (time NR)	Group x time interaction: pre-post increase in focusing attention (EXP only). Stats NU.
Schoenberg (et al.)	2014		Go/NoGo task	Time x condition x group interaction: significant pre-post increases for EXP in Go-P3 (t(23) = -2.986, p = .007) and NoGo-P3 (t(23) = -2.502, p = .02) amplitude at Pz, contrary to pre-post parietal decreases for CNT in Go-P3 (p = .42) and NoGo-P3 (p = .40).
Schoenberg (& S.)	2014		Go/NoGo task	Pre-post increase in event-related theta synchronization during the late time window (400-800 ms) for EXT (F(1, 49) = 10.933, p = .002), vs pre-post decrease for CNT
Slagter	2007		Attentional blink (time NR)	Group x time interaction (F(1, 20) = 5.4, p = .03): pre-post decrease in elicited P3B amplitude for EXP, not CNT
Sobolewski	2011		Looking at emotional pictures (Time NR)	Group x valence interaction (p = .03): EXP less affected by negative emotional load.
Teper	2013		Stroop (time NR)	Task: EXP > CMT (higher amplitude error-related negativity) (F(1, 36) = 3.32, p < .04)
Teper	2014		Performance feedback (neutral, aversive, and rewarding) (time NR)	Trait MM: predicts less differentiation of rewarding from neutral feedback. Stats NU
Van Leeuwen	2012		Target detection (time NR)	Task: MED > CNT (enhanced attentional processing). Stats NU.

Note: > = significantly greater than; < =significantly lower than; = = no significant differences; CNT = control group; E-C = eyes-closed; E-O =eyes-open; EXP =experimental group; FA= focussed-attention (concentrative) meditation; (from …) = initial number of participants in a pre-post study; MED = meditation; MM = Mindfulness meditation; NA = not available; NR = not reported; NU = not usable (here); NCC = neural correlates of consciousness (i.e., EEG measurement during MED vs RS); ROI = region of interest; RS = resting state. All bandwidth outcomes pertain to power, unless otherwise stated in parentheses (e.g., coherence). Most entries are comparing the experimental group (EXT; i.e., meditators) under different conditions (e.g., RS vs MED): significantly higher power levels during meditation are written as MED > RS; significantly lower levels as MED < RS; and no significant differences as MED = RS. Some entries are comparing two groups (i.e., EXP vs CNT) on a particular condition (e.g., RS): this will be indicated as RS: EXT >/=/< CNT. Studies featuring novice participants are indicated by the author being italicized in bold.