Review article

The psychological and neurophysiological concomitants of mindfulness forms of meditation

Ivanovski B, Malhi GS. The psychological and neurophysiological concomitants of mindfulness forms of meditation.

Objective: To provide a comprehensive review and evaluation of the psychological and neurophysiological literature pertaining to mindfulness meditation.
Methods: A search for papers in English was undertaken using PsycINFO (from 1804 onward), MedLine (from 1966 onward) and the Cochrane Library with the following search terms: Vipassana, Mindfulness, Meditation, Zen, Insight, EEG, ERP, fMRI, neuroimaging and intervention. In addition, retrieved papers and reports known to the authors were also reviewed for additional relevant literature.
Results: Mindfulness-based therapeutic interventions appear to be effective in the treatment of depression, anxiety, psychosis, borderline personality disorder and suicidal/self-harm behaviour. Mindfulness meditation *per se* is effective in reducing substance use and recidivism rates in incarcerated populations but has not been specifically investigated in populations with psychiatric disorders. Electroencephalography research suggests increased alpha, theta and beta activity in frontal and posterior regions, some gamma band effects, with theta activity strongly related to level of experience of meditation; however, these findings have not been consistent. The few neuroimaging studies that have been conducted suggest volumetric and functional change in key brain regions.
Conclusions: Preliminary findings from treatment outcome studies provide support for the application of mindfulness-based interventions in the treatment of affective, anxiety and personality disorders. However, direct evidence for the effectiveness of mindfulness meditation per se in the treatment of psychiatric disorders is needed. Current neurophysiological and imaging research findings have identified neural changes in association with meditation and provide a potentially promising avenue for future research.

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Introduction

Individuals in the East have benefited from regular meditation for thousands of years and yet only relatively recently has the practice been embraced by the Western world. Meditative practices are often embedded within religion, but it is their gradual disassociation from religious practice that has allowed them to be subjected to scientific inquiry. The study of consciousness itself, particularly the idea of altered states of consciousness, is something that has entertained philosophers and scientists for centuries. The study of specific meditative practices has indeed attempted to shed light on our understanding of consciousness, and recent collaborations between 'contemplators' and 'scientists' have been surprisingly fruitful, resulting in novel insights as to the nature of meditative states. The seemingly powerful effects of meditation are intriguing and the potential health benefits to individuals have aroused particular interest as

individuals search for alternatives to modern-day medicines.

Meditation can be defined as both a process and a state. According to the Yoga Sutras, meditation is the act of inward contemplation and the intermediate state between mere attention to an object and complete absorption within it (1). Some suggest that it can be broadly characterized into two main types namely, concentration and mindfulness meditation (2,3). Concentration meditation techniques involve the focusing of attention on a mental 'object', for example, counting or monitoring breathing, reciting a mantra or visualizing processes in the body, to still the mind and enhance clarity and awareness. In these forms of meditation, the individual *narrows* their attentional focus. Specific styles include Transcendental meditation (TM), Qiyong Yoga, Yoga Nidra, Sahaja Yoga and Samatha meditations. Mindfulness techniques on the other hand involve the expansion of attention in a nonjudgmental and nonreactive way to become more aware of one's current sensory, mental and emotional experiences. This technique requires *expanding* awareness. Mindfulness forms of meditation include Zen and Vipassana meditations.

The latter, Vipassana or Insight meditation, comes primarily from the Thai and Burmese Theravada Buddhist tradition. In this form of meditation, individuals assume the role of an observer of their thoughts and bodily sensations. In doing so, the observer then learns to be less judgmental of these sensations. The aim is to remain in the present moment and the ultimate goal is to increase equanimity (4) – a state of acceptance, nonreactivity and nonattachment that relies on awareness of thoughts and somatic sensations. Zen meditation stems from the Mahayana school of Buddhism that is practiced in China, Japan and Korea. This form of meditation focuses on the exclusion of extraneous thoughts to interrupt cognitive reasoning processes to achieve a heightened state of consciousness (5). This is achieved using techniques such as sitting in the lotus posture with thoughts suspended or pondering a word puzzle.

This broad categorization of meditation styles, initially proposed by Goleman (2,3), although helpful is also misleading as delivery models of meditation can incorporate both 'types' of practice and hence cannot be considered 'purely' as belonging to one school or the other. Some researchers have suggested that most meditation techniques lie somewhere along a continuum of mindfulness-concentration practice (6–8).

The lack of agreement on how to best define meditative practices is a reflection of poor under-standing that limits systematic categorization. A dimensional approach has its merits and may seem theoretically valid; however, we propose an extension and suggest that perhaps meditation techniques are best defined along two orthogonal axes (concentration and mindfulness) each of which is dimensional, rather than using a single concentration-mindfulness continuum. For the purpose of this review, however, we revert to the broad concentration/mindfulness distinction and draw attention to the limitations of such a classification system.

Mindfulness and concentration meditations have been widely researched since the 1970s; however, the majority of studies that have investigated the clinical effectiveness and neurophysiology of meditation have focused on investigating concentrative meditation techniques, in particular TM. Over the past decade, however, there has been a shift toward the investigation of mindfulness meditation (9) as mindfulness-based techniques have been increasingly embraced by psychologists and psychiatrists. This is evinced by their integration with other psychotherapeutic techniques for the treatment of both medical and psychological problems. Recent research findings have generally shown the effectiveness of such interventions [for a review see (10)]; however, there remains insufficient understanding of *how* these therapies exert neuropsychological and neurophysiological effects. As mentioned above, the meditation literature is extensive and recent reviews [eg, Cahn and Polich (11) and Murphy and Donovan (12)] have attempted to synthesize both the psychological and physical concomitants of meditative practices. Given the recent interest in the clinical application of mindfulness techniques, our review is limited to the psychological, electrophysiological and new imaging studies of mindfulness forms of meditation. Findings relating to the neurophysiology of concentrative techniques are considered but not reviewed in detail [for a comprehensive review see Cahn and Polich (11)].

Clinical application of mindfulness techniques

Mindfulness is a multifaceted construct that has proved difficult to operationalize (13), enveloping concepts that include nonjudgement, acceptance, present awareness, attention and intention. These 'components' are required to be present in order to experience mindfulness (14) and it has been said that mindfulness is an activity that can be *described* using words but that cannot be wholly captured by words as it is a subtle process that invokes

nonverbal experiences [for a complete description see Gunaratana (15)]. However, an examination of mindfulness requires a definition of its construct. Within the therapeutic context, mindfulness is defined as 'the awareness that emerges through paying attention on purpose, in the present moment, and non-judgmentally to the unfolding of experience moment by moment' [Kabat-Zinn (16), p. 145].

Mindfulness-based stress reduction

Psychological interventions that involve the integration of Eastern and Western philosophies gained currency in the 1970s. The clinical application of mindfulness interventions to disease is most well documented in the treatment outcome studies conducted by Kabat-Zinn and colleagues (17). These investigated the efficacy of a mindfulness-based stress reduction (MBSR) treatment programme in relieving 'suffering' across a variety of medical patient populations. The MBSR programme is an 8- to 10-week group intervention that incorporates intensive mindfulness meditation (weekly 2- to 2.5-h meetings and a full-day meditation session) and hatha yoga (10). The main goal of the programme is for individuals to become more aware of their thoughts and feelings and to recognize them as mere mental events rather than aspects of the self, hence ultimately changing the individuals' relationship to their thoughts (13,18,19). This change then results in a reduction of stress through improved emotion regulation.

Initial investigations were descriptive in nature, with most studies suffering from methodological problems (13); however, the effectiveness of MBSR has been shown (16) producing heightened neural activation in healthy individuals (20) and in patients suffering from chronic pain (21–23) and psoriasis (24) as compared with Treatment As Usual (TAU). For example, Davidson and colleagues (20) found significant increases in left-sided activation in the anterior cortical area and a significantly greater rise in antibody titers in MBSR-trained participants as compared with wait-list controls, suggesting that MBSR training can lead to neural changes consistent with better handling of negative emotion and can also modulate immune function.

MBSR has also been applied to the treatment of a variety of psychiatric conditions. Patients with generalised anxiety disorder (GAD) and panic disorder showed significant improvement following MBSR in measures of anxiety and depression (23) that were maintained at 3-year follow-up (25); however, these studies failed to include a control group for comparison. Patients with binge eating disorder showed significant improvement following MBSR across several measures of eating and mood (26); however, once again this study did not include a control group, and hence it is unclear whether MBSR has any additional effect over and above placebo in these populations with psychiatric disorders.

