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Awakening is not a metaphor: the effects of Buddhist meditation practices on basic wakefulness

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Buddhist meditation practices have become a topic of widespread interest in both science and medicine. Traditional Buddhist formulations describe meditation as a state of relaxed alertness that must guard against both excessive hyperarousal (restlessness) and excessive hypoarousal (drowsiness, sleep). Modern applications of meditation have emphasized the hypoarousing and relaxing effects without as much emphasis on the arousing or alertness-promoting effects. In an attempt to counterbalance the plethora of data demonstrating the relaxing and hypoarousing effects of Buddhist meditation, this interdisciplinary review aims to provide evidence of meditation's arousing or wake-promoting effects by drawing both from Buddhist textual sources and from scientific studies, including subjective, behavioral, and neuroimaging studies during wakefulness, meditation, and sleep. Factors that may influence whether meditation increases or decreases arousal are discussed, with particular emphasis on dose, expertise, and contemplative trajectory. The course of meditative progress suggests a nonlinear multiphasic trajectory, such that early phases that are more effortful may produce more fatigue and sleep propensity, while later stages produce greater wakefulness as a result of neuroplastic changes and more efficient processing.

Keywords: Buddhist meditation; relaxation; sleep; arousal; alertness; wakefulness

Introduction

Meditation practices that are derived from Buddhist traditions have been gradually adopted in the West and have become a topic of widespread interest in both science and medicine. In order to fit with modern Western values and worldviews, the practices have been largely decontextualized from their original Buddhist goal of "awakening" and recontextualized as clinical interventions or forms of "psychological and physiological self-maintenance."[1] This recontextualization has resulted in a modification of the traditional goals of practice and also in the way scientific studies report the effects of meditation, which may emphasize or deemphasize certain aspects of Buddhist formulations to serve modern needs and values.[2,3]

For example, Buddhist texts describe meditation practice as aiming to cultivate a state of relaxed alertness, and therefore must continually balance between the extremes of hyperarousal, agitation, and restlessness on the one hand, and hypoarousal, excessive relaxation, mental dullness, and sleep on the other (Fig. 1).[4–6] Within the modern context, however, much more emphasis has been placed on the relaxing effects of meditation without as much attention to the arousing or wake-promoting effects. In some modern formulations, the goal of meditation has expanded beyond relaxation and decreased arousal[7–10] to include a state of consciousness that is deliberately half-asleep, a "physiological twilight condition between waking and sleep,"[11–13] equivalent to sleep,[14,15] or a form of sleep-like hibernation, a "shallow torpor"[16] that is reversed by (i.e., the

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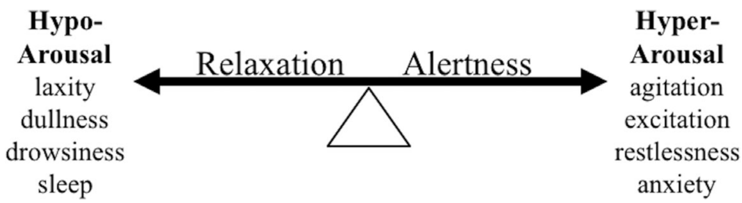

Figure 1. Meditation maintains a state of relaxed alertness by guarding against the extremes of hyperarousal (excitation, restlessness, anxiety) and hypoarousal (laxity, drowsiness, sleep).

opposite of) wakefulness.[17] As a result, meditation practices are often equated with nonspecific relaxation techniques[7] where hypoarousal and sleep are seen as desirable rather than obstacles to concentration (*samādhi*).[18]

In contrast to modern formulations that emphasize the hypoarousal end of the spectrum, traditional Buddhist texts tend to emphasize vigilant wakefulness as a means to a profound shift in perception called "awakening" (*bodhi*). Because meditation must balance mental laxity and agitation, relaxation is infused with courageous energy (*viriyā*), zeal (*atapi*), and an alert vigilant awareness such that a practitioner is devoted to wakefulness (*jāgariya*), and guarded against the hindrances of drowsiness and sleep.[19,20] Scholars familiar with the traditional Buddhist goals of meditation have criticized Western scientists for their overemphasis on relaxation.[1,21] In his book entitled *Buddhism and Science: A Guide for the Perplexed*, Buddhist studies scholar Donald Lopez laments "Where is the insistence that meditation is not intended to induce relaxation but rather a vital transformation of one's vision of reality?"[22] Others warn how "a practice that only relaxes the mind might eventually prove harmful."[23]

As an attempt to promote a more balanced view of the goal of mindfulness meditation, Jon Kabat-Zinn changed the name of his program from Stress Reduction and Relaxation Program[24] to Mindfulness-Based Stress Reduction (MBSR), characterized the term mindfulness as "being awake,"[24] and removed the word "relaxation" from audiotapes and handouts. Similar attempts to point out the arousing effects of meditation have been widespread[11,16,23] but also lost in the well-established enthusiasm around relaxation and its closely related cousin, sleep.

In an attempt to counterbalance the plethora of data demonstrating the relaxing and hypoarousing effects of Buddhist meditation, this interdisciplinary review aims to provide evidence of meditation's arousing or wake-promoting effects by drawing from both scientific studies and Buddhist textual sources. The construct of arousal is complex and multidimensional, with multiple distinct but overlapping inputs, including inputs from cortical, autonomic, endocrine, cognitive, and affective systems.[25] Although other reviews have focused more on somatic forms of arousal,[26] this review will focus on the cognitive dimensions of arousal that pertain to wakefulness and alertness.

