Review

# The neurobiology of Meditation and its clinical effectiveness in psychiatric disorders

Katya Rubia *

Institute of Psychiatry, Department of Child and Adolescent Psychiatry PO46, King's College University London, De Crespigny Park, London SE5 8AF, UK

A B S T R A C T

This paper reviews the evidence for changes of Meditation on body and brain physiology and for clinical effectiveness in disorders of psychiatry. The aim of Meditation is to reduce or eliminate irrelevant thought processes through training of internalised attention, thought to lead to physical and mental relaxation, stress reduction, psycho-emotional stability and enhanced concentration. Physiological evidence shows a reduction with Meditation of stress-related autonomic and endocrine measures, while neuroimaging studies demonstrate the functional up-regulation of brain regions of affect regulation and attention control. Clinical studies show some evidence for the effectiveness of Meditation in disorders of affect, anxiety and attention. The combined evidence from neurobiological and clinical studies seems promising. However, a more thorough understanding of the neurobiological mechanisms of action and clinical effectiveness of the different Meditative practices is needed before Meditative practices can be leveraged in the prevention and intervention of mental illness.

© 2009 Elsevier B.V. All rights reserved.

## Contents

## 1. Introduction

Neuropsychiatric disorders such as depression, alcohol and drug abuse are on the increase worldwide. Neuropsychiatric disorders account for 31% of total disability and are expected to rise by 2020 (Mathers and Loncar, 2005). Depression is the most common of all mental disorders with the greatest public health burden. According to estimates from the World Health Organisa-tion (WHO) by 2020 depression will be the leading cause for disability worldwide. Suicide is estimated to be the leading cause of death in young people in 2020 (Mathers and Loncar, 2005). There have been increases in the number of diagnoses of mental health problems including schizophrenia, dementia, alcohol and substance abuse, and most child psychiatric disorders, which in part may be confounded by better detection, improved services and diagnostic changes. Nevertheless, these will be an increasing part of the overall health burden in the future.

Currently, there is no long-term cure of mental illness. Conventional behavioural or pharmacological treatment, though not a cure, has shown effectiveness in the alleviation of symptoms.

* Tel.: +44 207 8480463; fax: +44 207 8480866.
  E-mail address: k.rubia@iop.kcl.ac.uk.

However, dissatisfaction has arisen with psychopharmacological interventions due to side effects, its escalating prescription rates in both adults and children, and recent uncertainties on the effectiveness and long-term benefits of some psychopharmacological treatments such as antidepressants and psychostimulants (Jensen et al., 2007; Kirsch et al., 2008). Innovative conceptual and therapeutic models of care continue to emerge that may be relevant to the amelioration of mental illness. One of these is Meditation. Meditation has in recent years received considerable attention as a potential adjunct or alone in the intervention of psychiatric disorders as it is cost-effective and presumably free of side effects. In this paper we discuss the physiological and neurophysiological underpinnings of the subjectively reported benefits of Meditation and its potential effectiveness as a complementary treatment approach for mental illness.

## 2. What is Meditation and why could it be a useful adjunct to achieve mental health?

Meditation is essentially a physiological state of demonstrated reduced metabolic activity – different from sleep – that elicits physical and mental relaxation and is reported to enhance psychological balance and emotional stability (Jevning et al., 1992; Young and Taylor, 2001). In Western psychology, three states of consciousness are described: sleep, dream and wakefulness. In Eastern philosophy and in several Western religious and mystical traditions, an additional and supposedly "higher" state of consciousness has been described, the so-called "fourth state of consciousness", the state of "thoughtless awareness" (Ramamurthi, 1995). In thoughtless awareness the incessant thinking processes of the mind are eliminated and the practitioner experiences a state of deep mental silence. This state can be achieved by the practice of "Meditation". According to the Yoga Sutras of Patanjali, one of the oldest recorded scriptures on Meditation, "Yoga is the suppression of the modifications of the mind" (Patanjali, 1993). Although today a large variety of Meditation practices have emerged, some of them not aiming to achieve anything beyond relaxation, the original goal of Meditation is the elimination or reduction of thought processes, the cessation or slowing of the internal dialogue of the mind, the "mental clutter". This elimination of the thinking process has been reported to lead to a deep sense of physical and mental calm while at the same time enhancing pure awareness, untainted by thoughts, and perceptual clarity. Meditative experiences of thoughtless awareness furthermore seem to trigger feelings of positive emotions which can range from detached serenity to ecstatic bliss. A common experience of Meditation is a meta-cognitive shift where thoughts and feelings rather than occupying full attention can be observed from a detached witnessing awareness from which they can be dealt with in a more efficient manner. Achieving this mystical peak experience of complete thoughtless awareness is the ultimate goal of many traditional Meditation techniques. However, most Meditation techniques have more commonly focussed on achieving trait effects in the practitioners such as enhanced concentration which is a pre-requisite to achieve the peak experience. Although Meditation techniques differ widely, a common characteristic of most techniques is the training of concentrative attention skills in order to achieve the reduction or elimination of thoughts. The majority of Meditation techniques are therefore in essence an attention training by which thoughts are consciously manipulated. This involves either the narrowing or focussing of the attention on internal events such as breathing, an object, one point in space, or a mantra (several Buddhist practices, Yoga Nidra, Sahaja Yoga) or expanding the attention non-judgmentally on the moment to moment experience and observing thoughts and feelings from a meta-cognitive awareness state (Mindful Meditation, Vipassana and Zen Buddhist practices) (Ivanovski and Malhi, 2007). Most Meditation techniques therefore as a prerequisite to the ultimate goal of thoughtless awareness enhance mediator functions of sustained focused attention (concentration), self-monitoring (preventing the attentional focus to wander off) and cognitive interference control (the ability to inhibit interference or disruption from unwanted thoughts or irrelevant external events).

Although achieving the peak experience of thoughtless awareness is the goal of the Meditator, it is the long-term trait effects of Meditation, achieved after years of training that are thought to be therapeutic and have attracted the interest of Western Science. These reported long-term trait effects of Meditation practices include: (1) at a physical level: feelings of deep relaxation and stress relief; (2) at a cognitive level: enhanced concentrative attention skills, improved self-control and self-monitoring and better ability to inhibit irrelevant interfering external and internal activity; (3) at the emotional level: positive mood, emotional stability and resilience to stress and negative life events (detachment); (4) at a psychological level: personality changes such as enhanced overall psycho-emotional balance.

These are the subjectively reported benefits of Meditation. Relatively few studies have investigated the objectively measurable psychological, physiological, and neurophysiological changes that correlate with the subjectively reported benefits of Meditation.

We are well aware that there are qualitative and quantitative differences among the existing Meditation techniques. Given the relatively scarce number of neurobiological, neuroimaging and clinical studies of Meditation, however, we aim in this review to shape out the commonalities of the effects of the researched Meditation techniques on cognitive functions, on physiological and neurophysiological systems, and on behavioural symptoms in psychiatric disorders. With the increasing growth of well designed and well-controlled Meditation studies, however, future studies will be needed that compare between different Meditation techniques in order to shape out the technique-specific differences of the effects of these diverse techniques on behaviour, cognitive function, underlying physiology and neurobiology and clinical effectiveness.

## 3. Peripheral physiological changes during Meditation

Studies comparing experienced Meditators compared to controls or short-term Meditators have demonstrated physiological changes during Meditation suggestive of a wakeful hypometabolic state that is characterised by decreased sympathetic nervous activity, important for fight and flight mechanisms, and increased parasympathetic activity, important for relaxation and rest (Cahn and Polich, 2006; Jevning et al., 1992; Rai et al., 1988; Young and Taylor, 2001). This wakeful hypometabolic state with parasympathetic dominance has been shown to be qualitatively and quantitatively different from simple rest or sleep (Jevning et al., 1992; Young and Taylor, 2001). Sahaja Yoga Meditation, for example, a technique that evokes thoughtless awareness on a daily basis, presumably via activation of parasympathetic–limbic pathways (Harrison et al., 2004), has been shown to reduce autonomic activity in short- and long-term practitioners compared to controls. This included a reduction in heart, respiratory and pulse rates, of systolic blood pressure and oxygen metabolism, and of urinary vanilly mandelic acid (VMA), and increases of skin resistance (Rai et al., 1988). These physiological alterations are indicators of deep parasympathetic activation and therefore physiological relaxation that have been related to stress relief and may have a role in the prevention of stress-related illness, such as respiratory, hypertensive of cardiovascular disease (Cahn and

Polich, 2006). In fact, the same physiological effects achieved with Sahaja Yoga Meditation in healthy individuals, could also be achieved in patients with asthma and hypertension after 4 weeks of Meditation training, which furthermore were related to the significant reduction of asthma attacks (Chugh, 1997; Manocha et al., 2002). Studies using other Meditation techniques such as mindful or Buddhist Meditation have reported similar changes indicative of increased parasympathetic activity, suggesting that this is a characteristic feature of Meditation (Cahn and Polich, 2006; Solberg et al., 2000b).