Mindfulness is also couched within dialectical behaviour therapy (DBT) (27), acceptance and commitment therapy (ACT) (28), mindfulness-integrated cognitive behaviour therapy (MiCBT) that is used as a generic model to address a broad range of disorders (4), mindfulness/acceptance-based treatments for GAD (29) and mindfulness-based cognitive therapy (MBCT) for relapse prevention in the treatment of depression (19,30) and the prevention of suicide (31). A mindfulness cognitive behavioural therapy has also been used to treat Obsessive Compulsive Disorder (OCD) (32). Research to date has provided promising results for the effectiveness of these approaches in the treatment of psychiatric conditions and interpersonal problems including social phobia (33), relapse prevention in major depression (34–36), acute depression (37), reduction of ruminative thinking (38), borderline personality disorder (39) as well as improving general wellbeing in healthy controls (40–43), and consequently, it is also being applied to other problems, for example, the prevention of recurrent suicidal behaviour (31,44). Teasdale et al. (45), however, caution against its indiscriminate use in the management of mental disorders prior to the development of valid treatment models.

MBCT and other mindfulness-based interventions

MBCT was developed in an attempt to reduce relapse rates in individuals with recurrent major depression by preventing the reactivation of depressive thinking patterns that were present in previous episodes (10,19,46). This is achieved through changing one's relationship to their thoughts, hence reducing the incidence of ruminative thinking that may precipitate relapse (19,46). MBCT in nondepressed individuals with a history of three or more depressive episodes reduced relapse rates to 37% as compared with 66% for the TAU group (35). These findings were replicated in a follow-up study (34). In a more recent study, Finucane and Mercer (37) used the MBCT programme in patients currently depressed and with a history of recurrent depression and anxiety, and reported noticeable improvement in 72% of patients on depression outcome measures and in 63% of patients on anxiety outcome measures.

In another recent treatment outcome study, mindfulness training (adapted from MBCT) coupled with task concentration training (TCT) was found to be effective in the treatment of social phobia, with gains being maintained at 2-month follow-up (33). Treatment gains were largely because of significant changes in the level of fear of negative evaluation, social phobia beliefs and the self-ideal discrepancy, with the authors concluding that attention as well as cognitive changes may have been responsible for the treatment effects.

Schwartz (32) used a mindfulness-based cognitive approach coupled with traditional behaviour therapy in the treatment of OCD and showed cerebral glucose metabolism changes in the orbitofrontal and cingulate cortices, and basal ganglia circuitry, and neurobiological changes that emerged as a consequence of psychological treatment. However, the predominant treatment approach in the study was behaviour therapy therefore significant attribution of the biological changes to the mindfulness-cognitive therapy component is not possible.

In a recent Cochrane review of meditation treatment for anxiety disorders, the authors found that only two investigations from an initial 50 met the rigorous study design criteria to be included in the meta-analysis (47). One of these studies compared the effectiveness of TM, electromyography-feedback and relaxation therapy (48) in the treatment of anxiety disorders, the other compared Kundalini meditation with the relaxation response (49) plus mindfulness meditation technique (from Kabat-Zinn's MBSR programme) in the treatment of OCD (50), but both studies failed to show any significant differences between the treatment modalities.

Acceptance and commitment therapy

ACT, based on Relational Frame Theory, incorporates acceptance, mindfulness and values clarification into a traditional behavioural framework whereby individuals are encouraged to accept internal events while simultaneously working toward behavioural goals (28,51). ACT is being investigated in a growing number of medical and psychiatric populations including chronic pain (52), anxiety disorders (panic disorder, specific phobia and social anxiety) (53) and depression [eg, Beck et al. (54), Zettle and Raines (56) and Folke and Parling (55)]. It has also been found to be effective in the treatment of psychosis. Bach and Hayes (57) randomized 80 patients to either TAU or TAU in combination with four individual sessions of ACT (ACT + TAU). They found that individuals receiving ACT despite reporting increased symptoms expressed lower levels of believability in these symptoms as compared with the TAU group. Furthermore, the rehospitalization rate was 50% lower for the ACT group as compared with the TAU group. In a more recent study, Gaudiano and Herbert (58) randomized 40 in-patients to an extensive TAU (ETAU) group or ETAU and ACT (ACT + ETAU) group and found that at discharge individuals in the ACT + ETAU group showed an improvement in affective symptoms, overall levels of impairment, the level of social impairment and the distress associated with hallucinations. Furthermore, decreases in the believability of hallucinations were only observed for the ACT + ETAU group and were found to be associated with change in distress levels when controlling for the frequency of hallucinations.

Dialectical behaviour therapy

DBT combines elements from client-centered, psychodynamic, gestalt, strategic and systems orientations and Zen psychology into a predominantly cognitive-behavioural framework (59). Inherent in the DBT approach is the dialectical perspective on the individual's experiences and interactions with others and their environment, as well as on the intervention itself (use of both change and acceptance to gain a balance in functioning) (59). It has a strong focus on the validation of the individual's experience, the therapeutic relationship and skills training (59). DBT has documented efficacy for the treatment of suicidal behaviour and borderline personality disorder in in-patient, out-patient, adult and adolescent population samples (39,60–65). For example, in a recent community out-patient trial comparing DBT to nonbehavioural psychotherapy (community treatment), subjects receiving DBT were 50% less likely to attempt suicide, required less hospitalization related to suicidal ideation, had reduced medical risk associated with all suicidal and self-injurious behaviours, better treatment adherence, and reduced emergency contact with the hospital (63).

Treatment outcome studies thus provide some support for the clinical application of integrated mindfulness and cognitive behavioural treatment approaches to the treatment of psychiatric disorders. Although the results are promising, it should be emphasized that some of the studies in this field do have methodological problems in particular failing to include an appropriate control condition. Replication of the findings using controls and evaluating effectiveness with specific populations

is necessary. Furthermore, the mindfulness meditation component is often only one of a number of components in these programmes and hence any positive results can only be attributed to the effectiveness of the programme as a whole and not the mindfulness meditation *per se*. The interpretation of positive findings as evidence for the efficacy of mindfulness meditation techniques is clearly flawed. To make such conclusions, first the evidence for the effectiveness of specific mindfulness meditation techniques must be obtained and second the question of *how* these treatments exert their therapeutic effects need to be evaluated?

Evidence for the efficacy of the mindfulness (Vipassana) meditation techniques (rather than the Western adaptations discussed earlier) comes from the few studies that have evaluated the effectiveness of traditional 10-day Vipassana courses in incarcerated populations. An earlier study of the Vipassana Meditation (VM) course in a prison population in India found evidence of reduced recidivism, depression, anxiety and hostility (66–68). A recent non-randomized study evaluated the short-term effectiveness of VM compared with TAU (comprising programmes such as chemical dependency treatment and substance use education, and other rehabilitation services including case management, vocational programmes, acupuncture, mental health services and adult education) on reducing post-incarceration substance use and related psychosocial problems (69). Results from this study showed that VM participants reported significantly less use of cocaine, alcohol and marijuana and fewer alcohol-related negative consequences 3 months following release from prison. There was also support for significantly lower levels of psychiatric symptoms, more internal alcohol-related locus of control and higher levels of optimism. Further investigation of the potential therapeutic effects of the standardized 10-day VM courses is clearly warranted.

Mechanisms of action: How does Mindfulness work?

Psychological processes

Mindfulness approaches, unlike traditional cognitive therapy, do not directly address the content of thought but rather alter the individual's *relationship* to their thoughts (19). As described earlier, mindfulness involves the nonjudgmental observation of constantly changing internal and external stimuli as they arise (10), and this skill is developed through a variety of meditation exercises. Mindfulness-based tasks encourage the individual to attend to either internal experiences, such as bodily sensations, thoughts and emotions, or external stimuli, such as sounds. The individual is required to observe these experiences but not evaluate them or react to them. Baer (10) asserts that mindfulness involves 'flexible awareness'. Individuals are asked to focus on the target of observation in the present moment, for example, body sensations or breathing, acknowledging passing thoughts and sensations, but not focusing on their content. Hence, mindfulness teaches that most sensory, cognitive and emotional experiences are transient and therefore impersonal. Mindfulness-based interventions do not focus on achieving cognitive or behavioural change; however, such change is often a consequence of *being* mindful (10). Given that mindfulness is a multifaceted construct, it is difficult to ascertain which components may be more instrumental in the achievement of the change that is associated with mindfulness-meditative practices. Whether it can in fact be segregated and examined as discrete components is a question in itself? However, the specific mechanism of action in mindfulness-based approaches is now of greater interest to researchers with evidence of it affecting cognitive processes such as ruminative thinking (38) and overgeneralizing of autobiographical memories (36,70) as well as attentional and perceptual processes. Shapiro et al. (71) have recently posited a triaxiomatic model that defines mindfulness as a state that arises when intention, attention and attitude are simultaneously cultivated and it is through this process that 'reperceiving' occurs, which they argue is the central process by which change is achieved. Shapiro et al. (71) go on to suggest that this process of reperceiving can be facilitated by self-regulation, values clarification, cognitive behavioural flexibility and exposure.