The link between attention and wakefulness

Although there are many different forms of meditation, most agree that the deliberate training of attention, either in a focused and directed or open and receptive way, is a foundational part of any meditation. This review emphasizes two common forms of attention training, focused attention (FA) and open monitoring (OM), which are foundational in Buddhist and many non-Buddhist meditation practices.[27]

Attention has been typically divided into three basic functionally and anatomically distinct types: orienting, executive attention, and alerting.[28,29] Orienting directs and limits attention to a selected stimulus. Executive attention, also called conflict monitoring or selective or focused attention, involves prioritizing among competing tasks or responses. Alerting consists of achieving and maintaining a state of mental preparedness and a high sensitivity to incoming stimuli, and is subdivided into phasic alertness and tonic alertness. Phasic alertness refers to the ability to increase response readiness briefly following a cue or warning signal. Tonic alertness, also called intrinsic alertness or vigilant attention,[30] is a general level of arousal, alertness, vigilance, wakefulness, or state of mental preparedness to detect or respond to infrequent or unexpected stimuli. Tonic alertness can also be measured by its deficit: a general level of sleepiness, fatigue, or lack of sustained attention characterized by attentional lapses or mind wandering.[31] Because tonic alertness provides the cognitive tone for performing more complicated functions, such as working memory and executive control,[32,33] it is thought that all other forms of attention are dependent on tonic alertness.[34] Studies of alertness training[35–38] or pharmacological enhancement of alertness[39] leading to improvements on a broad range of attentional tasks also support the idea that tonic alertness is a foundational prerequisite for other forms of attention. Although all three types of attention have been researched in meditation studies,[40–53] less emphasis has been placed on tonic alertness. Furthermore, tonic alertness has been described in terms of increased sustained attention or vigilance[40,49,54,55] but not in terms of increased wakefulness or arousal, an approach influenced by the modern Western view that meditation promotes relaxation and sleep rather than wakefulness.

The positive relationship between attention and arousal or wakefulness is evident in common everyday experiences. We have all noticed, for example, that paying attention, as well as learning, remembering, and regulating emotion are more difficult when we are tired, or that intensely engaging attention before bed can inhibit sleep. The idea that attention is positively correlated with greater arousal and wakefulness is well established within the fields of sleep and chronobiology,[56] but this correlation has been relatively unexplored within the field of meditation research. Thus, this review will adopt a sleep researcher's approach in order to examine the effects of contemplative practices on tonic alertness as defined by the complementary domains of sleep propensity and wakefulness. Specifically, this review will investigate the effects of Buddhist meditation on the following indices of sleep propensity/wakefulness: (1) the activation of sleep/wake–related brain areas, (2) subjective reports of sleepiness/fatigue, (3) electroencephalogram (EEG) activity during wakefulness, (4) behavioral measures of vigilance/sustained attention, (5) EEG during sleep, and (6) sleep duration.

Meditation effects on tonic alertness

Neuroimaging studies

Variations in wakefulness and sleep propensity correspond to specific brain areas that are also affected by meditation practices, both in a state-related way (during meditation) and a trait-related way (at rest or during tasks). Generally speaking, decreased alertness and the transition of wake to sleep onset is associated with a global decrease in activity in most brain areas, particularly frontal areas, but an increase in areas in the default mode network (DMN).[57–59] Tonic alertness is associated with activity in right hemisphere cortical areas and subcortical networks, particularly the dorsal anterior cingulate cortex (dACC), the dorsolateral prefrontal cortex (DLPFC), the anterior insula, the inferior parietal lobule, the thalamus, and the brain stem (Table 1).[30–32,35,60–64] A number of studies have found that meditation-related activation or volume increases are lateralized to the right hemisphere and correspond to tonic alertness–related brain areas (lateral PFC, inferior parietal, and anterior insula),[65–70] but see also counter-example.[71]

DLPFC. High levels of activity in the DLPFC correspond to alert wakefulness,[72–74] while a hypoactive DLPFC is associated with fatigue and increased sleep propensity.[72,75,76] Buddhist meditation practices have been found to be associated with increased activity in the DLPFC, both during meditation[45,65,77–80] and during tasks,[67,70,81,82] as well as larger frontal gray matter volumes.[66,83,84]

dACC. As part of its many functions, the dACC is thought to control arousal via brain stem noradrenergic activation and multiple thalamic nuclei.[31] The ACC has been implicated in the intentional modulation of arousal, with the right-sided ACC proposed to be more associated with increased arousal and left-sided activation with decreased arousal.[85,86] Buddhist meditation practices have been found to be associated with increases in activation in the dACC both during meditation[45,65,77,79,87] and during tasks.[70,81,82,88–90]

Insula. Often thought to underlie interoception,[91] the anterior insula has also been proposed as the substrate of basic awareness or consciousness,[92] is a central node in the intrinsic alertness network,[30,62] and corresponds with states of wakefulness and autonomic arousal during meditation.[45,68] The

Table 1. Effects of meditation practice on brain areas underlying tonic alertness/sleep