## 4. Neurophysiological effects during Meditation

As mentioned before, the key subjective experiences in Meditation, apart from a general relaxation response, are the reduction of mental activity and the generation of positive affect. Functional neuroimaging studies have in fact been able to corroborate these subjective experiences by demonstrating the up-regulation in brain regions of internalised attention and emotion processing with Meditation.

Many electrophysiological studies have examined the brain activation during a variety of concentrative Meditation techniques. A common finding has been that of increased low frequency activation of theta and alpha bands that has been suggested to reflect enhanced sustained attention to internal events (Cahn and Polich, 2006). Very few studies, however, have directly investigated the neural correlates of the peak experience of thoughtless awareness. Sahaja Yoga is one of the Meditation techniques that aim to eliminate thought processes in the practitioner. Electrophysiological (EEG) studies comparing the brain activation of 16 long-term Sahaja Yoga practitioners between 3 and 7 years of practice to short-term Meditators with up to 6 months of practice have been able to find specific brain activation patterns corresponding to the subjective feelings of thoughtless awareness and happiness (Aftanas and Golocheikine, 2001, 2002a,b, 2003). During the Meditation, compared to rest, the long-term Meditators showed more feelings of happiness and less mental activity than the short-term Meditators. In their EEG measures, the long-term Meditators showed increased power in low band frequency EEG activity of theta and alpha, which was particularly pronounced over the left frontal regions. The intensity of the feelings of happiness was positively correlated with the theta activity over left frontal regions. This is in line with the evidence for a role of the left frontal lobe in positive emotions whereas the right prefrontal lobe plays a greater role in negative ones (Canli et al., 1998). The intensity of mental activity correlated negatively with theta activity over frontal and mid and right central brain regions, suggesting that less internal dialogue was related to more activation in these regions. Frontal theta activity is thought to originate from limbic and frontal brain regions such as the anterior cingulate and prefrontal cortex and has been shown to be increased during both affective and attentional states such as emotion processing and sustained attention (Asada et al., 1999; Deiber et al., 2007; Gevins and Smith, 2000; Rachbauer et al., 2003; Sauseng et al., 2007). There was also increased activation in the alpha power range over the same regions, which is thought to reflect a reduction in brain regions that mediate mental effort and external attention (Osaka, 1984; Gevins et al., 1997; McEvoy et al., 2000). Increased activation in alpha activity has commonly been observed in Meditators of different traditions and been found to correlate with reduced levels of anxiety (Cahn and Polich, 2006). This pattern of increased fronto-parietal theta activity has also been observed during other concentrative Meditation techniques and seems to be a correlate of internalised attention (Cahn and Polich, 2006). In addition to enhanced fronto-parietal theta activation, the authors also found enhanced connectivity of fronto-parietal theta bands and a reduction in the chaotic dimensional complexity, suggesting the enforcement of attentional *networks* and the inhibition of task-irrelevant processes. Taken together, the findings suggest that during Meditation, the reduced mental activity is mediated by increased activation of networks of internalised attention which seem to trigger the activity in regions that mediate positive emotions (left frontal cortex) while decreasing networks related to external attention and irrelevant processes. The enhanced connection between frontal and parietal regions is probably the prerequisite for the general intensification of internalised attention necessary for the induction of the altered state of mental silence (Aftanas and Golocheikine, 2001, 2002b, 2003). In conclusion, these pioneering studies shows that the subjective experiences of mental silence and positive emotions during Meditation have very specific neurophysiological correlates in the activation and connectivity of regions that mediate internalised attention and positive affect.

Most modern functional imaging studies have typically been conducted in very small subject numbers and without the use of control conditions. Nevertheless, the findings so far seem to support the evidence that Meditation leads to increased activation in frontal and subcortical brain regions that are important for sustained attention and emotion regulation. A study of Lou et al. (1999) using positron emission tomography (PET), reported an increase in left prefrontal and limbic brain regions during the abstract sense of joy compared to rest in nine practitioners of Yoga Nidra Meditation. This is in line with the EEG findings of Aftanas and Golocheikine (2001, 2002a,b, 2003) and supports the hypothesis of a role of left fronto-limbic networks for the experience of happiness in Meditators. Single Photon emission tomography in nine practitioners of a concentrative Tibetan Buddhist Meditation who focussed on a mantra showed enhanced frontal and thalamic metabolism after Meditation compared to a rest scan, suggesting enhanced networks of focused concentration (Newberg, 2001). A study using PET that compared Zen Buddhist Meditation of concentration on breath to random thoughts in 11 practitioners found increased activation in left frontal cortex and the basal ganglia, again suggesting enhanced fronto-striatal networks of sustained attention (Ritskes et al., 2003). Functional magnetic resonance imaging (fMRI) was conducted in a small number of five Meditators with at least 4 years of Kundalini Yoga experience, consisting of body postures, breathing exercises and concentration techniques. The study design contrasted Meditation that consisted in passive observation of the breath and the silent repetition of a mantra at exhalation and inhalation with a control condition where subjects silently generated a random list of animals and did not observe their breathing. There was increased activation during late versus early Meditation in dorsolateral prefrontal and parietal cortex, limbic and paralimbic regions (amygdala, hypothalamus, hippocampus and anterior cingulate) and the basal ganglia (Lazar et al., 2000). The authors interpret their findings as an indication of increased activation of brain regions that mediate sustained attention and autonomic control. Given the very small subject numbers a replication in larger samples will be necessary to corroborate the findings.

A well-controlled fMRI study on one-pointed concentration Tibetan Buddhist Meditation compared experienced Meditators with non-Meditators and novices who practised the technique for 1 week (Brefczynski-Lewis et al., 2007). This Meditation technique consists of one-pointed concentration on one object, where the concentration is trained to be kept on that object, and brought back to that object when one has been distracted by outer perceptions or inner thoughts. In the block design fMRI design, several 2.7 s periods of one-pointed Meditation were contrasted with several periods of 1.5 s of simple relaxation. The authors found increased activation in frontal, parietal, insular and thalamic brain regions in

14 long-term Meditators compared to 16 novices. Interestingly there was an inverted u-shape function in brain activation during Meditation with lifetime hours of Meditation so that the most experienced Meditators with most hours of Meditation had less activation in attentional networks than the less experienced Meditators with less hours of Meditation practice. This is in line with the suggestion that at the highest level of expertise, concentration Meditation may result in a less cognitively active, quieter mental state, so that attention skills become less effortful. This would be in line with the neural efficiency hypothesis of skill learning, where the most skilled persons show less activation than less skilled ones (Grabner et al., 2006, 2005). One of the limitations of the study, however, is that the long-term Meditators were older than the novices. Although age was covaried, future studies should replicate the findings in age-matched groups, given evidence for considerable differences in neurofunctional networks during attention functions across the lifespan (Rubia et al., 2006, 2007). There was also heterogeneity in Meditation practices among the expert Meditators, although concentration stability was considered integral to all of them.

Two fMRI studies have been conducted using Mindfulness Meditation. Mindfulness Meditation involves focussed attention on internal and external sensory stimuli with "mindfulness", a specific non-judgemental awareness of present-moment stimuli without cognitive elaboration. One of these studies compared two well-matched groups of experienced Meditators and non-Meditators during mindfulness attention to their breathing contrasted with an arithmetical control task. Apriori regions of interest were used based on the findings of the study of Brefczynski–Lewis in anterior cingulate, medial prefrontal cortex, posterior cingulate and precuneus. The experienced Meditators compared to non-Meditators during mindful attention to their breathing showed enhanced activation in anterior cingulate and medial prefrontal cortex, which was interpreted as an indicator of enhanced attentional control in the Meditation experts (Hoelzel et al., 2007). A limitation of this study was the use of an arithmetic task as control condition that differed from the Meditation condition in several ways other than the meditative state such as mental effort, visual-stimulation, and response preparation.

There is some evidence that functional brain changes during meditation are observable even after short periods of practice as shown by a study in short-term Meditators of mindfulness based stress reduction (MBSR). MBSR involves daily exercises in focusing attention on the present moment, as described in Kabat-Zinn et al. (1992). An fMRI study compared the functional activation effects of 20 practitioners trained for 8 weeks in MBSR with 14 novices during the monitoring of momentary experience compared to narrative traits. One of the assets of the study was that it was a randomized trial, where participants were randomly assigned to either the Meditation training or novice group, resulting in very well-matched groups in terms of demographic data and psychological profile. The study showed enhanced activation in trainees of MBSR compared to novices in a right lateralised internalized attention network of inferior prefrontal cortex, inferior parietal lobe and the insula. Functional connectivity analyses further demonstrated a strong coupling between the right insula and the dorsolateral prefrontal cortex in the mindfulness trained group (Farb et al., 2007). Unfortunately this study did not use a pre–post-intervention design within the same subjects, which would have been more convincing and would have avoided issues of differences in cohorts and inter-subject variability in brain activation.