A review of the literature examining the components of mindfulness, such as attention and intention reveals that few studies have examined the direct effects of meditation on these psychological domains using standardized assessment tasks. An early investigation of the relation between meditation and attention proved negative (72). In this study, using volunteers trained in a Zen meditation exercise, attention was not found to be predictive of meditation response; however, it has been suggested that perhaps the measures of attention used (digit span, continuous additions and size estimations) did not assess those aspects of attention most relevant to meditation (73). A study using the Children's Embedded Figures Test showed an improvement in children's ability to focus and refocus their attention and ignore distracting stimuli as a result of an 18-week

breath-focused meditation (74), and improved measures of attention as a result of TM practice (75). Breath-counting meditation was also shown to reduce the frequency of intrusions and shorten discovery times on the Embedded Figures Test compared with two control groups (76). The use of yogic concentrative meditation in a 6-week training intervention for the treatment of adolescent attention deficit hyperactivity disorder (ADHD) resulted in substantial improvement in symptoms (77).

In relation to mindfulness-based practices, mindfulness and concentrative meditative practices were compared using a sustained attention auditory counting task, with results reflecting superior attentional performance for meditators compared with controls as well as long-term compared with short-term meditators (73). Furthermore, the mindfulness meditators performed better than the concentrative meditators on a task that assessed sustained attention using unexpected stimuli. Hence, mindfulness meditation appears to have a direct effect on attentional capacity both in terms of enhancing inhibition of distracting information and sustaining attention, implicating the enrolment of the right anterior frontal cortex (78). Furthermore, attentional 'absorption', or episodes of 'total' attention, has been found to be related to proficiency in meditative practice (mixed meditation types) such that absorption increases and trait anxiety decreases as a function of the length of meditative practice, suggesting that meditation practices are associated with decreased autonomic arousal and increases in cortical responsivity (79). Absorption is thought to reflect greater 'openness to experience' (73). Likewise, the depth of concentration during Zen meditation is thought to be related to openness to experience either because of an increase in empathy or in affective sensitivity (80). Hence, mindfulness meditation seems to lead to improvements in multiple aspects of attention, including sensitivity, concentration, openness to experience and ability to inhibit distracting stimuli. Further, these changes are related to the duration of meditation practice.

Mindfulness practice has also been shown to have an effect on perceptual sensitivity. A study assessing visual sensitivity thresholds in mindfulness meditators (81) showed that following 3-months of intensive meditation, meditation practitioners were able to detect light flashes of shorter duration when compared with before the intensive meditation, suggesting changes in perceptual sensitivity, and this change was not observed in a group of meditators that did not meditate as intensely. The intensive meditation

practitioners were also able to discriminate between two light flashes separated by a shorter interval, reflecting increased perceptual acuity, when compared with before the 3-month intensive meditation and with the non-intensive meditating controls (81). A related study comparing three groups of mindfulness meditators to non-meditating controls supported the finding of decreased threshold to short light flashes in mindfulness meditators (all three groups) compared with controls; however, the finding of increased discriminative ability was not found, suggesting that the improved discriminative ability that was observed in the earlier study was because of the intensive meditation practice (82). The authors postulated that perhaps changes in perceptual discrimination ability are short-term consequences of intensive meditation practice, whereas visual sensitivity threshold changes reflect long-term effects.

Perceptual rivalry, such as binocular rivalry involves variability in conscious awareness in spite of unchanging external stimulation (83). In a study of experienced Tibetan Buddhist monks, it was found that meditation alters these fluctuations in consciousness and attention and that different types of meditation have variable 'functional' effects on visual switching during rivalry (83). In this study, 'compassion' meditators (involves contemplating the suffering in the world combined with emitting 'loving kindness') showed no significant changes in switch rates, whereas 'one-point' focus meditators (involves focusing attention on a single object to calm the mind and reduce distraction to other events, both internal and external) had a significantly slower switch rate (ie, greater perceptual dominance) both during and after meditation, and increased stabilization during meditation.

Learning processes such as habituation and desensitization have also been implicated in the mechanisms of mindfulness. Kabat-Zinn et al. (18,23) suggest that symptom relief in patients with chronic pain and anxiety sufferers is because of the process of desensitization as a result of prolonged exposure and hence suggest that the neuronal pathways and regions involved in habituation and desensitization are implicated in the neural mechanisms of mindfulness. A more recent neurobehavioural account proposes that mindfulness practice acts directly on activating frontal inhibitory networks, enabling the extinction of responses learned through operant conditioning by breaking down associations between thoughts (memories, beliefs, anticipations) and their concomitant body sensations (4).

Summary of psychological processes. Given the many facets of meditation, it is not surprising that it has effects on a variety of psychological domains. Meditation techniques, including mindfulness meditation, thus appear to provide individuals with enhanced ability to concentrate and inhibit distracting stimuli, reduced expectancy response when presented with unexpected stimuli, greater visual perceptual sensitivity, and improved sustained attention and attention switching. The magnitude of the change observed within these psychological domains appears to be related to the level of meditation experience. Given these observable changes, one would anticipate concomitant neurophysiological changes. Furthermore, proposed psychological mechanisms of action underlying mindfulness techniques include behavioural processes such as habituation, exposure, desensitization and extinction of operant conditioned responses.

Neurophysiological concomitants

The neural basis of meditation has been investigated using electroencephalography (EEG), evoked potential and cognitive event-related potential (ERP) technologies, positron emission tomography (84–86), functional magnetic resonance imaging (fMRI) (87) and spectroscopy (88). These investigations have provided some insight into the neurophysiology of meditation including evidence of resultant immediate and long-term changes in cortical activity [eg, Aftanas and Golosheikin (90), Lutz et al. (91) and Takahashi et al. (89)]; however, methodological problems have plagued early research and the multitude of meditation techniques examined make generalization difficult. The main obstacle faced by researchers attempting to synthesize the literature is highlighted in studies such as those conducted by Dunn et al. (92) that investigated differences in brain activity using EEG in control subjects while performing a concentration-based meditation task, a mindfulness-meditation task and a baseline relaxation task. They found that both meditation tasks differed from the relaxation task and that mindfulness meditation produced greater delta (frontal and posterior regions), theta (frontal region), alpha (central posterior) and beta 1 (frontal, central and posterior) activity than the other conditions (92). On this basis, Dunn et al. were able to differentiate concentration and mindfulness forms of meditation using EEG. Other studies also report differences between meditative practices [eg, Lehmann et al. (93) and Lou et al. (84)]. In an attempt to provide an overall framework for all types of meditative practice, Newberg and Iversen (94) posited a model of the neural basis of meditation. They highlight the potential neural differences between volitional (unguided) and guided meditations, and present a model of volitional meditation that involves the activation of a complex system involving a variety of cerebral structures and increased activation of the parasympathetic autonomic nervous system with concomitant neurochemical changes. However, we respectfully suggest that because the variety of meditations differ in procedure and process, it is quite likely that they also differ in patterns of brain activity and that amalgamation of the findings in an attempt to identify common neurophysiological elements of 'meditation' is likely to be unsuccessful and lacks a theoretical rationale. Furthermore, integration of the findings relating to the different styles of meditation may conceal necessary subtle differences that are specific to different meditative techniques. Hence, in this review, only findings specific to investigations of mindfulness-based meditations and interventions have been considered.

A search for papers in English was undertaken using PsycINFO (from 1804 onward), MedLine (from 1966 onwards) and the Cochrane Library with the following search terms: Vipassana, Mindfulness, Meditation, Zen, Insight, EEG, ERP, fMRI, MRI, Neuroimaging, Efficacy, Psychiatry and Intervention. Retrieved papers and literature known to the authors were also reviewed for additional relevant reports. In addition, extensive Internet searches were also conducted using Google™ (search engine) with the search terms listed above.

An extensive search of the literature showed a paucity of studies examining the neurophysiology of 'mindfulness' meditation. As discussed earlier, mindfulness is the fundamental attentional perspective underlying the Theravada (VM) and Mahayana (Zen meditation) Buddhist traditions as well as the Vajrayana tradition of Tibetan Buddhism (16). Cahn and Polich (11) suggest that mindfulness meditations include both Vipassana and Zen meditations as well as the modern adaptations of mindfulness highlighting once again the difficulty of partitioning meditative practices into concentrative and mindfulness forms. Adopting the classification of Cahn and Polich (11) involves excluding the Tibetan Buddhist meditation practices, of which there are many variations as this would further complicate classification. For example, the Tibetan tradition incorporates mantras and visualization techniques, whereas the

Vipassana tradition limits attentional focus on the *actual* experiences that manifest within the framework of mind and body from moment to moment (95). At the time of writing, 14 studies that had examined the neurophysiology of 'mindfulness' meditation (10 EEG studies, 1 ERP study and 4 imaging studies) were identified. Findings from these studies are reviewed in the next section and are summarized in Table 1. We first provide a brief summary of the interpretation of EEG data.