					DLPFC	dACC	AIC	IPL	SPL	BG	THAL	DMN
Sleep					↓	↓	↓	↓	↓	↓	↓	↑
Tonic alertness					↑R	↑R	↑R	↑R	↑R	↑	↑	
Meditation studies	Type of meditation	Sample	Design	Task								
Allen *et al.*, 2012[81]	6-week mindfulness	MOD	LRCT, CS	Affective stroop at R	↑L	↑	↑R					↑B
Baerentsen *et al.*, 2010[115] (onset vs. rest)	Zen, Mantra	EX	WS	M vs. R				↑B	↓R	↑B		↓
Baerentsen *et al.*, 2010[115] (sustained vs. rest)	Zen, Mantra	EX	WS	M vs. R	↓R					↑		
Baerentsen, 2001[113] (meditation vs. rest)	Mixed	EX	WS	M vs. R	↓B	↑B		↑R		↑		↓
Baron Short 2010[79] (less experienced meditators)	Tibetan, Zen, OM	EX, NM	CS, WS	M vs. C (picture viewing)		↓						
Baron Short 2010[79] (meditators vs. controls)	Tibetan, Zen, OM	EX, NM	CS, WS	M vs. C (picture viewing)	↑							
Baron Short 2010[79] (more experienced meditators)	Tibetan, Zen, OM	EX, NM	CS, WS	M vs. C (Picture Viewing)		↑						
Brefczynski-Lewis *et al.*, 2007[45]	Tibetan FA	EX, NM	CS	M vs. R	↑L		↓R	↑	↑ B	↑L	ND	↑↓L
Brefczynski-Lewis *et al.*, 2007[45] (fewer hours EX)	Tibetan FA	EX, NM	CS	M vs. R		↑						
Brefczynski-Lewis *et al.*, 2007[45] (more hours EX)	Tibetan FA	EX, NM	CS	M vs. R		↓						
Brewer *et al.*, 2011[100]	FA, OM, LKM	EX, NM	WS, CS	M vs. R				↓				↓
Farb *et al.*, 2007[67]	8-week MBSR	MOD, NM	CS	M while reading self-related vs. control words	↑L		↑R	↑				↓
Farb *et al.*, 2010[88]	8- week MBSR	MOD, NM	CS	Watching sad videos vs. R	↑↓L	↑R	↑R		↓R		↑	
Gard *et al.*, 2012[90]	Vipassana	EX, NM	CS, WS	anticipation/pain during M and C	↑↓	↑R	↑R	↓		↓		
Goldin and Gross 2010[102]	8-week MBSR	MOD, NM	LRCT, WS	M vs. C (count backwards)				↑	↑			↑
Goldin *et al.*, 2012[103]	8-week MBSR	MOD, NM	LRCT, CS	Self-reference vs. control words at R								↑
Goldin *et al.*, 2009[101]	8-week MBSR	NOV	LRCT, WS	Self-reference vs. control words at R	↓			↑	↑			↑ ↓
Grant *et al.*, 2010[94] (S)	Zen	EX, NM	CS, WS	R		↑R	↑R	↑				
Grant *et al.*, 2011[89]	Zen	EX, NM	CS	During pain	↓B	↑B	↑B			↑B	↑B	
Hasenkamp *et al.*, 2012[65]	FA- AWARE Phase	EX	WS	M	↑L	↑B	↑B		↑L			
Hasenkamp 2012[65]	FA- FOCUS Phase	EX	WS	M	↑R							
Hasenkamp 2012[65]	FA- SHIFT phase	EX	WS	M			↓B	↑B	↓L	↑B	↑ B	↓B
Hölzel *et al.*, 2008[83] (S)	Vipassana	EX, NM	CS	R			↑					↑
Hölzel *et al.*, 2007[87]	Vipassana	EX, NM	CS, WS	M vs. C (arithmetic)		↑						↑B
Hölzel *et al.*, 2011[93] (S)	8-week MBSR	MOD	LRCT, WS	R								↑
Ives-Deliperi 2011[71]	MBSR trained experts	EX	WS	M vs. C (generation of numbers)	↓R	↓L	↓B		↓B			↑R
Klimecki *et al.*, 2012[114]	6-hr LKM	NOV	WS	Neutral vs. distressing videos at R						↑R		↑R
Lazar *et al.*, 2005[66]	Insight	EX, NM	CS	R	↑		↑					

Continued

Table 1. *Continued*

					DLPFC	dACC	AIC	IPL	SPL	BG	THAL	DMN
Lee *et al.*, 2012[82]	FA, LKM	EX, NM	CS, WS	Emotion photos vs. cognitive task at R and while M	↑							
Lee *et al.*, 2012[82] (FA only)	FA	EX, NM	CS, WS	Emotion photos vs. cognitive task at R and while M			↑L		↑R		↓R	
Lee *et al.*, 2012[82] (LK only)	LKM	EX, NM	CS, WS	Emotion photos vs. cognitive task at R and while M	↑L	↑L			↑R	↑L		
Luders *et al.*, 2009[84] (S)	Mixed	EX, NM	CS	R	↑						↑R	
Luders *et al.*, 2012[96] (Cortical gyrification) (S)	Mixed	EX, NM	CS	R	↑B			↑L	↑R			
Manna *et al.*, 2010[77] – monks FA > rest	Theravada FA	EX, NOV	WS	M vs. R	↑R ↓L	↑B	↓L					
Manna *et al.*, 2010[77] – monks OM > rest	Theravada OM	EX, NOV	WS	M vs. R	↑L				↑L			
Manna *et al.*, 2010[77] – monks OM > FA	Theravada FA,OM	EX, NOV	WS	M vs. R	↑B	R	↑L		↑L			
Manna *et al.*, 2010[77]- NOV FA > rest	10-day FA	EX, NOV	WS	M vs. R								↑L
Manna *et al.*, 2010[77]- NOV OM > rest	10-day FA	EX, NOV	WS	M vs. R	↑R	↑B						
Pagnoni 2007[48] (S)	Zen	EX, NM	CS	Attention Task						↑L		
Ritskes *et al.*, 2003[80]	Zen	EX	WS	M vs. R	↑R	↓				↑		
Taylor 2011[95]	Zen and mindfulness	EX, NOV	CS	M vs. R, while viewing emotional images								↓R
Yu *et al.*, 2011[78]	Zen FA	NOV	WS	M	↑							
Zeidan 2011[70]	4-day FA	NOV	L,WS	During pain	↑	↑B	↑R					↓B