In conclusion, there is converging evidence that fronto-parietal and fronto-limbic brain networks seem to be activated in the attention practices that lead to Meditation, presumably reflecting processes of internalised sustained attention and emotion regula-

tion. Hereby, the most consistent findings across Meditation imaging studies are the functional up-regulation of brain regions that are known to mediate attention control. However, there are also differences between methods in the brain activation patterns elicited. This is likely to be related to the difference in the practices used to achieve the state of Meditation. For example, activation of the insula and the anterior cingulate, which are known to be important areas for interoceptive attention and autonomic control (Critchley et al., 2004) appear to be particularly enhanced in those Meditative practices that train the attentional focus on breathing or internal body states, such as Kundalini Yoga or mindful observation of the breathing (Farb et al., 2007; Hoelzel et al., 2007; Lazar et al., 2000). Different brain activation networks may thus be activated by different Meditation traditions. A recent study on a form of Tibetan Buddhist Meditation, for example, showed a very different activation pattern compared to the majority of EEG studies that show enhanced theta activation (Cahn and Polich, 2006). This study showed enhanced high-amplitude gamma activity in eight experienced Buddhist practitioners compared to novices (Lutz et al., 2004). The Meditators did not try to achieve a state of thoughtless awareness, but concentrated on feelings of non-referential compassion. They showed highly synchronised gamma activity over frontal and parietal brain regions that correlated with lifetime hours of Meditation practice and were also observed during rest. The gamma activity recorded was the highest observed so far in non-pathological states (Lutz et al., 2004). Gamma activity has been related to higher level, effortful cognitive and emotional processing (Jausovec and Jausovec, 2005; Rennie et al., 2000). These findings thus show activation of higher order effortful affective and cognitive processes in Tibetan Buddhist Meditators during their concentrative practics that are, however, qualitatively different from the slow-wave, presumably more effortless activation patterns that are achieved by other Meditation techniques during thought reduction or the state of thoughtless awareness (Cahn and Polich, 2006; Aftanas and Golocheikine, 2001). One of the limitations of this study was that the long-term Meditators were not matched in age or cultural background to the novices. Nevertheless, the differences in findings between this and previous EEG studies show that different Meditation techniques may elicit very different brain activation patterns based on the specific practices that are used to achieve a meditative state. Meditation practices that focus on concentration of an object or mantra seem to elicit the activation of fronto-parietal networks of internalised attention (Brefczynski-Lewis et al., 2007; Aftanas and Golocheikine, 2001, 2002a,b, 2003; Newberg, 2001; Ritskes et al., 2003), while Meditation techniques that focus on breathing may elicit additional activation of paralimbic regions of insula and anterior cingulate (Farb et al., 2007; Hoelzel et al., 2007; Lazar et al., 2000), and Meditation techniques that focus on an emotion may elicit fronto-limbic activation (Lou et al., 1999; Lutz et al., 2004). Future studies will be needed to disentangle the brain activation patterns related to different peak experiences in different Meditation traditions.

Further evidence supporting the hypothesis that Meditation experiences are related to limbic brain activation comes from studies that show Meditation-elicited changes in neurochemicals that are released by limbic brain regions and modulate mood and affect. A functional imaging study using PET compared rest (listening to speech) to active Meditation (Meditation under verbal instruction) during Yoga Nidra Meditation. This relaxation Meditation method is based on breathing exercises that induce a detached state characterised by reduced readiness for action and enhanced sensory awareness (Kjaer et al., 2002). They found decreased binding of a radioactive tracer that competes with endogenous dopamine in the ventral striatum. This corresponds to about 65% increase in dopamine release in limbic brain regions.

Dopamine is a neurotransmitter that is crucial for motivational and fronto-limbic affective systems of the brain. The increase in dopamine was correlated with increase in theta activity, thought to reflect enhanced internalised attention (Kjaer et al., 2002). The findings of dopamine release in limbic brain regions is also in line with the above reported activation findings in left frontal and limbic areas during the abstract sense of joy using the same Meditation technique (Lou et al., 1999). Several studies of Meditation have observed increases in blood plasma levels of melatonin (Harinath et al., 2004; Massion et al., 1995; Solberg et al., 2000a, 2004a,b; Tooley et al., 2000) and serotonin (Bujatti and Riederer, 1976; Solberg et al., 2000a, 2004b; Walton et al., 1985), chronically in long-term Meditators compared to controls or acutely after Meditation. Both neurochemicals are closely linked, play an important role in mood stabilisation, positive affect, stress-prevention and aging and there is evidence for their implications in affective disorders such as depression (Young and Leyton, 2002; Neumeister, 2003; Stockmeier, 2003; Pacchierotti et al., 2001). Melatonin has been shown to have a stimulating effect on the immune system and the antioxydative defense system, thus delaying aging (Brzezinski, 1997; Massion et al., 1995); a meta-analysis on 10 randomised controlled trials of melatonin in tumor patients showed that melatonin significantly reduced the risk of death at 1 year follow-up (Mills et al., 2005). It is thus very likely that the subjective feelings of general well-being and positive affect during Meditation are at least in part mediated by the release of mood stabilising neuro-hormones and neuro-transmitters (dopamine, serotonin, and melatonin) in limbic brain regions.

A caveat in all these reviewed functional imaging studies of Meditation is that they were based on a comparison between two different groups of subjects, mostly a group of long-term Meditators compared to novices. This carries the important confound that people who decide to meditate may be different at baseline in their cultural and religious background and psychological traits. Inter-individual differences and variability in brain activation and brain structure could potentially confound brain activation or structure findings that are attributed to Meditation alone. At a minimum, future Meditation imaging research should try to control as much as possible for group differences in demographic variables, including personality traits and religious background. Ideally, future imaging studies of Meditation should be conducted longitudinally to measure within subject changes in brain structure and brain function pre- and post Meditation before and after the Meditation experience.

## 5. Evidence for long-term benefits of Meditation

The majority of Meditation studies have investigated the physiological and neurobiological correlates of the acute effects of Meditation. Clinically more interesting, however, is whether Meditation has sustainable effects on cognitive functions, brain plasticity and mental health. Very few studies have provided evidence for long-term, sustainable effects.

Evidence exists for long-term improvements with Meditation in cognitive skills, mainly in the domains of attention, inhibitory control and perceptual sensitivity. Thus, long-term Meditators have been shown to be superior to controls in selective and sustained attention and inhibitory control as well as in EEG neurophysiological correlates of performance (Cahn and Polich, 2006). Furthermore, several studies have shown enhanced perceptual acuity and enhanced attentional and inhibitory skills in long-term practitioners of Mindfulness Meditation practice (Brown et al., 1984; Jha et al., 2007; Slagter et al., 2007) and one-pointedness Tibetan Buddhist Meditation (Carter et al., 2005). Improvements in reaction time and executive functions have also

been reported in practitioners of other Buddhist Meditation techniques (Sudsuang et al., 1991). These benefits in tasks of inhibitory self-control, attention and perception are likely to reflect the long-term effects of concentrative practices that teach attentional focus and the inhibition of task-irrelevant external and internal activity such as thoughts or environmental distraction. Remarkably, there is evidence that even very short-term Meditation based mental training of weeks to months can enhance performance on attention tasks (Slagter et al., 2007; Tang et al., 2007).

A study of Aftanas and Golosheykin (2005) compared 27 long-term Meditators of Sahaja Yoga to controls on a range of trait personality measures. The long-term Meditators scored significantly lower in personality features of anxiety, neuroticism, psychoticism, and depression and scored higher in emotion recognition and expression (Aftanas and Golosheykin, 2005). The authors suggested that long-term Meditation leads to higher psycho-emotional stability and better emotional skills. Cross-sectional studies, however, are confounded by cohort effects. Furthermore, Meditation practices are often associated with lifestyle changes that could also affect health and personality. Longitudinal studies using well-controlled study groups will be needed to establish long-term effects on personality.