EEG is a well recognized and widely used technique that measures cortical activity by recording electrical signals from the scalp. These electrical signals are described in terms of frequency bands with the more reliable patterns being delta (0.5–4 Hz), theta (4–8 Hz), alpha (8–12 Hz), beta (12–30 Hz) and gamma (30–70 Hz). Delta activity is associated with pathological conditions such as tumors (96) but also occurs during sleep and therefore in meditation research usually reflects that the individual is asleep. Theta activity on the other hand is associated with alertness, attention and the efficient processing of cognitive and perceptual tasks (96); however, there are two types of theta activity with one form associated with lower levels of alertness (97). Theta activity has also been shown to be associated with orienting, working memory and affective processing (98–101) with frontal theta activity indicative of concentration. Hence, increases in theta activity may reflect increased cognitive processing and awareness. In contrast, alpha activity that is characterized by large rhythmic waves is generally associated with relaxation and the lack of active cognitive processes such that when an individual is asked to engage in a cognitive task alpha activity will cease. This is known as alpha blocking or desynchronization (96). However, desynchronization of higher band alpha waves is indicative of increased cognitive processing and external attention, whereas synchronization reflects internal attention (102). Furthermore, alpha can be categorized as fast or slow, with fast alpha reflecting task-related activity, whereas slow alpha reflects non-task-related cognitive processing (103). Cognitive activity is characterized by higher frequency and lower amplitude waves known as beta and gamma waves. Beta activity is related to alertness and gamma activity has been shown to be associated with the processing of meaningful activity and the integration of stimuli into a coherent whole (96).

Vipassana meditation. Neurophysiological investigations. As described earlier, Dunn et al. (92)

compared concentrative, mindfulness and relaxation tasks and found that both meditation tasks differed from the relaxation task and that mindfulness meditation produced greater delta (frontal and posterior regions), theta (frontal region), alpha (central posterior) and beta 1 (frontal, central and posterior) activity than the other conditions. Cahn and Polich (11), however, describe the finding of greater frontal theta activity in mindfulness meditation as unexpected, given the presumed association between frontal theta and focused concentration and suggest this observed theta activity may be indicative of drowsiness resulting from the use of inexperienced meditators and higher global theta during resting relaxation. Future EEG investigations of mindfulness meditation may seek to clarify this matter.

Neuroimaging investigations. In more recent years, researchers have used imaging techniques to investigate mindfulness meditation and preliminary studies show differential activation of neural networks as well as structural changes in meditators compared with non-meditators. Using fMRI, Lazar et al. (104) compared Vipassana (mindfulness) and Kundalini yoga (mantra based) meditators and showed dorsal cingulate cortex activation for both meditation conditions but only right temporal lobe activation for the Vipassana group. While there were no decreases in activation observed, there was a differential distribution of activated networks in the two groups. The two meditation groups showed a similar but non-overlapping engagement of frontal and parietal cortices as well as subcortical structures, and these patterns differed from those observed during control tasks. Differences between the two meditator groups were also observed in changes in respiratory rate, with the Vipassana participants experiencing little or no decrease in ventilatory rate, whereas the Kundalini participants had decreases of greater than four breaths/minute during meditation as compared with baseline. This study provided further evidence that different forms of meditation appear to engage different neural structures.

More recently, using MRI Lazar et al. (105) compared 20 experienced Vipassana meditators and control subjects and found significant differences in cortical thickness between the two groups across both cerebral hemispheres as well as in each hemisphere separately. More specifically, they found that a large region of the right anterior insula and right middle and superior frontal sulci were significantly thicker in meditators than controls. A trend for greater thickness for meditators than controls was also observed in the left superior temporal gyrus and in the fundus of the

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Table 1. Investigation of mindfulness and Zen meditations using EEG, ERP and neuroimaging techniques

Study	Subjects	Level of participant's experience	Meditation type	Imaging tool	Principal findings and interpretation
Dunn et al. (92)	10 students	Nil prior to training. Formal training = 5 weeks of concentration meditation; 5 weeks of mindfulness meditation, plus informal practice (36–38 days, approximately 15 mins/day).	Mindfulness meditation, concentration meditation and relaxation (control).	EEG	Both meditation tasks differed from the relaxation task and mindfulness meditation also produced more delta (frontal and posterior regions), theta (frontal region), alpha (central posterior) and beta 1 (frontal, central and posterior) activity than the concentration meditation condition. This suggests that concentration and mindfulness 'meditations' are unique forms of consciousness and not merely degrees of a state of relaxation.
Lazar et al. (104)	33	Extensive training	Mindfulness vs. Kundalini vs. control task	fMRI	The two groups showed similar but nonoverlapping engagement of the frontal and parietal cortices as well as subcortical structures. Dorsal cingulate cortex activation for both meditation types, but only right temporal lobe activation for the Vipassana group. Hence, evidence for differential engagement of neural structures dependent on meditation type.
Lazar et al. (105)	20 experienced meditators (13 men; mean age: 38.2 years); 15 control subjects (10 men; mean age: 36.8 years)	9.1 (7.1) years; 6.2 (4) h/week	Insight	MRI	Right anterior insula and right middle and superior frontal sulci (Brodmann areas 9 and 10) were significantly thicker in meditators than controls. Left superior temporal gyrus and fundus of the central sulcus cortex was thicker in meditators but this was not significant. Regular meditation practice is associated with increased thickness in a subset of cortical regions related to somatosensory, auditory, visual and intero-ceptive processing.
Davidson et al. (20)	25 meditators (19 women; mean age: 36 years); 16 controls (10 women; mean age: 36 years)	Nil	MBSR (8-week group programme)	EEG (pre-, post-, follow-up)	Significant decrease in anxiety and negative affect from pre- to post-treatment. Significantly greater left-sided activation at central sites (C3/4) in meditators compared with controls. Significant increases in antibody titers to influenza vaccine in meditators compared with controls. Meditation may positively alter brain and immune function.
Kasamatsu and Hirai (106)	48 meditators (age range: 24–72 years); 22 controls (age range: 23–60 years)	20 disciples (1–5 years experience); 12 disciples (5–20 years experience); 16 priests (>20 years experience); 22 controls with no experience with Zen meditation	Zen meditation	EEG	Increased alpha amplitude, decreased alpha frequency, frontal alpha activity and theta bursts. Nonhabituating alpha blocking. Theta activity was positively correlated with the level of meditation experience.
Becker and Shapiro (107)	10 Zen meditators (8 men; mean age: 37.8 years); 10 yoga meditators (5 men, mean age: 31.5 years); 10 TM meditators (4 men; mean age: 28.7 years); 10 'ignore' controls (4 men; mean age: 29.5 years); 10 'attend' controls (5 men; mean age: 26.5 years)	Zen meditators: mean length of practice, 7.5 years; Range: 3–20 years. Yoga meditators: mean length of practice, 5 years; range: 3–8.5 years. TM meditators: mean length of practice, 7 years; range: 3.5–10.5 years.	TM vs. Zen vs. Yoga meditators, vs. 2 control groups	EEG	Habituation to stimulus, hence no effect of meditation on alpha blocking. No significant differences between the meditation groups in the P300, P200 responses. Increased N100 response for TM and yoga meditators.
Lo et al. (108)	Experiment 1: 20 experienced meditators; 10 controls subjects. Experiment 2: 8 subjects (2 nonmeditators)	Details not specified	Zen meditators	EEG	Evidence of alpha blocking related to experiencing the 'inner light of the self', as reflected by changes from alpha to small amplitude beta.
Murata et al. (109)	22 male students (age range: 20–26 years; mean age: 23.3 ± 2.05 years).	Novice	Su-soku (Zen meditation)	EEG	Increased frontal slow alpha coherence. Lower trait anxiety was correlated with internalized attention meditation, while high trait anxiety was correlated with relaxation-based meditation.
Murata et al. (115)	10 priests (age range: 33–53 years; mean age: 43.6 years); 10 disciples (age range: 25–41 years; mean age: 31.2 years) and 10 controls (age range: 28–32 years; mean age: 30.0 years)	10 priests with extensive experience (10–30 years), 10 disciples with moderate experience (3–5 years); 10 novices	Zen (ZaZen) meditation	EEG	Slow alpha appeared in all three groups but frontal theta activity only appeared in the experienced group, with its frequency increasing proportionally to the level of experience.
Faber et al. (116)	1	Experienced	Zen meditation	EEG	Increased theta coherence and decreased gamma coherence.