NOTE: Type of study: S, structural (gyrification, volume); all others are functional (fMRI, PET). Type of meditation: FA, focused attention; OM, open monitoring; LKM, loving-kindness. Design: CS, cross-sectional; WS, within-subjects; RCT, randomized controlled trial; L, longitudinal. Sample: EX, expert; MOD, moderate; NOV, novice; NM, nonmeditator. Task: M, meditation; R, rest; C, control task. Brain areas: follow Brodmann area (BA), when provided, or authors' designation. L, left; R, right; B, bilateral; ND, no difference; DLPFC, dorsolateral prefrontal cortex (BA 9–12, 45, 46, 47); dACC, dorsal anterior cingulate cortex (BA 11, 24, 25, 32); AIC, anterior insular cortex (BA 13, 14, 47, 48); IPL, inferior parietal lobule (BA 39, 40, 43) (also called the temporal–parietal junction or TPJ); SPL, superior parietal lobule (BA 7, precuneus); BG, basal ganglia (caudate, putamen, globus pallidus); THAL, thalamus; DMN, default mode network (mPFC, PCC).

(right) insula has been found to have greater gray matter concentration[83,93] and thickness[66,94] in meditators and greater activation both during meditation[65,77] and on tasks following mindfulness training.[67,70,81,88–90,95] Larger volume and increased gyrification in the right anterior insula have been found to correlate with duration of meditation training.[83,96]

DMN. The default mode is a network of midline brain structures, including the medial PFC and posterior cingulate, that is active during rest or when the brain is not otherwise engaged, and is thought to be involved in stimulus-independent, self-referential thought and mind wandering.[97] Converging evidence suggests that meditation training may be associated with decreased DMN activity,[67,70,88,95,98–100] but see also counter-examples.[101–103] Because increased DMN activity is associated with negative mental health outcomes,[104,105] it has been posited that "one mechanism through which meditation may be efficacious is by repeated disengagement or reduction of DMN activity."[65]

Instead of being a sign of mental excitation, mind wandering and DMN activation are associated with decreased sympathetic arousal,[106] lower levels of alertness and vigilance,[107] and increases in delta power that indicate sleepiness.[108–110] The DMN includes some of the only brain regions that actually increase their activity during the transition from wakefulness to stage 1 sleep,[57–59] and vigilance can be pharmacologically induced by suppressing the DMN.[111] Thus, DMN activation and mind wandering can be viewed as a sign of mental laxity and drowsiness on a continuum with stage 1 sleep and dreaming.[112] In this view, when meditation decreases DMN activation/mind wandering, the result is not a calming in the direction of relaxation/sleep, but rather a move in the opposite direction: toward an increased alertness and vigilance that counteracts mental laxity and sleepiness.

Subcortical and brain stem structures. Studies of subcortical structures have found increased activation or gray matter density in tonic alertness-related areas in meditators, such as the thalamus,[84,88,89] basal ganglia,[48,89,113,115] and arousal-related areas of the brain stem, such as the reticular formation.[116]

Neurotransmitters
Increases in wake-related/sleep-inhibiting neurotransmitters, such as norepinephrine,[16,26,47,117,118] dopamine,[119] and serotonin[78,120–123] have been found in studies of non-Buddhist forms of meditation, although the relationship between peripheral and brain levels is unclear.

Functional connectivity

In addition to activation of alertness-related areas and deactivation of sleep-related areas, functional connectivity (FC) or correlated activity between brain areas can also serve as an index of sleepiness or wakefulness. The fading of consciousness during nonrapid eye movement (NREM) sleep is thought to be associated with the breakdown of effective connectivity between multiple cortical areas,[124] specifically within nodes of the DMN, and between the DMN and the attention network.

Intra-DMN connectivity
Connectivity between anterior and posterior nodes of the DMN remains intact during wake and into light and rapid eye movement (REM) sleep[125–127] but decouples during slow-wave sleep and vegetative states, when consciousness is at a minimum. Thus, the functional integrity of the DMN has been thought to be indicative of the level of consciousness.[127] FC studies of meditation have indicated increased connectivity between anterior and posterior nodes of the DMN at rest[128,129] and during meditation[130,131] in experienced meditators with 10,000 h of practice but not following 8 weeks of training,[132] which suggests that increases in DMN connectivity (and potentially an associated increase in wakefulness) correspond with later but not earlier stages of practice.

DMN and attention network connectivity
Typically, vigilance is associated with maximal anticorrrelation between the DMN and the attention network.[133] Impaired vigilance and lack of anticorrelation is caused by insufficient DMN deactivation so that self-referential processes and mind wandering intrude into (and impair) task performance.[134] Participants with more meditation experience exhibited increased connectivity between attentional regions and medial frontal regions (i.e., less anticorrelation), both during meditation[100,130,135] and during rest.[100,128] In experienced meditators, the decreased anticorrelation is associated with attention systems remaining active at rest when the DMN is active, and faster suppression of the DMN during attentional engagement and task performance.[65,100]

Although there is much variability in the methodologies, practices, and sample characteristics, more than 25 neuroimaging studies have found that Buddhist meditation practices are associated with activation/enlargement of the areas that underlie tonic alertness and/or prevent sleep both during meditation (state) and at rest or during tasks (trait). In order to promote sleep, the brain areas activated in meditation would need to be deactivated.[136] Furthermore, changes in FC both at rest and during meditation also correspond with greater wakefulness, especially in more experienced meditators. On the basis of the brain imaging findings, one might predict that meditators would be generally more awake and less sleepy, especially as practice progresses.