Only two studies, to our knowledge, have examined the long-term plastic effects of Meditation on brain structure. Lazar et al. (2005) compared 20 Buddhist Meditators who practised insight/Mindfulness Meditation for an average time of 9 years to age and demographically matched controls. The authors searched for changes between groups in apriori defined regions of the frontal lobe, interoceptive and unimodal sensory regions. The Meditators compared to controls had significantly increased cortical thickness in right middle and superior frontal cortex and the insula. Furthermore, these areas were significantly negatively correlated with age in controls but not Meditators, suggesting that in the Meditators the normal age-related cortical thinning is delayed in right fronto-limbic brain regions (Lazar et al., 2005). The thickness of the right prefrontal regions in 40–50-year-old Meditators was comparable to the thickness in 20–30-year-old controls and young Meditators. The second study also investigated structural differences in 20 practitioners of 2–16 years of Vipassana Mindfulness Meditators compared to age and demographically well-matched controls. The Meditators had increased grey matter concentration in right insula and hippocampus and at a trend level in left inferior temporal lobe. Left inferior temporal lobe and at a trend level the insula grey matter concentration increases correlated significantly with the lifetime hours of Meditation practice (Hoelzel et al., 2007). The right prefrontal cortex is known to be crucial for sustained attention and concentration functions, and the increased thickness probably reflects Meditation-induced cortical plasticity due to years of dedicated concentration practice. The insula, found to be increased in both studies, is an area that is important for interoceptive attention and breath awareness (Critchley et al., 2004). An experience-dependent plastic change in this region may reflect the specific Meditation practice of focussing attention to internal and visceral functions, thus enhancing body awareness. The hippocampus plays an important role in cortical arousal and via its connections to the amygdala influences emotional and attentional processes (de Curtis and Pare, 2004; Wu and Guo, 1999). Interestingly, across the whole brain, gray matter concentration in the medial orbitofrontal region, an area known to be important for emotion control, correlated with the years of Meditation practice. These correlation findings could be the neurophysiological underpinnings of the subjective reports of improved emotion control in Meditators. Given the relatively small subject numbers, however, the findings of these two studies need to be considered preliminary. Furthermore, the second study did

not apply multiple comparison correction. The problem of inter-subject variability in cross-sectional study designs in imaging studies has already been addressed in the context of the functional imaging studies. Longitudinal study designs testing for structural changes before and after years of Meditation practices or randomised controlled trials will be more informative and convincing with respect to causality than cross-sectional designs, where it cannot be excluded that brain changes are related to psychological traits or more healthy lifestyles in people who are drawn to practice Meditation.

There is also evidence that Meditation induces lasting changes in brain function. EEG studies show that the typical slow-wave (alpha-theta) brain patterns elicited during concentration Meditation techniques of different Yoga traditions are also observed during rest, thus showing lasting trait effects (Aftanas and Golosheykin, 2005; Cahn and Polich, 2006). This may suggest that long-term Meditators when resting enter into a semi-meditative state or achieve a permanent reduction of the internal mental dialogue. Sahaja Yoga Meditators during rest have also shown a reduction of the typical left over right hemispheric asymmetry observed in parietal lobes of healthy controls, suggesting enhanced hemispheric balance (Aftanas and Golosheykin, 2005). Transcendental Meditation, a commercial Meditation technique with relatively secretive, non-concentrative practices involving mantra repetition, has also shown to elicit long-term functional brain changes. Long-term transcendental Meditation practitioners showed thus cumulative effects of the frequency of transcendent experiences on cortical preparatory response in ERP measures, concomitant with enhanced selective attention (Travis et al., 2000, 2002).

An interesting study investigating the neural correlates of emotional reactivity of long-term Meditators compared to controls showed reduced psychological, physiological and electrophysiological reactivity to stressful stimuli, providing for the first time neurophysiological evidence to support the hypothesis that Meditation leads to "detachment" and greater emotional resilience to stressful life events (Aftanas and Golosheykin, 2005). Twenty-five Sahaja Yoga Meditators were compared to controls in their response to a stressful video-clip. The Meditators compared to controls showed reduced subjective ratings of negative emotions elicited by the movie, reduced levels of an autonomic indicator of stress (skin potential levels) and reduced gamma activity over frontal brain regions in response to the stressful stimuli. Gamma activity over frontal regions in the control group is reflective of increased focused arousal in relation to the emotional involvement and reactivity (Jausovec and Jausovec, 2005; Rennie et al., 2000). These findings provide neurophysiological evidence for the claim for long-term effects of Meditation on emotional stability, detachment and resilience to stressful events.

## 6. Specificity of the neural substrates of Meditation compared to relaxation

It has been argued that Meditation is not different from simple relaxation. And there are certainly some Meditation techniques that do not claim to go beyond relaxation. Nevertheless, one would expect the neurobiology of the more concentrative Meditation techniques to differ from that of general relaxation, given that in addition to relaxing the body these "cognitive relaxation" techniques aim at reducing mental activity, hence also relaxing the mind. Mental relaxation, in turn, may feedback to the body and lead to a deeper physical relaxation. In fact, physiological studies have shown that Meditation is different from simple relaxation or sleep (Jevning et al., 1992; Young and Taylor, 2001; Cahn and Polich, 2006). At a neurophysiological level, there appear to be differences in the neural networks associated with generic

relaxation and Meditation. Physical relaxation, such as simple muscle relaxation, has been associated with activation in primary and secondary motor regions that are known to inhibit movement (Toma et al., 1999; Oga et al., 2002). Functional imaging studies of relaxation biofeedback have shown activation in paralimbic and limbic regions, known to mediate the control of sympathetic arousal and interoceptive awareness, such as the orbitofrontal cortex, anterior cingulate, the insula, thalamic regions and the amygdala (Critchley et al., 2001, 2002; Nagai et al., 2004). While some of these brain regions, in particular anterior cingulate and insula, have also been found to be activated during Meditation, in particular during those techniques that focus on breathing and attention to internal bodily states such as Kundalini Yoga or mindful attention on breathing (Farb et al., 2007; Hoelzel et al., 2007; Lazar et al., 2000), most Meditation techniques appear to recruit additional fronto-limbic and fronto-parietal neural networks (Brefczynski-Lewis et al., 2007; Aftanas and Golocheikine, 2001, 2002a,b, 2003; Newberg, 2001; Ritskes et al., 2003; Lou et al., 1999; Lutz et al., 2004; Farb et al., 2007; Hoelzel et al., 2007; Lazar et al., 2000).

Most importantly, some of the functional imaging studies of the more concentrative Meditation techniques reviewed in chapter 4 have directly contrasted Meditation with relaxation. They found activation specific to Meditation, over and above relaxation, in paralimbic areas and in fronto-limbic affective and fronto-parietal attention networks (Aftanas and Golocheikine, 2001, 2002a,b, 2003; Brefczynski-Lewis et al., 2007; Lutz et al., 2004; Newberg, 2001). This suggests that Meditation is associated with stronger activation in paralimbic areas of autonomic control, perhaps due to deeper control of the autonomic system and interoceptive awareness compared to relaxation, but also with the activation of additional fronto-parietal and fronto-limbic brain regions, independent from the physiological relaxation effect.

Furthermore, several of the studies described in chapters 3 and 4 have compared the physiology (Cahn and Polich, 2006; Jevning et al., 1992; Rai et al., 1988; Young and Taylor, 2001) or neurobiology (Aftanas and Golocheikine, 2001, 2002a,b, 2003; Brefczynski-Lewis et al., 2007; Hoelzel et al., 2007; Farb et al., 2007) of Meditation between long- and short-term Meditators, finding specific differences in physiology and brain activation in the long-term Meditators. If Meditation was not different from simple generic relaxation, one would expect short- and long-term Meditators to be similarly relaxed and not differ in their physiological or neurophysiological substrates. These studies (described in chapter 4) observed enhanced activation in fronto-parietal attention networks in experienced compared to less experienced or novice Meditators, suggesting experience-dependent "dose"-effects of Meditation on these neurofunctional networks (Aftanas and Golocheikine, 2001, 2002a,b, 2003; Brefczynski-Lewis et al., 2007; Farb et al., 2007). These dose-effects are further confirmed by studies that found that activation and even structural changes in fronto-parietal networks correlated with the lifetime hours of Meditation practice (Brefczynski-Lewis et al., 2007; Hoelzel et al., 2007; Lutz et al., 2004). Furthermore, one study found a direct correlation between the individual variability of the subjective quality of the Meditation and the degree of brain activation. The authors found that the intensity of brain activation in fronto-parietal and fronto-limbic regions correlated linearly with the subjectively reported intensity of the state of thought reduction and Meditation-induced happiness, respectively (Aftanas and Golocheikine, 2001, 2002a,b, 2003). Similar "dose"-effects have also been observed within subjects, where fronto-parietal and fronto-limbic brain activation within subjects was stronger in deeper, compared to initial, lighter meditative states (Lazar et al., 2000). These findings of within and between subjects experience-dependent effects of Meditation on fronto-parietal and fronto-

limbic networks further reinforce the view that these networks are specific to the meditative experience as they can be modulated by practice in a linear, dose-dependent manner.