Table 1. Continued

Study	Subjects	Level of participant's experience	Meditation type	Imaging tool	Principal findings and interpretation
Kubota et al. (117)	25 (11 men; age range: 18–34 years; mean age: 23.1 years)	Novice	Su-soku meditation (Zen meditation)	EEG	Significant difference in frontal midline theta rhythm during meditation compared with control condition. Increase in sympathetic and parasympathetic indexes during frontal theta activity.
Takahashi et al. (89)	20 men (mean age: 24.6 years; age range: 21–26 years)	Nil	Su-soku (Zen meditation)	EEG, ECG, breath rate	Percent change in slow alpha power in frontal areas (reflecting internalized attention) was negatively correlated with sympathetic indexes and was positively correlated with novelty seeking score (associated with DA activity). Percent change in fast theta power in frontal area (reflecting mindfulness) was positively correlated with parasympathetic index and with harm avoidance score (associated with serotonergic activity). Results suggest that the two major behaviours of mind during meditation are characterized by different combinations of psychophysiological properties and personality traits.
Baerentsen et al. (120)	5 (3 men; mean age: 51 years; age range: 46–56 years)	Experience range: 7–23 years	Zen meditation	fMRI	Increased activity in the hippocampus, left frontal, paracentral and inferior parietal lobes, right temporal lobe, superior right gyrus paracentralis, prefrontal cortex and ACC. Decreased activity in the right occipital cortex and left prefrontal lobe, posterior cingulate and right central cortex. Reflect dominance of the frontal cortical-subcortical system in the initiation of meditation.
Ritskes et al. (121)	11 (8 men; mean age: 48 years; age range: 32–62 years)	Mean level of experience: 8 years; range: 15–25 years	Zen meditation	fMRI	Increased activation in the prefrontal cortex, basal ganglia and decreased activation of the gyrus occipital superior and anterior cingulate.

central sulcus, providing the first evidence of structural change associated with meditation. Lazar et al. suggest that regular meditation practice may slow age-related thinning of the frontal cortex; however, preexisting differences between individuals who choose to meditate and those who do not cannot be ruled out. Replication of this intriguing finding is eagerly awaited – especially as the prospect of meditation having neuroprotective effects is of profound clinical importance.

Mindfulness-based interventions. At the time of writing, there had only been one neuroimaging investigation of the neural changes associated with the mindfulness-based interventions. Davidson et al. (20) found significant increases in left-sided activation in the anterior cortical area and a significantly greater rise in antibody titers in Kabat-Zinn's MBSR-trained participants compared with wait-list controls, suggesting that MBSR training can lead to neural changes consistent with better handling of negative emotion and can also modulate immune function. Consistent with this hypothesis was the finding of a reduction in anxiety levels and negative affect scores for the meditation group. Moreover, Cahn and Polich (11) suggest that meditation practice may alter the fundamental electrical balance between the cerebral hemispheres and this may modulate individual differences in affective processing.

Zen meditation. Neurophysiological investigations. EEG and ERP investigation of Zen meditations are much more abundant than Vipassana/Insight/mindfulness meditations. Most reviews cite the work of Kasamatsu and Hirai as instrumental in demonstrating the distinction between meditative state and rest. However, there is a paucity of research evaluating the differences between Zen meditation techniques and relaxation strategies. Although the results from these studies show some significant findings and are hence encouraging, it must be stressed that some of these studies suffer from methodological flaws, but are, however, repeatedly cited in reviews as reflecting significant results. It should be stressed that these studies need to be critically evaluated before findings can be generalized, with particular regard to the use of adequate controls and sample sizes. Furthermore, researchers have suggested that Zen meditation lies closer to the mindfulness pole on the mindfulness-concentration continuum (11); however, some of the research studies described below investigated 'su-soku', a Zen technique that involves counting of the breath, which may be more accurately classified as a concentrative technique. This again highlights the

difficulty in comparing across studies, given the variety of techniques used even within general meditation conditions.

In their initial study, Kasamatsu and Hirai (106) used EEG to compare meditators and controls during an eyes-open rest control condition or meditation and found increased alpha amplitude and decreased alpha frequency, frontal alpha activity and theta bursts. Auditory click sounds were also played to participants during meditation and resting state and the sudden reduction in alpha waves in response to each stimulus did not habituate in the three Zen masters, but it did for the controls. The authors concluded that these findings showed a 'hypersensitivity' of attention in meditation practitioners; however, Becker and Shapiro (107) suggest that this reflects constant 'orienting' or 'startle'. It should however be noted that despite a sample size of 70 subjects, Kasamatsu and Hirai (106) reported their findings largely by case illustration rather than group statistical analyses; therefore, the strength and generalizability of these findings are limited.

Attempting to extend the findings of Kasamatsu and Hirai (106), Becker and Shapiro (107) compared TM, Zen and yoga meditators to two control groups. Each group was informed that they would hear a series of clicks (presented every 15 s) during the testing session. The meditators were instructed to continue meditating as normal, whereas the control groups were asked to either strongly attend to each click by counting them or to ignore the clicks. In this study, all groups habituated to the auditory stimulus at the same rate, that is, meditation was not found to have an effect on alpha blocking as was the case in the study by Kasamatsu and Hirai (106). Auditory evoked potentials (AEPs) were also assessed; however, the three meditation groups were found not to differ significantly in the P300 response, while the P200 was significantly reduced for all the groups. The yoga and TM meditators were found to have larger N100 amplitudes to the earlier clicks, but this finding was paradoxical because meditators were meant to be engaged in meditation rather than attending to the clicks; hence, a lower N100 amplitude would have been anticipated (107).

EEG alpha blocking (a decrease in alpha power activity from prestimulus to poststimulus) is believed to be a measure of the process of deautomization, which refers to the perception of each stimulus occurrence as novel under the mindfulness meditative state (11); however, studies have shown mixed results. In general, yogic (concentrative) practice is characterized by the absence of alpha blocking and Zen (mindfulness) practice is characterized by a lack of alpha-blocking habituation (11); hence, Becker and Shapiro (107) failed to support these conclusions. Lo et al. (108), however, found evidence of alpha blocking in Zen meditators, and this was found to be correlated with the perception of experiencing the 'inner light of the self' as reflected by a flattening of alpha-dominated EEG to small amplitude beta waves.

Murata et al. (109) investigated the relationship between trait anxiety levels, relaxation response and internalized attention (alpha synchronization) during a Zen meditation technique known as 'susoku' using 22 novice meditators. Results showed increased frontal alpha (slow) coherence (frontal to central), with lower levels of trait anxiety correlating with internalized attention meditation, whereas higher trait anxiety induced meditation characterized predominantly by a relaxation response (109). This study although interesting failed to control for placebo effects.

Initial EEG meditation research has focused predominantly on alpha band effects; however, it has been proposed that increases in theta (4–8 Hz) activity rather than increases in alpha power are a specific state effect of meditative practice and that theta increases may also be positively correlated with the level of meditation experience (106). In general, long-term meditators (mixed meditation types) relative to nonmeditator controls tend to exhibit trait higher theta and alpha power (7,79,99,110–114). Murata et al. (115) compared 20 monks (10 with extensive experience, 10 with moderate experience) to 10 controls prior to and during Zen meditation and found that slow alpha appeared in all the groups but that theta activity only appeared in the experienced group affecting the frontal region, with the likelihood of it occurring increasing proportionally to the level of experience, hence supporting the previous findings of Kasamatsu and Hirai (106). Increased theta activity was also observed in the frontal region, left of the midline as well as posterior temporal region. No significant changes in beta were observed. In a single case study repeated-measure design involving three meditation scans and one control condition over 4 days, Faber et al. (116) found increased theta coherence and decreased gamma coherence, except over temporal regions where gamma coherence increased.

Kubota et al. (117) suggest that frontal theta reflects the involvement of attentional and working memory systems in the prefrontal neural circuitry, including the anterior cingulate cortex (ACC), and that activity within these systems is integrated with peripheral autonomic functioning. To test this

hypothesis, a study involving instruction of 25 novice participants in the 'su-soku' Zen technique was conducted. A significant difference in frontal midline theta rhythm during meditation as compared with the resting control condition was found. Both sympathetic and parasympathetic indexes increased during frontal theta activity, suggesting a close relationship between cardiac autonomic functioning and activity of the medial frontal neural circuitry. There was no difference in occipital alpha wave activity.

Takahashi et al. (89) monitored EEG, ECG (measuring heart rate variability as an index) and respiratory rate in 20 novice meditators and found increased theta and slow alpha wave activity in frontal areas and decreased sympathetic and increased parasympathetic activity during meditation. The authors point out that alpha and theta waves are independently involved in behaviours of the mind during meditation and suggest that successful meditation involves slower frontal alpha synchronization coupled with reduced sympathetic activity and that mindfulness may activate fast theta activity in the frontal areas as well as increased parasympathetic activity.

These EEG and ERP studies examine a variety of meditation styles using a number of study designs and this naturally diminishes the generalizability of findings. Interpretation of the results is further complicated by the use of differing methodologies in the analysis of the spectral data as highlighted by recent research investigating alternative methods of analyzing such data (eg, Lo and Leu (118) and Chang and Lo (119)).