Less sleepy during wake

Subjective measures
Although many meditation studies have described subjective reports of decreased arousal, especially in the hyperaroused,[137] reports of increased energy and arousal following meditation are also prevalent. Early uncontrolled studies of mindfulness training in clinical samples found increased energy and

decreased fatigue as secondary outcomes.[138–140] Later randomized control trials specifically targeted fatigue[141–145] and called mindfulness meditation “vitality training.”[146] Improvements in fatigue were maintained up to 1 year[141,143,144,146] and correlated with improvements in neuropsychological functioning.[145] Studies in nonclinical populations with active controls have also found improvements in fatigue, alertness, and attention following Buddhist meditation training.[46,147]

Behavioral measures

Several studies have found improvements on behavioral measures of tonic alertness following both brief and long-term practice of both FA and OM meditations. Valentine and Sweet[40] compared experienced Buddhist meditators to controls on a sustained attention task that included both phasic and tonic alerting (i.e., expected and unexpected stimuli). Alerting capabilities were associated with length of practice and OM practitioners outperformed FA meditators on indices of tonic (but not phasic) alertness. Jha *et al.*[49] investigated multiple forms of attention in novices undergoing MBSR training and long-term meditators on a 1-month intensive Vipassana retreat. Orienting and directed attention improved in the MBSR group, but tonic alertness improved only in long-term meditators and was directly associated with prior meditation practice.

Although the above studies suggest that only OM practice in advanced meditators supports increased tonic alertness, other studies have found increases in tonic alertness following both long- and short-term FA training. Following 3 months of intensive Tibetan-style *shamatha* training, MacLean *et al.*[54] found increases in vigilance that were related to improvements in visual sensitivity, which persisted at least 3 months after the retreat ended. Lee[82] found that expert (2 h/day for 5 years) FA and loving-kindness meditators made significantly fewer omission errors on a continuous performance task than novices, indicating greater levels of tonic alertness. Kaul *et al.*[55] found that meditation-naive university students, who performed a 40-min FA meditation, improved their performance on the psychomotor vigilance task (PVT) in comparison to a nap or a control activity. This study also found that meditation improved decrements in PVT vigilance following a night of sleep deprivation, so that meditation practice increased wakefulness. This study suggests that some brief increases in tonic alertness may be apparent after only a single practice session of FA training.

Waking EEG

In some of the early meditation studies using objective polysomnographic measurements of sleep propensity, both Elson *et al.*[148] and Banquet and Sailhan[149] found that meditators were more likely to remain awake and less likely to fall asleep (defined as stage 2 sleep or delta EEG, respectively) than nonmeditator controls during a comparable period of relaxed wakefulness.[148,149] This finding is consistent with the notion that meditative training involves learning to keep a relaxed and yet aroused mental state for successively longer periods of time.

Although many early studies of waking EEG during meditation reported enhanced theta and alpha power consistent with a possibly near sleep-like state, recent investigations with more rigorous methodology have failed to replicate these findings.[11] Instead, localized frontal midline theta increases have been more consistently obtained in meditators,[150–152] especially during FA practices, indicative of the concentrated cognitive engagement indexed by frontal midline theta.[153,154] Other studies have reported higher baseline (trait) and state-related increases in gamma power in long-term Tibetan Buddhist practitioners,[129] Vipassana meditators,[151] as well as meditators in other traditions,[155] which are indicative of a more highly alert and aware brain state.

Reports of increases in midline frontal delta power[156] or decreases in gamma power[98] that are thought to indicate decreased DMN activity also support the idea of the wake-promoting and sleep-inhibiting effects of meditation. In addition, Cahn[151] reported decreased bilateral frontal delta power as a state effect of Vipassana meditation in long-term practitioners, consistent with a more highly alert brain state. A comprehensive analysis of waking EEG during breath-focused awareness before, during, and after an intensive 3-month meditation retreat indicated decreases in central and parietal beta power and a concomitant significant decrease in peak alpha frequency.[157] The decreased beta activity might be conceived of in relation to decreased active processing consistent with the traditional understanding that beta activity is associated with an active and aroused brain-processing state.[158] However, the authors note that decreased beta activity has been correlated with increased blood oxygen level–dependent signal in precentral motor areas[159] and with facilitating sensory processing of attended somatosensory stimuli,[160] and thus, this decrease in beta power was interpreted as indicative of enhanced cortical activation. The decrease in peak alpha frequency was thought to correspond to a decrease in cognitive effort because increased cognitive load leads to increases in peak alpha frequency.[161] This has also been previously reported as a trait effect of meditation.[11]