In conclusion, although there is some overlap between Meditation and simple relaxation in the activation of paralimbic brain regions, such as the anterior cingulate or insula that mediate sympathetic arousal known to be reduced with both techniques, there is evidence that the neural networks associated with Meditation may be stronger in paralimbic regions and extend to additional fronto-parietal attention and fronto-limbic affective systems, presumably related to the state of internalised attention and emotional contentment that is characteristic to the *cognitive* relaxation that is Meditation. This may be particular the case in the more concentrative Meditation techniques. Furthermore, it appears that these Meditation-specific neural networks can be progressively modulated with practice, experience and the intensity of the meditative experience.

Certainly, more direct head-to-head comparisons between different Meditation and relaxation techniques are needed to shape out the neural networks that are specific to Meditation over and above those related to simple relaxation. Future functional imaging studies of Meditation should therefore include a relaxation state as comparison for the meditative state under investigation to be able to dissociate Meditation-specific from relaxation-specific neurofunctional effects.

## 7. Clinical effectiveness of Meditation in psychiatric disorders

Given the preliminary but growing evidence for short and long-term effects of Meditation on physiological indicators of stress, on personality and cognitive functions, and on functional and structural plasticity of brain regions that are important for attention and emotion regulation, mental disorders, typically characterized by affective and cognitive-attentional problems, are an obvious target to study the clinical effects of Meditation.

Research of the clinical application of Meditation effects is still very much in its infancy, but there is some emerging evidence that Meditation has positive effects on stress-related diseases and on some neuropsychiatric disorders. Among mental disorders, disorders of affect regulation and anxiety in particular are thought to benefit, given the attributed role of Meditation techniques in the relief of stress and anxiety, on emotional resilience and mood regulation and the neurobiological evidence for the up-regulation of underlying fronto-limbic neural networks that mediate affect regulation. Another key target group could be disorders of attention, given that several Meditation techniques are associated with enhanced attention skills in long-term Meditation practitioners and with functional and structural effects on fronto-parietal networks of sustaining attention.

### 7.1. Depression and anxiety disorders

Depression is the most common form of mental illness, with an escalating prevalence in ever younger populations. It is one of the main causes for disability and has a high burden of disease (see Section 1). The relapse rates of conventional treatment are high (Vitiello and Swedo, 2004). Furthermore, a recent meta-analysis on antidepressant medication has raised serious concerns about its clinical efficacy (Kirsch et al., 2008). Finding non-pharmacological treatment options is therefore desirable, in particularly in teenagers where antidepressant pharmacological Medication has been controversial due to side effects and suicide risk (Vitiello and Swedo, 2004).

Several clinical trials have shown positive effects of several weeks of Mindfulness Meditation based stress-reduction interventions in patients with major depression and anxiety on symptoms of depression, anxiety, panic and rumination (Arias et al., 2006; Kabat-Zinn et al., 1992; Miller et al., 1995; Ramel et al., 2004; Toneatto and Nguyen, 2007). However, no study has used Mindfulness Meditation per se in psychiatric disorders. Also, the few studies that actually correlated mindfulness practices with outcomes did not find support for the amount of mindfulness practice accounting for the benefits, calling into question the role of mindfulness practice as the mechanism for the symptomatic improvements (Ivanovski and Malhi, 2007).

Sahaja Yoga Meditation over 6 weeks showed a significant reduction in the symptoms of anxiety, depression and general mental health in 24 patients with major depression compared to a control group and a group receiving CBT (Morgan, 2001). Although the effect sizes were high, ranging from Cohen's $d$ of 1.2–2.1, replication in a larger sample is needed to corroborate the findings of effectiveness of this Meditation technique in disorders of depression.

Another Yoga technique, called Sudarshan Kriya Yoga, has shown effectiveness in patients with depression on symptoms of anxiety and depression in a randomised controlled trial (Janakiramaiah et al., 2000). Sudarshan Kriya Yoga is based on a specific breathing technique (Pranayama) based on ancient Vedic tradition. Meditation was as good as Imipramine, an antidepressant, but inferior to electroconvulsive therapy. Abnormalities of the P300 which have been observed in patients with depression in some studies (Gangadhar et al., 1993; Karaaslan et al., 2003) but not others (Bruder et al., 1991; Hansenne et al., 2000) were not predictive of the response to Meditation (Brown and Gerberg, 2005; Janakiramaiah et al., 2000; Murthy et al., 1998). The effect sizes were relatively small and a replication in larger samples may be needed to confirm the results. Furthermore, the study could not be blinded due to the nature of the intervention methods. The efficacy of the same Meditation technique has also been tested in 60 people with drug abuse, randomized to either Meditation or control conditions. The Meditation group improved significantly more in their depression symptoms and also in physiological measures of the stress hormone levels of cortisol and acetylcholine with large effect sizes (Vedamurthachar et al., 2006).

A small study investigated the effect of Mindfulness Meditation based cognitive behavioural therapy on prefrontal alpha-asymmetry resting EEG patterns in patients with depression with high relapse risk, randomized to either MBCT or treatment as usual (Barnhofer et al., 2007). Chronic and acute depression is typically associated with reduced activation over the left frontal lobe (Henriques and Davidson, 1990, 1991). Results showed a significant time by group interaction with a large effect size which was not due to a change in the alpha-asymmetry in the Meditation treated patients, but a deterioration towards relatively stronger right-hemisphere activation in the control group. The authors interpreted their findings as a protective effect of Meditation on depression; however, the observed differential effects were entirely attributable to the treatment as usual group and not the Meditation technique.

A couple of Meditation studies have been conducted in obsessive-compulsive disorder (OCD). The first study was an open trial of 12 months Kundalini Yoga practice, consisting of posture and breathing exercises, in five medicated patients. There was a significant reduction in OCD symptoms and severity of about 50% (Shannahoff-Khalsa, 1997). The second study was a blinded randomised controlled trial with 12 months of Kundalini Yoga as the active condition and relaxation response and mindfulness based Meditation as active control condition (Shannahoff-Khalsa et al., 1999). Only the Kundalini Yoga group improved but not the control group. Significant improvements were observed in OCD symptoms (38%) and in mood and anxiety measures. The groups were then joined and all subjects practiced Kundalini Yoga. The

remaining 11 patients were measured again after 15 months and showed improvements of symptoms by 70% and improvement of anxiety and mood measures between 50 and 70% (Shannahoff-Khalsa, 1997, 2004, 2006; ShannahoffKhalsa and Beckett, 1996; Shannahoff-Khalsa et al., 1999).

A small exploratory study investigated Mindfulness Meditation based stress-reduction interventions on 18 women with binge eating problems over 6 weeks. The MBSR treatment showed a significant improvement in binge eating frequency and severity as well as symptoms of anxiety and depression after 6 weeks that persisted 3 weeks after treatment (Kristeller et al., 2004). Although the effect size was large (with a Cohen's *d* of 2), this study needs to be considered preliminary given that there was no control group.

In conclusion, research of the effects of Meditation on disorders related to depression and anxiety is certainly promising but needs to be further explored in larger sample sizes and using randomised controlled trials that include an active comparison group.

### 7.2. Attention deficit hyperactivity disorder

We conducted a study in children with attention deficit hyperactivity disorder (ADHD), which is defined as a disorder of age-inappropriate symptoms of hyperactivity, inattention and impulsiveness (American Psychiatric Association, 1994). Children with ADHD typically suffer from deficits in cognitive functions of self-control and attention (Rubia et al., 2001, 2007) and are known to have reduced size (Krain and Castellanos, 2006) and function of fronto-parietal neural networks during tasks of inhibition and attention (Rubia et al., 1999, 2001, 2005, 2008, 2009; Smith et al., 2006). The treatment of choice is psychostimulant medication and there has been a fourfold increase in prescription rates over the last decade in Western countries. The escalating stimulant prescription rates have caused growing concern, given side effects and the unknown long-term effects of stimulant medication on brain development. Furthermore, recent evidence shows that the superiority of medication treatment over behavioural treatments wanes after several years, raising worrying questions over potential sensitisation effects (Jensen et al., 2007).

We hypothesised that Sahaja Yoga Meditation would reduce symptoms of hyperactivity through the reduction of sympathetic activity (Rai et al., 1988; Manocha et al., 2002). We further hypothesised that the problems with inattention and impulse control would be counteracted with Meditation, given the above mentioned evidence for Meditation training induced improvement of cognitive functions of sustained attention, inhibitory control and self-monitoring (Brown et al., 1984; Jha et al., 2007; Slagter et al., 2007), and the neuroimaging evidence for activation of fronto-parietal attention networks with Sahaja Yoga Meditation (Aftanas and Golocheikine, 2001, 2002a,b, 2003). These are typically under-activated in children with ADHD during tasks of inhibitory control and attention (Rubia et al., 1999, 2001, 2005, 2008, 2009; Smith et al., 2006). In fact, after 6 weeks of treatment with Sahaja Yoga Meditation adjunctive to their usual treatment regime, 26 children with ADHD showed a significant reduction of the main symptoms of hyperactivity, impulsiveness and inattention, which was equally observed in medicated and non-medicated patients (Harrison et al., 2004). The effect size was high (Cohen's *d* of 1.2). Furthermore, of the treated children, 50% of children either stopped or reduced their medication, and still improved in symptoms (Harrison et al., 2004). Secondary benefits were an improved child–parent relationship and enhanced self-esteem. This study suggests that Sahaja Yoga Meditation is a promising non-pharmacological treatment option for children with ADHD that needs to be further explored in larger samples of medication-naïve children and including an active control group.