Neuroimaging investigations. Recent attention has also turned to the application of neuroimaging techniques to the study of Zen meditation. For example, Baerentsen et al. (120) investigated the changes in neural activation patterns at the onset of meditation using fMRI in five experienced Zen meditators and found increased activity in the left frontal, paracentral, inferior parietal lobe, right temporal lobe, superior right gyrus paracentralis, prefrontal cortex, hippocampus and ACC. Decreased activity was found in the visual cortex, left prefrontal lobe and posterior cingulate. These findings provide tentative support for the notion of frontal cortical-subcortical system dominance in the initiation of Zen meditation (120).

More recently, Ritskes et al. (121) examined 11 experienced Zen meditators using fMRI as they 'switched' from normal consciousness to meditative state and found increased activation in the prefrontal cortex, specifically the right gyrus frontalis medius, and basal ganglia and decreased activation in the superior occipital gyrus and anterior cingu-

late. Reduced activations are taken to indicate that during meditation, the individual becomes less aware of his/her conscious orientation and that there is a lessening of interference from the effects of 'will' or intent (121). This explanation is in contrast to the triaxiomatic model of mindfulness meditation proposed by Shapiro et al. (71) in which 'intention' is a key component.

Summary of neurophysiological findings. Vipassana and modern forms of mindfulness meditation. Electroencephalogram investigations report increased delta, theta, alpha and beta 1 wave activity in frontal and posterior brain regions in mindfulness meditators during meditation as compared with when relaxed. Neuroimaging research of VM has detailed involvement of the dorsal cingulate cortex, right temporal lobe and an MRI investigation has reported increased cortical thickness in the right anterior insula, right middle and superior frontal sulci in Vipassana meditators as compared with controls. To date, there has only been one neuroimaging study of MBSR treatment, which showed increased activation in the left anterior cortex. To our knowledge, no other combined clinical intervention (eg, MCBT, MBCT, ACT) has been investigated using neurophysiological or neuroimaging methods.

Zen meditation. Electroencephalogram investigations of Zen meditation consistently show increased alpha and theta power, increased alpha coherence and overall frequency slowing, and the less consistent finding of gamma band effects. Increased alpha power is generally observed in frontal regions. There are mixed findings relating to alpha blocking and habituation, and the small number of ERP investigations carried out to date have failed to show differences in AEPs such as the P300 response. However, theta activity is shown to have a close positive association with the level of practice. Neuroimaging research of Zen meditation has shown increased activation of the frontal cortical-subcortical system, including prefrontal cortex, basal ganglia and reduced activation across a number of other brain regions.

Conclusions

Mindfulness-based interventions are increasingly being applied to the treatment of a variety of psychiatric disorders. In recent times, these techniques have been evaluated in well-designed randomized controlled trials and have been shown to be efficacious at least in the short term. However, many meditative interventions comprise a mixture

of mindfulness, behavioural and cognitive techniques and hence clinical findings cannot provide specific support for the effectiveness of mindfulness meditation. The few studies that have investigated the traditional VM courses have shown positive results, but these are yet to be evaluated in populations with psychiatric disorders. Mindfulness and Zen meditation techniques have however been shown to result in improved attentional and perceptual processes and to have a direct impact on cognitive processes such as ruminative thinking and autobiographical memory. These findings have clear implications for their use as an intervention for conditions such as ADHD and depression. EEG, fMRI and MRI investigations show neural changes associated with these techniques; however, some of this research suffers from methodological problems including inappropriate control tasks or small sample sizes.

The widespread acceptance of these 'new-wave' therapies necessitates both clinical and neurobiological research examining the psychological and neurophysiological processes underpinning these techniques. This would provide a greater understanding of the techniques, brain functioning and potential impact upon psychiatric disorders.

Acknowledgement

References

1. TAYLOR E. Introduction. In: MURPHY M, DONOVAN S, eds. The physical and psychological effects of meditation. Sausalito, CA: Institute of Noetic Sciences, 1999.
2. GOLEMAN D. The meditative mind: the varieties of meditative experience. New York: Jeremy P. Tarcher/Perigee Books, 1988.
3. GOLEMAN D. The varieties of the meditative experience. New York: EP Dutton, 1977.
4. CAYOUN BA. Mindfulness-integrated cognitive behaviour therapy (MiCBT): general principles and guidelines. In Press.
5. KATO H. Zen and psychology. Jpn Psychol 2005;47:125–136.
6. ANDRESEN J. Meditation meets behavioural medicine. The story of experimental research on meditation. J Consciousness Studies 2000;7:17–74.
7. SHAPIRO D, WALSH RN. Meditation: classical and contemporary perspectives. New York: Aldine, 1984.
8. WALLACE BA. The Buddhist tradition of Samatha: methods for refining and examining consciousness. J Consciousness Studies 1999;6:175–187.
9. GERMER CK, SIEGEL RD, FULTON PR. Mindfulness and psychotherapy. New York: Guilford Press, 2005.
10. BAER RA. Mindfulness training as a clinical intervention: a conceptual and empirical review. Clin Psychol Sci Pract 2003;10:125–143.
11. CAHN BR, POLICH J. Meditation states and traits: EEG, ERP and neuroimaging studies. Psychol Bull 2006;132:180–211.
12. MURPHY M, DONOVAN S. The physical and psychological effects of meditation. Sausalito, CA: Institute of Noetic Sciences, 1999.
13. BISHOP SR. What do we really know about mindfulness-based stress reduction? Psychosom Med 2002;64:71–84.
14. GERMER CK. Mindfulness: what is it? What does it matter? In: GERMER CK, SIEGEL RD, FULTON PR, eds. Mindfulness and psychotherapy. New York: Guilford Press, 2005:3–27.
15. GUNARATANA B. Mindfulness in plain English. Somerville, MA: Wisdom Publications, 2002.
16. KABAT-ZINN J. Mindfulness-based interventions in context: past, present, and future. Clin Psychol Sci Pract 2003;10:144–156.
17. KABAT-ZINN J. Mindfulness-based stress reduction. Constructivism in the Human Sciences 2003;8:73–107.
18. KABAT-ZINN J. An outpatient program in behavioral medicine for chronic pain patients based on the practice of mindfulness meditation: theoretical considerations and preliminary results. Gen Hosp Psychiatry 1982;4:33–47.
19. TEASDALE JD, SEGAL Z, WILLIAMS JMG. How does cognitive therapy prevent depressive relapse and why should attentional control (mindfulness) training help? Behav Res Ther 1995;33:25–39.
20. DAVIDSON RJ, KABAT-ZINN J, SCHUMACHER J et al. Alterations in brain and immune function produced by mindfulness meditation. Psychosom Med 2003;65:564–570.
21. KABAT-ZINN J, LIPWORTH L, BURNEY R. The clinical use of mindfulness meditation for the self-regulation of chronic pain. J Behav Med 1985;8:163–190.
22. KABAT-ZINN J, LIPWORTH L, BURNEY R, SELLERS W. Four-year follow-up of a meditation-based program for the self-regulation of chronic pain: treatment outcomes and compliance. Clin J Pain 1987;2:159–173.
23. KABAT-ZINN J, MASSION AO, KRISTELLER J et al. Effectiveness of a meditation-based stress reduction program in the treatment of anxiety disorders. Am J Psychiatry 1992;149:936–943.
24. KABAT-ZINN J, WHEELER E, LIGHT T et al. Influence of a mindfulness meditation-based stress reduction intervention on rates of skin clearing in patients with moderate to severe psoriasis undergoing photo therapy (UVB) and photochemotherapy (PUVA). Psychosom Med 1998;60:625–632.
25. MILLER JJ, FLETCHER K, KABAT-ZINN J. Three year follow-up and clinical implications of a mindfulness meditation-based stress reduction intervention in the treatment of anxiety disorders. Gen Hosp Psychiatry 1995;17:192–200.
26. KRISTELLER JL, HALLET CB. An exploratory study of a meditation-based intervention for binge eating disorder. J Health Psychol 1999;4:357–363.
27. LINEHAN MM. Cognitive behavioral treatment of borderline personality disorder. New York: Guilford Press, 1993.
28. HAYES SC, STROSAHL KD, WILSON KG. Acceptance and commitment therapy: an experiential approach to behaviour change. New York: Guilford, 1999.
29. ROEMER L, ORSILLO SM. Expanding our conceptualization of and treatment for generalized anxiety

disorder: Integrating mindfulness/acceptance-based approaches with existing cognitive-behavioral models. Clin Psychol: Sci Prac 2002;**9**:54–58.

30. SEGAL ZV, WILLIAMS JMG, TEASDALE JD. Mindfulness-based cognitive therapy for depression: A new approach to preventing relapse. New York: Guilford Press, 2002.

31. WILLIAMS JMG, SWALES M. The use of mindfulness-based approaches for suicidal patients. Arch Suicide Res 2004;**8**:315–329.

32. SCHWARTZ JM, STOESSEL PW, BAXTER LR Jr, MARTIN KM, PHELPS ME. Systematic changes in cerebral glucose metabolic rate after successful behavior modification treatment of obsessive-compulsive disorder. Arch Gen Psychiatry 1996;**53**:109–113.