In addition to spontaneous EEG, investigations of event-related EEG dynamics in relation to sensory stimuli further bolster the notion that meditation is associated with a concurrently more alert and efficient brain state. Decreased P300 amplitude to initial visual stimuli on an attentional blink task,[43] and increased frontal theta synchronization[162] to normally unattended subsequent stimuli following an intensive 3-month retreat, indicates a broadening of attentional capacities across time that facilitates increased processing of difficult-to-detect stimulus trains. This same group of subjects also showed an enhanced perception and concomitant theta synchronization in response to challenging subtle auditory targets in an auditory oddball paradigm, further delineating brain mechanisms underlying meditative practice effects in improving attentional engagement to demanding cognitive tasks.[51] Using a simpler and passive auditory oddball paradigm in assessing state effects of Vipassana meditation, it has also been shown that while later signatures (P300, delta synchronization) of automated frontal cognitive engagement to unexpected distracter stimuli are decreased, markers of enhanced early stimulus representation (N100, gamma synchronization) are concomitantly observed, consistent with the notion of a highly aware brain state that is simultaneously less reactive.[163,164]

Overall, findings in more recent awake EEG studies of meditators, whether assessed by increased frontal theta power associated with highly focused cognitive states, increased gamma power associated with more active cortical processing, decreases in measures of DMN activation or measures of enhanced sensory and attentional processing with concomitantly decreased automated reactivity, have been consistently indicative of increased brain alertness.

More awake during sleep

In many Tibetan Buddhist[165] and also non-Buddhist traditions,[166] the goal of cultivating vigilant awareness in every waking moment is extended beyond the waking state to sleep states as well. One teacher instructs, "When you fall asleep, you are asleep with virtually full awareness."[165] Several studies have described meditators' self-reports of ongoing conscious awareness during sleep.[166,167] In support of such increased wakefulness during sleep, several polysomnographic sleep studies have found greater cortical arousal during sleep in meditators, including increased stage 1 sleep, alpha–theta (wake-like) EEG, arousals, reduced slow-wave sleep,[149,166,168] and increased gamma.[169]

Ferrarelli *et al.*[169] found that long-term meditators had increased parietal-occipital EEG gamma power (25–40 Hz) during whole-night NREM sleep compared to nonmeditating controls. Increased gamma was positively correlated with the length of lifetime daily meditation practice (Spearman's $\sigma = 0.475$, $P < 0.02$). In an EEG-based longitudinal randomized controlled trial (RCT), Britton *et al.*[168] found increased wakefulness and decreased sleep propensity following Mindfulness-Based Cognitive Therapy (MBCT) that was correlated with improved mood and meditation practice amount. Over the course of the trial, the MBCT group increased in stage 1 minutes, awakenings, and arousals, and decreased in percent of slow-wave (stages 3 and 4) sleep compared to waitlist controls. Each of these objective indices of increased cortical arousal was correlated with amount of home meditation practice in a linear dose–dependent fashion, which further supports that the increased arousal was due to meditation. Although there was no overall treatment effect on sleep duration, average (diary) total sleep at posttreatment was negatively correlated with minutes of daily practice, so that more meditation was associated with less sleep (Fig. 2A–D).

There are several lines of evidence to suggest that these increases in cortical arousal are beneficial and desirable, rather than indicators of poor sleep or insomnia. First, these indices of increased cortical