A subsequent small pilot study further supports the potential effectiveness of Meditation in people with ADHD. The feasibility study enrolled 25 adults and adolescents with ADHD in an 8-week Mindfulness Meditation based cognitive behavioural therapy training program and showed pre–post-improvements in self-reported ADHD symptoms and performance on tasks of selective attention and cognitive inhibition. The effects sizes for symptom reduction were relatively high (Cohen's *d* of 1.8). In addition, improvements in anxiety and depressive symptoms were also observed (Zylowska et al., 2008). Unfortunately, however, the authors did not include a control group and used self-reports of measures of ADHD symptoms, which are likely to be influenced by placebo effects.

To summarise, the combined evidence from neuroimaging studies, showing enhanced activation and structural plasticity with Meditation in fronto-parietal networks of internalized attention, and the preliminary findings of these two clinical studies in people with attention deficits suggest that both Sahaja Yoga Meditation and mindfulness based Meditation techniques could well be useful tools to enhance self-control and concentration functions in pathologies who suffer from problems with these, either alone or as an adjunct to existing conventional treatment.

In conclusion, the investigation of the effectiveness of Meditation on major psychiatric disorders is still very much in its infancy. The majority of studies have been conducted in small subject numbers and few have used an active control group, which makes it difficult to rule out non-specific effects. However, the so far reported beneficial effects in these small-sampled studies of Meditation techniques or Meditation based behavioural therapies for disorders of affect, anxiety and attention deficits are promising.

## 8. Overall conclusions

Several Meditation techniques appear to have short and long-term effects on functional and structural brain plasticity as well as on physiological indicators of relaxation and stress relief. There is evidence to suggest that these effects are specific to Meditation over and above simple relaxation effects. There is furthermore preliminary evidence for enhanced psycho-emotional balance and focussed attention skills in long-term Meditators. The up-regulating functional effects on fronto-parietal attention networks and fronto-limbic networks of emotional control could be the neurophysiological mechanisms of action for reported psycho-emotional and cognitive effects. Although clinical Meditation research has mostly been conducted in small sample sizes and poorly controlled conditions, there is some evidence for its effectiveness in disorders of anxiety, attention and affect. The combined evidence from neurobiological and clinical studies for an up-regulation of attentional and motivational networks and for a reduction in symptoms of anxiety, depression and attention, respectively, bears promise. Both together suggest that some Meditation techniques could potentially play a role in the prevention as well as the intervention of disorders of attention and affect regulation.

Given the relatively small field of research into Meditation effects on brain physiology and psychiatric disorders, the goal of this review was to shape out the commonalities of the different Meditation techniques on cognition, on physiological and neuro-physiological underpinnings, and on clinical effects. However, there is large heterogeneity in the different Meditation traditions and practices and there is already some evidence that different Meditation techniques may have different effects on the brain and, by inference, presumably on behaviour and cognition. More large-scale and well-controlled neurobiological and clinical research studies are needed to understand more thoroughly the neuro-physiological mechanisms of action and the clinical effectiveness

of these different Meditation practices. So far, hardly any studies have compared between different Meditation techniques and no comparative Meditation studies exist in the fields reviewed in this paper. Future studies, therefore, need to move a step further and investigate the specificity of the cognitive, behavioural, physiological and neurophysiological effects of these different Meditation techniques by directly comparing between them. It is likely that the many different existing Meditation practices differ in their specific cognitive, behavioural and neurofunctional effects. Meditation techniques with emphasis on concentrative practices, for example, may be more suitable for pathologies with attention problems, while Meditation techniques that emphasise emotional stress reduction may be more efficient in affective pathologies. Once we have established a more thorough understanding of the specific behavioural and cognitive effects and the underlying neurofunctional mechanisms of action of these different Meditation techniques, however, there is scope for the use of some of these Meditation techniques as a promising health intervention for specific disorders, either alone or as an adjunct to existing conventional treatment.

## References

Aftanas, L., Golosheykin, S., 2005. Impact of regular meditation practice on EEG activity at rest and during evoked negative emotions. International Journal of Neuroscience 115 (6), 893–909.

Aftanas, L.I., Golocheikine, S.A., 2001. Human anterior and frontal midline theta and lower alpha reflect emotionally positive state and internalized attention: high-resolution EEG investigation of meditation. Neuroscience Letters 310 (1), 57–60.

Aftanas, L.I., Golocheikine, S.A., 2002a. Linear and non-linear concomitants of altered state of consciousness during meditation: high resolution EEG investigation. International Journal of Psychophysiology 45 (1–2), 158–1158.

Aftanas, L.I., Golocheikine, S.A., 2002b. Non-linear dynamic complexity of the human EEG during meditation. Neuroscience Letters 330 (2), 143–146.

Aftanas, L.I., Golocheikine, S.A., 2003. Changes in cortical activity in altered states of consciousness: the study of meditation by high-resolution EEG. Journal of Human Physiology 29 (1), 143–151.

American Psychiatric Association, 1994. Diagnostic and Statistical Manual of Mental Disorders, 4th ed. American Psychiatric Association, Washington.

Arias, A.J., Steinberg, K., Banga, A., Trestman, R.L., 2006. Systematic review of the efficacy of meditation techniques as treatments for medical illness. Journal of Alternative and Complementary Medicine 12 (8), 817–832.

Asada, H., Fukuda, Y., Tsunoda, S., Yamaguchi, M., Tonoike, M., 1999. Frontal midline theta rhythms reflect alternative activation of prefrontal cortex and anterior cingulate cortex in humans. Neuroscience Letters 274 (1), 29–32.

Barnhofer, T., Duggan, D., Crane, C., Hepburn, S., Fennell, M.J.V., Williams, J.M.G., 2007. Effects of meditation on frontal alpha-asymmetry in previously suicidal individuals. Neuroreport 18 (7), 709–712.

Brefczynski-Lewis, J.A., Lutz, A., Schaefer, H.S., Levinson, D.B., Davidson, R.J., 2007. Neural correlates of attentional expertise in long-term meditation practitioners. Proceedings of the National Academy of Sciences of the United States of America 104 (27), 11483–11488.

Brown, D., Forte, M., Dysart, M., 1984. Differences in visual sensitivity among mindfulness meditators and non-meditators. Perceptual and Motor Skills 58 (3), 727–733.

Brown, R.P., Gerbarg, P.L., 2005. Sudarshan Kriya yogic breathing in the treatment of stress, anxiety, and depression. Part II. Clinical applications and guidelines. Journal of Alternative and Complementary Medicine 11 (4), 711–717.

Bruder, G.E., Towey, J.P., Stewart, J.W., Friedman, D., Tenke, C., Quitkin, F.M., 1991. Event-related potentials in depression: influence of task, stimulus hemifield and clinical features on P3 latency. Biological Psychiatry 30, 233–246.

Brzezinski, A., 1997. Melatonin in humans. New England Journal of Medicine 336 (3), 186–195.

Bujatti, M., Riederer, P., 1976. Serotonin, noradrenaline, dopamine metabolites in transcendental meditation-technique. Journal of Neural Transmission 39 (3), 257–267.

Cahn, B.R., Polich, J., 2006. Meditation states and traits: EEG, ERP, and neuroimaging studies. Psychological Bulletin 132 (2), 180–211.

Canli, T., Desmond, J.E., Zhao, Z., Glover, G., Gabrieli, J.D.E., 1998. Hemispheric asymmetry for emotional stimuli detected with fMRI. Neuroreport 9 (14), 3233–3239.

Carter, O.L., Presti, D.E., Callistemon, C., Ungerer, Y., Liu, G.B., Pettigrew, J.D., 2005. Meditation alters perceptual rivalry in Tibetan Buddhist monks. Current Biology 15 (11), R412–R413.

Chugh, D., 1997. The effects of Sahaja Yoga in bronchial asthma and essential hypertension. New Delhi Medicos N13 5 (4), 46–47.

Critchley, H.D., Wiens, S., Rotshtein, P., Ohman, A., Dolan, R.J., 2004. Neural systems supporting interoceptive awareness. Nature Neuroscience 7 (2), 189–195.

Critchley, H.D., Melmed, R.N., Featherstone, E., Mathias, C.J., Dolan, R.J., 2001. Brain activity during biofeedback relaxation: a functional neuroimaging investigation. Brain 124 (5), 1003–1012.