33. BOGELS SM, SIJBERS GFVM, VONCKEN M. Mindfulness and task concentration training for social phobia: a pilot study. Journal of Cognitive Psychotherapy: An International Quarterly J Cognit Psychother 2006;**20**:33–44.

34. MA SH, TEASDALE JD. Mindfulness-based cognitive therapy for depression: replication and exploration of differential relapse prevention effects. J Consult Clin Psychol 2004;**72**:31–40.

35. TEASDALE JD, WILLIAMS JM, SOULSBY JM, SEGAL ZV, RIDGEWAY VA, LAU MA. Prevention of relapse/recurrence in major depression by mindfulness-based cognitive therapy. J Consul Clin Psychol 2000;**68**:615–623.

36. WILLIAMS J, TEASDALE J, SEGAL Z, SOULSBY J. Mindfulness-based cognitive therapy reduces overgeneral autobiographical memory in formerly depressed patients. J Abnormal Psychol 2000;**109**:150–155.

37. FINUCANE A, MERCER SW. An exploratory mixed methods study of the acceptability and effectiveness of mindfulness-based cognitive therapy for patients with active depression and anxiety in primary care. BMC Psychiatry 2006;**6**:14.

38. RAMEL W, GOLDIN PR, CARMONA PE, MCQUAID JR. The effects of mindfulness meditation on cognitive processes and affect in patients with past depression. Cogn Ther Res 2004;**28**:433–455.

39. VAN DEN BOSCH LMC, KOETER MW, STIJNEN T, VERHEUL R, VAN DEN BRINK W. Sustained efficacy of dialectical behaviour therapy for borderline personality disorder. Behav Res Ther 2005;**43**:1231–1241.

40. ASTIN JA. Stress reduction through mindfulness meditation. Psychother Psychosom 1997;**66**:97–106.

41. MASSION AO, TEAS J, HEBERT JR, WERTHEIMER MD, KABAT-ZINN J. Meditation, melatonin, and breast/prostate cancer: hypothesis and preliminary data. Med Hypotheses 1995;**44**:39–46.

42. SHAPIRO SL, SCHWARTZ GE, BONNER G. Effects of mindfulness-based stress reduction on medical and premedical students. J Behav Med 1998;**21**:581–599.

43. WILLIAMS KA, KOLAR MM, REGER BE, PEARSON JC. Evaluation of a wellness-based mindfulness stress reduction intervention: a controlled trial. Am J Health Promot 2001;**15**:422–432.

44. WILLIAMS JMG, DUGGAN DS, CRANE C, FENNELL MJV. Mindfulness-based cognitive therapy for prevention of recurrence of suicidal behaviour. J Clin Psychol 2006;**62**:201–210.

45. TEASDALE JD, SEGAL ZV, WILLIAMS JMG. Mindfulness training and problem formulation. Clin Psychol: Sci Prac 2003;**10**:157–160.

46. TEASDALE JD. Mindfulness-based cognitive therapy. In: YIEND J, ed. Cognition, emotion, and psychopathology. UK: Cambridge University Press, 2004: 270–289.

47. KRISANAPRAKORNKIT T, KRISANAPRAKORNKIT W, PIYAVHATKUL N, LAOPAIBOON M. Meditation therapy for anxiety disorders. The Cochrane Database of Systematic Reviews 2006; Issue 1: Art. No.:CD004998.pub004992. DOI: 004910.001002/14651858.CD14004998.pub14651852.

48. RASKIN M, BALI LR, PEEKE HV. Muscle biofeedback and transcendental meditation. Arch Gen Psychiatry 1980;**37**:93–97.

49. BENSON H. The relaxation response. New York: Avon, 1975.

50. SHANNAHOFF-KHALSA D, RAY LE, LEVINE S, GALLEN CC, SCHWARTZ BJ, SIDOROWICH JJ. Randomised controlled trial of yogic meditation techniques for patients with obsessive-compulsive disorder. CNS Spectr 1999;**4**:34–47.

51. GAUDIANO BA, HERBERT JD. Acute treatment of inpatients with psychotic symptoms using acceptance and commitment therapy: pilot results. Behav Res Ther 2006;**44**:415–437.

52. WICKSELL RK, DAHL J, MAGNUSSON B, OLSSON GL. Using acceptance and commitment therapy in the rehabilitation of an adolescent female with chronic pain: a case example. Cognitive Behav Pract 2005;**12**:415–423.

53. ORSILLO SM, ROEMER L, BLOCK-LERNER J, LEJEUNE C, HERBERT JD. Act with anxiety disorders. In: HAYES SC, STROSAHL KD, eds. A practical guide to acceptance and commitment therapy. New York: Springer Science and Business Media, 2005: 103–132.

54. BECK A, RUSH J, SHAW B, EMERY G. Cognitive therapy of depression. New York: Guilford Press, 1979.

55. FOLKE F, PARLING T. Acceptance and commitment therapy in group format for individuals who are unemployed and on sick leave suffering from depression: A randomized controlled trial. Dissertation: University of Uppsala, Sweden.

56. ZETTLE R, RAINES J. Group cognitive and contextual therapies in treatment of depression. J Clin Psychol 1989;**45**:438–445.

57. BACH P, HAYES SC. The use of acceptance and commitment therapy to prevent the rehospitalisation of psychotic patients: a randomised controlled trial. J Consult Clin Psychol 2002;**70**:1129–1139.

58. GAUDIANO BA, HERBERT JD. Acute treatment of inpatients with psychotic symptoms using acceptance and commitment therapy: Pilot results. Beh Res Ther 2006;**44**:415–437.

59. SCHEEL KR. The empirical basis of dialectical behaviour therapy: summary, critique and implications. Clin Psychol Sci Pract 2000;**7**:68–86.

60. KATZ LY, COX BJ, GUNASEKARA S, MILLER AL. Feasability of dialectical behaviour therapy for suicidal adolescent inpatients. J Am Acad Child Adolesc Psychiatry 2004;**43**:276–282.

61. KROGER C, SCHWEIGER U, SIPOS V et al. Effectiveness of dialectical behaviour therapy for borderline personality disorder in an inpatient setting. Behav Res Ther 2006;**44**:1211–1217.

62. LINEHAN MM, ARMSTRONG HE, SUAREZ A, ALLMON D, HEARD HL. Cognitive behavioural treatment of chronically parasuicidal borderline patients. Arch Gen Psychiatry 1991;**48**:1060–1064.

63. LINEHAN MM, COMTOIS KA, MURRAY AM et al. Two-year randomised controlled trial and follow-up of dialectical behaviour therapy vs therapy by experts for suicidal behaviours and borderline personality disorder. Arch Gen Psychiatry 2006;**63**:757–766.

64. Linehan MM, Schmidt H, Dimeff L, Craft C, Kanter J, Comtois KA. Dialectical behaviour therapy for patients with borderline personality disorder and drug dependence. Am J Addict 1999;**8**:279–292.

65. Verheul R, Van den Bosch LMC, Koeter MW, de Ridder MAJ, Stijnen T, Van den Brink W. Dialectical behaviour therapy for women with borderline personality disorder. Br J Psychiatry 2003;**182**:135–140.

66. Chandiramani K, Verma SK, Dhar PL. Psychological effects of Vipassana on Tihar Jail inmates. Unpublished manuscript, 1998; Cited in Bowen S, Witkiewitz K, Dillworth TM et al. Mindfulness meditation and substance abuse in an incarcerated population. Psychol Addict Behav 2006;**20**:343–347.

67. Kumar T. Vipassana meditation courses in Tihar Jail. Paper presented at the Indian Institute of Technology, Delhi, India; 1995 April.

68. Vora RL. Jail courses and Vipassana (Baroda jail). Presented at an international seminar of the Indian Institute of Technology, Delhi, India; 1995 April.

69. Bowen S, Witkiewitz K, Dillworth TM et al. Mindfulness meditation and substance use in an incarcerated population. Psychol Addict Behav 2006;**20**: 343–347.

70. Watkins E, Teasdale JD. Adaptive and maladaptive self-focus in depression. J Affect Disord 2004;**82**:1–8.

71. Shapiro SL, Carlson LE, Astin JA, Freedman B. Mechanisms of mindfulness. J Clin Psychol 2006;**62**: 373–386.

72. Maupin EW. Individual differences in response to a Zen meditation exercise. J Consult Psychol 1965;**29**:139–145.

73. Valentine ER, Sweet PLG. Meditation and attention: a comparison of the effects of concentrative and mindfulness meditation on sustained attention. Ment Health Relig Cult 1999;**2**:59–70.

74. Linden W. Practicing of meditation by school children and their levels of field dependence-independence, test anxiety and reading achievement. J Consult Clin Psychol 1973;**41**:139–143.