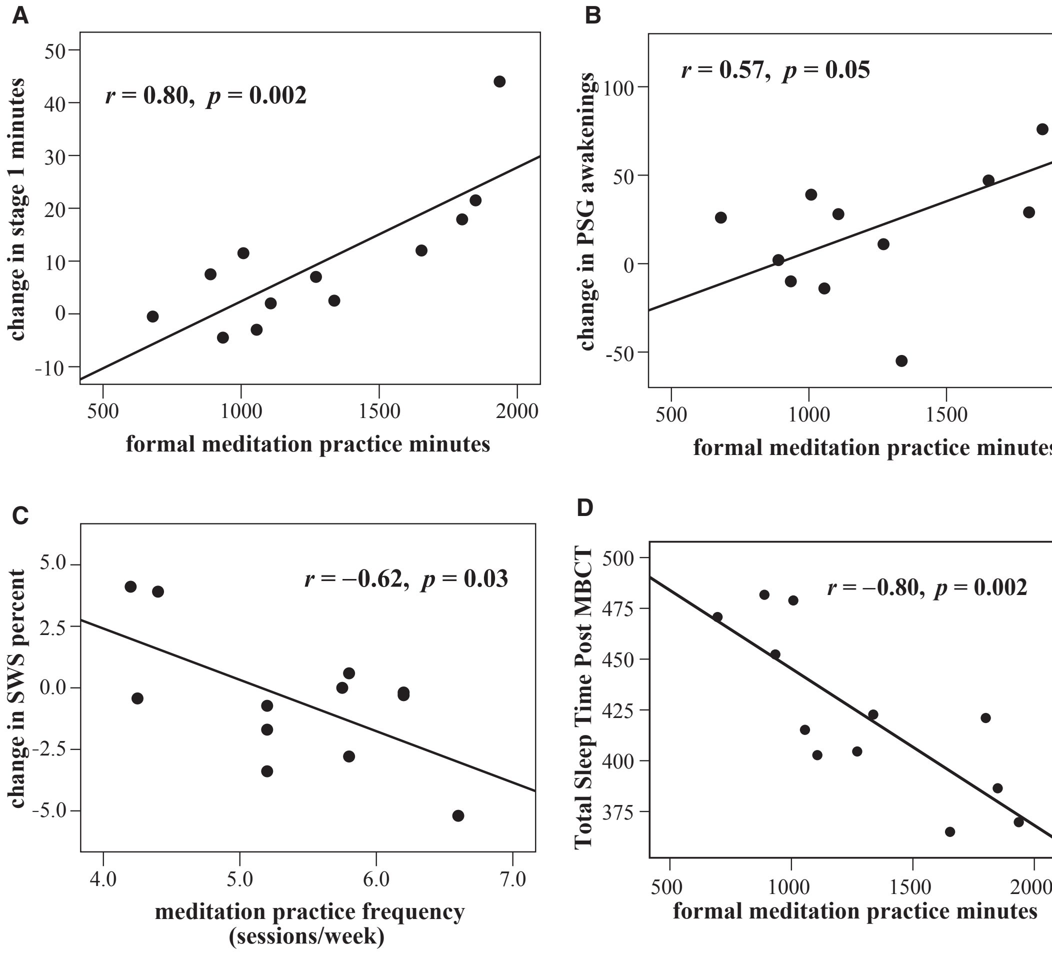

Figure 2. Correlation between meditation practice and changes in sleep or arousal variables following MBCT, including (A) stage 1 minutes, (B) arousal and awakenings, (C) slow-wave sleep (SWS) percent, and (D) total (diary) sleep time. Figures A–C reprinted, with permission, from Britton *et al.*[168]

arousal were also associated with an improvement in depression Beck Depression Inventory (BDI) scores, including increased awakenings, arousals, stage 1 minutes, as well as reduced overall sleep time ($r = -0.60$), so that the larger the increase in cortical arousal, the larger the decrease in depression scores.

Meditation and sleep amount

Decreased sleep duration in meditators during periods of intensive practice, such as multiday silent retreats is a well-known phenomenon[27] and is considered a sign of meditative proficiency and progress.[19] Kornfield[167] documented decreased sleep duration in Theravada Vipassana meditators on 3-month retreats (12–15 h of meditation/day) compared to a control group who meditated 1–2 h/day. Seventy percent of the retreat participants reported an average 2-h decrease in sleep duration in comparison to 10% of controls, who also reported increases in sleep duration (10%). The periods of sleep decrease were associated with periods of greatest self-reported and teacher-observed mindfulness.

In a qualitative study in our laboratory, a meditator who had completed a 3-month Tibetan-style *shamatha* retreat (12–15 h/day), reported that for the first 2 weeks of the retreat, her sleep duration initially *increased* to 8 h/night before gradually diminishing to 1.5–3 h/night by the eighth week. Buddhist texts suggest a nocturnal sleep time among proficient meditators of approximately 4 hours.[19]

Other studies have begun to assess the effects of daily meditation practice on sleep duration outside a retreat context. Kaul *et al.*[55] measured 15 days of diary-reported sleep in a small sample of experienced Indian meditators ($n = 7$) who practice focused (breath) awareness techniques 1.5–3.5 h/day (for at least 3 years) compared to matched nonmeditating controls ($n = 23$). Sleep diaries indicated a significantly shorter average nocturnal sleep duration in meditators than controls (5.2 h vs. 7.8 h, $P < 0.00001$).

A recent study examined sleep duration of meditators in daily life, using objective, EEG-based measures of sleep in a much larger sample. This cross-sectional study[169] recorded single-night polysomnographic sleep studies (high-density EEG) in long-term (8700 average lifetime meditation hours) Tibetan and Theravada Buddhist meditators and age- and gender-matched nonmeditating controls. The meditators had a significantly reduced total sleep time (6.2 h vs. 6.7 h, $P = 0.001$) as well as increased minutes of wake after sleep onset (74 min vs. 44 min, $P = 0.003$) compared to controls.

In contrast to advanced Buddhist meditators who view decreased sleep as a sign of progress, modern clinical applications seek to increase sleep duration and depth with meditation practice. High-quality empirical support for clinically-oriented meditation programs, such as MBSR, promoting sleep have not been particularly strong (see Ref. 170 for a review) and often lack objective measures of sleep, particularly EEG. Although some RCTs have found positive effects of meditation training on self-reported sleep quality,[171–173] other RCTs have found no difference from controls.[174–176] Subjective ratings of sleep quality appear to be more affected by meditation than specific sleep parameters (such as sleep duration)[176,178] with both positive and negative changes in arousal when measured by objective measures.[171–173] After many mixed or equivocal studies of MBSR, some sleep researchers have suggested that "mindfulness meditation as a single intervention might not yield strong effects on sleep"[173] and instead created programs that include mindfulness as part of a multicomponent cognitive-behavioral sleep treatment.[177,178] As an indication of the current state of the research, the most recent (2012) U.S. Government Report judged the level of evidence of clinically-oriented meditation programs for improving sleep to be "insufficient."[179]

What factors determine whether meditation training will increase or decrease arousal, promote wakefulness or sleep? This is an important research question that is largely unknown, but probably encompasses a number of factors, including dose and type of practice, sample characteristics (condition/disorder), degree/type of sleep disturbance, comparison group, concurrent medication,[171] age and method of measuring sleep or wakefulness (subjective/objective).