Critchley, H.D., Melmed, R.N., Featherstone, E., Mathias, C.J., Dolan, R.J., 2002. Volitional control of autonomic arousal: a functional magnetic resonance study. NeuroImage 16, 909–919.

de Curtis, M., Pare, D., 2004. The rhinal cortices: a wall of inhibition between the neocortex and the hippocampus. Progress in Neurobiology 74 (2), 101–110.

Deiber, M.P., Missonnier, P., Bertrand, O., Gold, G., Fazio-Costa, L., Ibanez, V., Giannakopoulos, P., 2007. Distinction between perceptual and attentional processing in working memory tasks: a study of phase-locked and induced oscillatory brain dynamics. Journal of Cognitive Neuroscience 19 (1), 158–172.

Farb, N.A.S., Segal, Z.V., Mayberg, H., Bean, J., McKeon, D., Fatima, Z., Anderson, A.K., 2007. Attending to the present: mindfulness meditation reveals distinct neural modes of self-reference. Social Cognitive and Affective Neuroscience 2, 313–322.

Gangadhar, B.N., Ancy, N., Janakiramaiah, N., Umapathy, C., 1993. P300 amplitude in non-bipolar, melancholic depression. Journal of Affective Disorders 28, 57–60.

Gevins, A., Smith, M.E., 2000. Neurophysiological measures of working memory and individual differences in cognitive ability and cognitive style. Cerebral Cortex 10 (9), 829–839.

Gevins, A., Smith, M.E., McEvoy, L., Yu, D., 1997. High-resolution EEG mapping of cortical activation related to working memory: effects of task difficulty, type of processing, and practice. Cerebral Cortex 7, 374–385.

Grabner, R.H., Neubauer, A.C., Stern, E., 2006. Superior performance and neural efficiency: the impact of intelligence and expertise. Brain Research Bulletin 69 (4), 422–439.

Grabner, R.H., Stern, E., Neubauer, A.C., 2005. Neural efficiency in tournament chess players: a matter of expertise or intelligence? Journal of Psychophysiology 19 (2), 118–1118.

Hansenne, M., Pitchot, W., Pinto, E., Reggers, J., Papart, P., Ansseau, M., 2000. P300 event-related brain potential and personality in depression. European Psychiatry 15 (6), 370–377.

Harinath, K., Malhotra, A.S., Pal, K., Prasad, R., Kumar, R., Kain, T.C., Rai, L., Sawhney, R.C., 2004. Effects of Hatha yoga and Omkar meditation on cardiorespiratory performance, psychologic profile, and melatonin secretion. Journal of Alternative and Complementary Medicine 10 (2), 261–268.

Harrison, L., Manosh, R., Rubia, K., 2004. Sahaja Yoga Meditation as a family treatment program for attention deficit hyperactivity disorder children. Journal of Clinical Psychology and Psychiatry 9 (4), 479–497.

Henriques, J.B., Davidson, R.J., 1990. Regional brain electrical asymmetries discriminate between previously depressed and healthy control subjects. Journal of Abnormal Psychology 99 (1), 22–31.

Henriques, J.B., Davidson, R.J., 1991. Left frontal hypoactivation in depression. Journal of Abnormal Psychology 100 (4), 535–545.

Hoelzel, B.K., Ott, U., Hempel, H., Hackl, A., Wolf, K., Stark, R., Vaitl, D., 2007. Differential engagement of anterior cingulate and adjacent medial frontal cortex in adept Meditators and non-Meditators. Neuroscience Letters 421 (1), 16–21.

Ivanovski, B., Malhi, G.S., 2007. The psychological and neurophysiological concomitants of mindfulness forms of meditation. Acta Neuropsychiatrica 19 (2), 76–91.

Janakiramaiah, N., Gangadhar, B.N., Murthy, P., Harish, M.G., Subbakrishna, D.K., Vedamurthachar, A., 2000. Antidepressant efficacy of Sudarshan Kriya Yoga (SKY) in melancholia: a randomized comparison with electroconvulsive therapy (ECT) and imipramine. Journal of Affective Disorders 57 (1–3), 255–259.

Jausovec, N., Jausovec, K., 2005. Differences in induced gamma and upper alpha oscillations in the human brain related to verbal/performance and emotional intelligence. International Journal of Psychophysiology 56 (3), 223–235.

Jensen, P.S., Arnold, L.E., Swanson, J.M., Vitiello, B., Abikoff, H.B., Greenhill, L.L., Hechtman, L., Hinshaw, S.P., Pelham, W.E., Wells, K.C., Conners, K., Elliott, G.F., Epstein, J.N., Hoza, B., March, J.S., Molina, B.S.G., Newcorn, J.Y.H., Severe, J.B., Wigal, T., Gibbons, R.D., Hur, K., 2007. 3-Year follow-up of the NIMH MTA study. Journal of the American Academy of Child and Adolescent Psychiatry 46 (8), 989–1002.

Jevning, R., Wallace, R.K., Beidebach, M., 1992. The physiology of meditation – a review – a wakeful hypometabolic integrated response. Neuroscience and Biobehavioral Reviews 16 (3), 415–424.

Jha, A.P., Krompinger, J., Baime, M.J., 2007. Mindfulness training modifies subsystems of attention. Cognitive Affective & Behavioral Neuroscience 7 (2), 109–119.

Kabat-Zinn, J., Massion, A.O., Kristeller, J., Peterson, L.G., Fletcher, K.E., Pbert, L., Lenderking, W.R., Santorelli, S.F., 1992. Effectiveness of a meditation-based stress reduction program in the treatment of anxiety disorders. American Journal of Psychiatry 149 (7), 936–943.

Karaaslan, F., Gonul, A.S., Oguz, A., Erdinc, E., Esel, E., 2003. P300 changes in major depressive disorders with and without psychotic features. Journal of Affective Disorders 73 (3), 283–287.

Kirsch, I., Deacon, B.J., Huedo-Medina, T.B., Scoboria, A., Moore, T.J., Johnson, B.T., 2008. Initial severity and antidepressant benefits: a meta-analysis of data submitted to the Food and Drug Administration. PLoS Medicine 5 (2), doi:10.1371/journal.pmed.0050045.

Kjaer, T.W., Bertelsen, C., Piccini, P., Brooks, D., Alving, J., Lou, H.C., 2002. Increased dopamine tone during meditation-induced change of consciousness. Cognitive Brain Research 13 (2), 255–259.

Krain, A.L., Castellanos, F.X., 2006. Brain development and ADHD. Clinical Psychology Review 26 (4), 433–444.

Kristeller, J.L., Quillian-Wolever, R., Sheets, V., 2004. Mindfulness meditation in treating binge eating disorder: a randomized clinical trial. International Journal of Eating Disorders 35 (4), 453–1453.

Lazar, S.W., Bush, G., Gollub, R.L., Fricchione, G.L., Khalsa, G., Benson, H., 2000. Functional brain mapping or the relaxation response and meditation. Neuroreport 11 (7), 1581–1585.

Lazar, S.W., Kerr, C.E., Wasserman, R.H., Gray, J.R., Greve, D.N., Treadway, M.T., McGarvey, M., Quinn, B.T., Dusek, J.A., Benson, H., Rauch, S.L., Moore, C.I., Fischl, B., 2005. Meditation experience is associated with increased cortical thickness. Neuroreport 16 (17), 1893–1897.

Lou, H.C., Kjaer, T.W., Friberg, L., Wildschiodtz, G., Holm, S., Nowak, M., 1999. A O-15-H2O PET study of meditation and the resting state of normal consciousness. Human Brain Mapping 7 (2), 98–105.

Lutz, A., Greischar, L.L., Rawlings, N.B., Ricard, M., Davidson, R.J., 2004. Long-term Meditators self-induce high-amplitude gamma synchrony during mental practice. Proceedings of the National Academy of Sciences of the United States of America 101 (46), 16369–16373.

Manocha, R., Marks, G.B., Kenchington, P., Peters, D., Salome, C.M., 2002. Sahaja yoga in the management of moderate to severe asthma: a randomised controlled trial. Thorax 57 (2), 110–115.

Massion, A.O., Teas, J., Hebert, J.R., Wertheimer, M.D., Kabat-Zinn, J., 1995. Meditation, melatonin and breast prostate-cancer—hypothesis and preliminary data. Medical Hypotheses 44 (1), 39–46.

Mathers, C.D., Loncar, D., 2005. Updated projections of global mortality and burden of disease, 2002–2030 data sources, methods and results. Evidence and Information for Policy.

McEvoy, L.K., Smith, M.E., Gevins, A., 2000. Test–retest reliability of cognitive EEG. Clinical Neurophysiology 111, 457–463.

Miller, J.J., Fletcher, K., Kabat-Zinn, J., 1995. 3-year follow-up and clinical implications of a Mindfulness Mediation-based stress reduction intervention in the treatment of anxiety disorders. General Hospital Psychiatry 17 (3), 192–200.