75. Rani NJ, Rao PV. Meditation and attention regulation. J Indian Psychol 1996;**14**:26–30.

76. Kubose SK. An experimental investigation of psychological aspects of meditation. Psychologia 1976;**19**: 1–10.

77. Harrison LJ, Manocha R, Rubia K. Sahaja yoga meditation as a family treatment programme for children with attention deficit-hyperactivity disorder. Clin Child Psychol Psychiatry 2004;**9**:479–497.

78. Wilkins AJ, Shallice T, McCarthy R. Frontal lesions and sustained attention. Neuropsychologia 1987;**25**: 359–365.

79. Davidson RJ, Goleman D, Schwartz GE. Attentional and affective concomitants of meditation: a cross-sectional study. J Abnorm Psychol 1976;**85**:235–238.

80. Lesh TV. Zen meditation and the development of empathy in counselors. J Humanistic Psychol 1970;**10**: 39–74.

81. Brown DP, Forte M, Dysart M. Visual sensitivity and mindfulness meditation. Percept Mot Skills 1984; **58**:775–784.

82. Brown DP, Forte M, Dysart M. Differences in visual sensitivity among mindfulness meditators and non-meditators. Percept Mot Skills 1984;**58**:727–733.

83. Carter OL, Presti DE, Callistemon C, Ungerer Y, Liu GB, Pettigrew JD. Meditation alters perceptual rivalry in Tibetan Buddhist monks. Curr Biol 2005;**15**:R412–R413.

84. Lou HC, Kjaer TW, Friberg L, Wildschiodtz G, Holm S, Nowak M. A ^{15}0-h$_2$o pet study of meditation and the resting state of normal consciousness. Hum Brain Mapp 1999;**7**:98–105.

85. Herzog H, Lele VR, Kuwert T, Langen KJ, Kops ER, Feinendegen LE. Changed pattern of regional glucose metabolism during yoga meditative relaxation. Neuropsychobiology 1990/1991;**23**:182–187.

86. Kjaer TW, Bertelsen C, Piccini P, Brooks D, Alving J, Lou HC. Increased dopamine tone during meditation-induced change of consciousness. Cogn Brain Res 2002; **13**:255–259.

87. Lazar SW, Bush G, Gollub RL, Fricchione GL, Khalsa G, Benson H. Functional brain mapping of the relaxation response and meditation. Neuroreport 2000; **11**:1581–1585.

88. Newberg A, Alavi A, Baime M, Pourdehnad M, Santanna J, d'Aquili E. The measurement of regional cerebral blood flow during the complex cognitive task of meditation: a preliminary spect study. Psychiatry Res 2001;**106**:113–122.

89. Takahashi T, Murata T, Hamada T et al. Changes in EEG and autonomic nervous activity during meditation and their association with personality traits. Int J Psychophysiol 2005;**55**:199–207.

90. Aftanas LI, Golosheikin SA. Changes in cortical activity in altered states of consciousness: the study of meditation by high-resolution eeg. Hum Physiol 2003;**29**:143–151.

91. Lutz A, Greischar LL, Rawlings NB, Ricard M, Davidson RJ. Long-term meditators self-induce high-amplitude gamma synchrony during mental practice. Proc Natl Acad Sci U S A 2004;**101**:16369–16373.

92. Dunn BR, Hartigan JA, Mikulas WL. Concentration and mindfulness meditations: unique forms of consciousness? Appl Psychophysiol Biofeedback 1999;**24**:147–165.

93. Lehmann D, Faber PL, Achermann P, Jeanmonod D, Gianotti LRR, Pizzagalli D. Brain sources of EEG gamma frequency during volitionally meditation-induced, altered states of consciousness, and experience of the self. Psychiatry Res 2001;**108**:111–121.

94. Newberg AB, Iversen J. The neural basis of the complex mental task of meditation: Neurotransmitter and neurochemical considerations. Medical Hypotheses 2003;**61**: 282–291.

95. Hart W. The art of living: Vipassana meditation as taught by S.N. Goenka. San Francisco: Harper, 1987.

96. Stern RM, Ray WJ, Quigley KS. Psychophysiological recording, 2nd ed. New York: Oxford University Press, 2001.

97. Schacter DL. EEG theta waves and psychological phenomena: a review and analysis. Biol Psychol 1977; **5**:47–82.

98. Aftanas L, Lotova NV, Koshkarov VI, Makhnev VP, Mordvinstev YN, Popov SA. Non-linear dynamic complexity of the human EEG during evoked emotions. Int J Psychophysiol 1998;**28**:63–76.

99. Aftanas LI, Golocheikine SA. Human anterior and frontal midline theta and lower alpha reflect emotionally positive state and internalized attention: high-resolution EEG investigation of meditation. Neurosci Lett 2001; **310**:57–60.

100. Basar E, Basar-Eroglu C, Karakas S, Schurmann M. Gamma, alpha, delta, and theta oscillations govern cognitive processes. Int J Psychophysiol 2001;**39**: 241–248.

101. Dietl T, Dirlich G, Vogl L, Lechner C, Strian F. Orienting response and frontal midline theta activity:

a somatosensory spectral perturbation study. Clin Neurophysiol 1999;**110**:1204–1209.

102. SHAW JC. Intention as a component of the alpha-rhythm response to mental activity. Int J Psychophysiol 1996;**24**:7–23.

103. KLIMESCH W, DOPPELMAYR M, RUSSEGGER H, PACHINGER T, SCHWAIGER J. Induced alpha band power changes in human EEG and attention. Neurosci Lett 1998;**244**:73–76.

104. LAZAR SW, ROSMAN IS, VANGEL M et al. Functional brain imaging of mindfulness and mantra-based meditation. Washington, DC: Society for Neuroscience, 2003.

105. LAZAR SW, KERR CE, WASSERMAN RH et al. Meditation experience is associated with increased cortical thickness. Neuroreport 2005;**16**:1893–1897.

106. KASAMATSU A, HIRAI T. An electroencephalographic study on the Zen meditation (zaZen). Folia Psychiatrica et Neurologica Japonica 1966;**20**:315–336.

107. BECKER DE, SHAPIRO D. Physiological responses to clicks during Zen, yoga, and tm meditation. Psychophysiology 1981;**18**:694–699.

108. LO PC, HUANG ML, CHANG KM. EEG alpha blocking correlated with perception of inner light during Zen meditation. Am J Chin Med 2003;**31**:629–642.

109. MURATA T, TAKAHASHI T, HAMADA T et al. Individual trait anxiety levels characterizing the properties of Zen meditation. Neuropsychobiology 2004;**50**:189–194.

110. DELMONTE MM. Physiological responses during meditation and rest. Biofeedback Self Regul 1984;**9**:181–200.

111. JEVNING R, WALLACE R, BEIDEBACH M. The physiology of meditation: a review: a wakeful hypometabolic integrated response. Neurosci Biobehav Rev 1992;**16**:415–424.

112. SCHUMAN M. The psychophysiological model of meditation and altered states of consciousness: a critical review. In: DAVIDSON JM, DAVIDSON RJ, eds. The psychobiology of consciousness. New York: Plenum Press, 1980: 333–378.

113. WEST MA. Meditation and the EEG. Psychol Med 1980;**10**:369–375.

114. WOOLFOLK RL. Psychophysiological correlates of meditation. Arch Gen Psychiatry 1975;**32**:1326–1333.

115. MURATA T, KOSHINO Y, OMORI M et al. Quantitative EEG study on Zen meditation (zaZen). Japanese Journal of Psychiatry & Neurology 1994;**48**:881–890.

116. FABER PL, LEHMANN D, GIANOTTI LRR, KAELIN M, PASCUAL-MARQUI RD. Scalp and intacerebral (LORETA) theta and gamma EEG coherence in meditation. Paper presented at the meeting of the International Society for Neuronal Regulation; 2004 April; Winterthur, Switzerland.

117. KUBOTA Y, SATO W, TOICHI M et al. Frontal midline theta rhythm is correlated with cardiac autonomic activities during the performance of an attention demanding meditation procedure. Cogn Brain Res 2001;**11**:281–287.

118. LO PC, LEU JS. Quantification of pseudo-periodicity of alpha rhythm in meditation EEG. Journal of Medical & Biological Engineering 2005;**25**:7–13.

119. CHANG KM, LO PC. Hurst exponents and linear regression with an application to low-power beta characterization in meditation EEG. Am J Electroneurodiagn Technol 2005;**45**:130–138.

120. BAERENTSEN KB, HARTVIG NV, STODKILDE-JORGENSEN H, MAMMEN J. Onset of meditation explored with fMRI. NeuroImage 2001;**13** (6, Suppl. 1): 297–297.

121. RITSKES R, RITSKES-HOITINGA M, STODKILDE-JORGENSEN H, BAERENTSEN K, HARTMAN T. MRI scanning during Zen meditation: the picture of enlightenment? Constructivism in the Human Sciences 2003;**8**:85–90.