Nonlinear progress

In order to make sense of the mixed and contradictory findings, it may help to approach the trajectory of meditative expertise as nonlinear in regard to arousal and tonic alertness.[180] Specifically, relaxing and sleep-promoting effects might be expected at low doses or early stages of practice (such as an introductory 8-week program), but more alertness, wakefulness, and less sleep might be expected as dose or practice progresses. Britton *et al.*[178] found that as little as 5–10 min/day for 2–3 days/week (<1 h/week) increased self-reported sleep duration by more than an hour, but that as practice times approached 30 min/day (>3 h/week), then sleep duration began to decrease (Fig. 2D) and cortical arousal began to increase (Fig. 2A–C).[168] Similarly, our 3-month retreat participant slept more during the first 2 weeks, then progressively less, in line with findings of decreased sleep following intensive[167] or long-term daily practice.[55,169]

Both Buddhist sources and recent research support the idea that early stages of practice require more effort and produce more fatigue than later stages of practice.[27,181,182] Most beginning meditators start with a form of FA training, which relies on orienting, executive, and phasic alerting forms of attention. Like training a muscle, attention is redirected from self-referential thought back to the meditative object, over and over until attentional stability can be established. Proficient meditators can disengage faster and more easily from self-referential thought (DMN activity).[65] Attention enhances efficiency of sensory information processing and enhances sensory acuity by increasing the ratio of signal to noise in neural communications.[183] Meditation-related increases in perceptual sensitivity and sensory acuity[43,184–186] require fewer cognitive resources and less effort for stimulus detection

Table 2. **Correlation between meditation experience/expertise and alertness**

Study	Expertise	Alertness/sleepiness	*r* value (Pearson)
Self-report Measures			
Ong *et al.*[137]	KIMS score	Diary-rated daytime sleepiness	–0.65^{*a}(posttreatment)
			–0.71^{**a}(6 months)
			–0.54^{*a}(12 months)
		Diary-rated daytime tiredness	–0.66^{**a}(posttreatment)
			–0.62^{**a}(6 months)
Cahn[164]	Years of daily practice	Drowsiness during control condition	−0.60*
Britton, Bootzin *et al.*[178]	Frequency of practice in mindfulness-based sleep treatment (5–10 min day/2–3 days week)	Total sleep duration	+ .56*
Britton, Haynes *et al.*[168]	Minutes of home practice during MBCT	Total sleep duration	−.80**
Neuroimaging Measures (EEG, fMRI)			
Britton, Haynes *et al.*[168]	Minutes of home practice during MBCT	Increase in stage 1 minutes during sleep	.80**
	Minutes of home practice during MBCT	Increase PSG awakenings and arousals during sleep	.57*
	Frequency of practice (times per week)	Decrease in percent of slow-wave sleep (stages 3/4)	−.62*
Ferrarelli[169]	Lifetime daily practice hours (non-retreat)	Increased occipital-parietal gamma during NREM sleep	.48$**^{a}$
Luders[96]	Lifetime hours of meditation practice	Increased gyrification in R anterior insula	NR
Holzel[83]	Lifetime hours of Vipssanna meditation	Increased volume of R anterior insula	.36
Hasenkamp[65]	Lifetime hours of meditation practice	Decreased activity in DMN	−.74***
Baron Short[79]	Lifetime hours of meditation practice (<10 yrs vs >10 yrs)	Activation of DLPFC and ACC during mindfulness meditation	NR
Behavioral Measures			
Jha[49]	Lifetime meditation experience	Magnitude of the alerting score post-retreat (negative value indicated better performance)	−.52*
Valentine[40]	Meditation experience	Performance on tonic alerting task	NR

$^{\#}P = .06$, $^{*}P < .05$, $^{**}P < .01$, $^{***}P < .005$
^{a}Spearman's σ
KIMS = Kentucky Inventory of Mindfulness Skills
NR = not reported

and therefore free up resources to be available for other functions.[43,54] Like having stronger muscles, more efficient processing is less taxing or fatiguing and supports more enduring alertness. Reports that increases in directed attention/phasic alerting lead to improved tonic alertness[49,187] support Kabat-Zinn's statement that "By paying attention you literally become more awake."[188] Indeed, many studies have found positive correlations between meditative expertise (practice amount) and subjective, neurological, and behavioral measures of wakefulness (see Table 2).

However, the relationship between phasic and tonic alertness is more likely bidirectional and mutually reinforcing,[35–38] as the resources that are freed up by more efficient processing (sensory acuity) can promote a form of tonic alertness that makes the meditator more aware of internal and external stimuli,[43,54,189] thus leading to more efficient processing, until the system runs so effortlessly that it may require much less recovery time (i.e., sleep).

Neuroimaging studies are beginning to support a nonlinear trajectory of meditative practice and proficiency. Brain areas underlying tonic alertness are activated in early stages of training, compared to nonmeditators, but these areas begin to deactivate as meditative expertise becomes more proficient and effortless in later stages.[45,87,181,190] This eventual effortlessness that accompanies increased efficiency in later stages is thought to arise from increased connectivity between brain areas that were previously not coactivated.[100,130,181,191]

Thus, the point when meditation practice no longer produces drowsiness and sleep, but instead engenders increased and sustained wakefulness, may be an indicator of the neuroplastic changes that signify meditative proficiency. In this sense, "awakening" is not a metaphor, but rather an iterative process of neuroplastic modifications and increased efficiency that supports a new level of perceptual sensitivity and insight.

Conclusion

The purpose of this review was to provide evidence, by drawing from both scientific studies and Buddhist textual sources, of meditation's arousing or wake-promoting effects in an attempt to counterbalance the common modern characterization of Buddhist meditation as a relaxation technique that promotes hypoarousal and sleep. Traditional Buddhist formulations and a host of recent subjective, behavioral, and neuroimaging studies of meditation suggest that Buddhist meditation practices may promote greater wakefulness and lower sleep propensity, especially as practice progresses. With a more interdisciplinary approach that includes traditional Buddhist formulations, the scientific study of meditation may gain a more comprehensive view of the full range of possible effects and applications of contemplative practices.

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Conflicts of interest

The authors declare no conflicts of interest.

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