Mills, E., Wu, P., Seely, D., Guyatt, G., 2005. Melatonin in the treatment of cancer: a systematic review of randomized controlled trials and meta-analysis. Journal of Pineal Research 39 (4), 360–366.

Morgan, A., 2001. Sahaja Yoga: an ancient path to modern mental health? Transpersonal psychology. Transpersonal Psychology Review 4, 41–49.

Murthy, P., Janakiramaiah, N., Gangadhar, B.N., Subbakrishna, D.K., 1998. P300 amplitude and antidepressant response to Sudarshan Kriya Yoga (SKY). Journal of Affective Disorders 50 (1), 45–48.

Nagai, Y., Critchley, H.D., Featherstone, E., Trimble, M.R., Dolan, R.J., 2004. Activity in ventromedial prefrontal cortex covaries with sympathetic skin conductance level: a physiological account of a "default mode" of brain function. NeuroImage 22 (1), 243–251.

Neumeister, A., 2003. Tryptophan depletion, serotonin, and depression: where do we stand? Psychopharmacology Bulletin 37 (4), 99–115.

Newberg, A., 2001. The measurement of regional cerebral blood flow during the complex cognitive task of meditation: a preliminary SPECT study. Psychiatry Research: Neuroimaging 106 (2), 113–122.

Oga, T., Honda, M., Toma, K., Murase, N., Okada, T., Hanakawa, T., Sawamoto, N., Nagamine, T., Konishi, J., Fukuyama, H., Kaji, R., Shibasaki, H., 2002. Abnormal cortical mechanisms of voluntary muscle relaxation in patients with writer's cramp: an fMRI study. Brain 125 (4), 895–903.

Osaka, M., 1984. Peak alpha frequency of EEG during a mental task: task difficulty and hemispheric differences. Psychophysiology 21 (1), 101–105.

Pacchierotti, C., Iapichino, S., Bossini, L., Pieraccini, F., Castrogiovanni, P., 2001. Melatonin in psychiatric disorders: a review on the melatonin involvement in psychiatry. Frontiers in Neuroendocrinology 22 (1), 18–32.

Patanjali, 1993. The Yoga Sutras of Patanjali. Editor and Translation: Alistair Shearer, 1993.

Rachbauer, D., Labar, K.S., Doppelmayr, M., Klimesch, W., 2003. Increased event-related theta activity during emotional scene encoding. Brain and Cognition 51 (2), 186–187.

Rai, U.C., Seti, S., Singh, S.H., 1988. Some effects of Sahaja Yoga and its role in the prevention of stress disorders. Journal of International Medical Sciences 19–23.

Ramamurthi, B., 1995. The 4th state of consciousness—the Thuriya-Avastha. Psychiatry and Clinical Neurosciences 49 (2), 107–110.

Ramel, W., Goldin, P.R., Carmona, P.E., McQuaid, J.R., 2004. The effects of mindfulness meditation on cognitive processes and affect in patients with past depression. Cognitive Therapy and Research 28 (4), 433–455.

Rennie, C.J., Wright, J.J., Robinson, P.A., 2000. Mechanisms of cortical electrical activity and emergence of gamma rhythm. Journal of Theoretical Biology 205 (1), 17–35.

Ritskes, R., Ritskes-Hoitinga, M., Stodkilde-Jorgensen, H., 2003. MRI scanning during meditation: the picture of enlightenment? Constructivism in the Human Sciences 8, 85–90.

Rubia, K., Smith, A.B., Woolley, J., Nosarti, C., Heyman, I., Taylor, E., Brammer, M., 2006. Progressive increase of fronto-striatal brain activation from childhood to adulthood during event related tasks of cognitive control. Human Brain Mapping 27, 973–993.

Rubia, K., Smith, A., Taylor, E., Brammer, M., 2007. Linear increase in the integrated function of right inferior prefrontal, striato-thalamic and cerebellar regions during inhibition and of anterior cingulate during error-related processes. Human Brain Mapping 28, 1163–1177.

Rubia, K., Smith, A., Halari, R., Matsukura, F., Mohammad, M., Taylor, E., Brammer, M.E., 2009. Disorder-specific dissociation of orbitofrontal dysfunction in boys with pure conduct disorder during reward and ventrolateral prefrontal dysfunction in boys with pure attention-deficit/hyperactivity disorder during sustained attention. American Journal of Psychiatry 166, 83–94.

Rubia, K., Halari, R., Smith, A., Mohammad, M., Scott, S., Giampietro, V., Taylor, E., Brammer, M.E., 2008. Dissociated functional brain abnormalities of inhibition in boys with pure conduct disorder and in boys with pure attention-deficit/hyperactivity disorder. American Journal of Psychiatry 165, 889–897.

Rubia, K., Overmeyer, S., Taylor, E., Brammer, M., Williams, S.C.R., Simmons, A., Bullmore, E.T., 1999. Hypofrontality in attention deficit hyperactivity disorder during higher-order motor control: a study with functional MRI. American Journal of Psychiatry 156 (6), 891–896.

Rubia, K., Smith, A.B., Brammer, M., Toone, B., Taylor, E., 2005. Medication-naïve adolescents with attention-deficit hyperactivity disorder show abnormal brain activation during inhibition and error detection. American Journal of Psychiatry 162 (6), 1067–1075.

Rubia, K., Taylor, E., Smith, A., Oksanen, H., Overmeyer, S., Newman, S., 2001. Neuropsychological analyses of impulsiveness in childhood hyperactivity. British Journal of Psychiatry (179), 138–143.

Sauseng, P., Hoppe, J., Klimesch, W., Gerloff, C., Hummel, F.C., 2007. Dissociation of sustained attention from central executive functions: local activity and inter-regional connectivity in the theta range. European Journal of Neuroscience 25 (2), 587–593.

Shannahoff-Khalsa, D., 2006. A perspective on the emergence of meditation techniques for medical disorders. Journal of Alternative and Complementary Medicine 12 (8), 709–713.

Shannahoff-Khalsa, D.S., 1997. Yogic meditation techniques are effective in the treatment of obsessive-compulsive disorders. In: Hollander, E., Stein, D.E. (Eds.), Obsessive-compulsive Disorders: Etiology, Diagnosis, and Treatment. Marcel Dekker, New York, pp. 283–329.

Shannahoff-Khalsa, D.S., 2004. An introduction to Kundalini yoga meditation techniques that are specific for the treatment of psychiatric disorders. Journal of Alternative and Complementary Medicine 10 (1), 91–101.

ShannahoffKhalsa, D.S., Beckett, L.R., 1996. Clinical case report: efficacy of yogic techniques in the treatment of obsessive compulsive disorders. International Journal of Neuroscience 85 (1–2), 1–17.

Shannahoff-Khalsa, D.S., Ray, L.E., Levine, S., Gallen, C.C., Schwartz, B.J., Sidorowich, J.J., 1999. Randomized controlled trial of yogic meditation techniques for patients with obsessive-compulsive disorders. CNS Spectrums. CNS Spectrum: The International Journal of Neuropsychiatric Medicine 4, 34–46.

Slagter, H.A., Lutz, A., Greischar, L.L., Francis, A.D., Nieuwenhuis, S., Davis, J.M., Davidson, R.J., 2007. Mental training affects distribution of limited brain resources. PLoS Biology 5 (6), 1228–1235.

Smith, A.B., Taylor, E., Brammer, M., Toone, B., Rubia, K., 2006. Task-specific hypoactivation in prefrontal and temporoparietal brain regions during motor inhibition and task switching in medication-naive children and adolescents with attention deficit hyperactivity disorder. American Journal of Psychiatry 163 (6), 1044–1051.

Solberg, E., Ekeberg, O., Holen, A., Osterud, B., Halvorsen, R., Vikman, A., 2000a. Melatonin and serotonin during meditation. Journal of Psychosomatic Research 48 (3), 268–269.

Solberg, E., Ingjer, F., Ekberg, O., Holen, A., Standal, P.A., Vikman, A., 2000b. Blood pressure and heart rate during meditation. Journal of Psychosomatic Research 48 (3), 283–1283.

Solberg, E.E., Ekeberg, O., Holen, A., Ingjer, F., Sandvik, L., Standal, P.A., Vikman, A., 2004a. Hemodynamic changes during long meditation. Applied Psychophysiology and Biofeedback 29 (3), 213–221.

Solberg, E.E., Holen, A., Ekeberg, O., Osterud, B., Halvorsen, R., Sandvik, L., 2004b. The effects of long meditation on plasma melatonin and blood serotonin. Medical Science Monitor 10 (3), CR96–CR101.

Stockmeier, C.A., 2003. Involvement of serotonin in depression: evidence from postmortem and imaging studies of serotonin receptors and the serotonin transporter. Journal of Psychiatric Research 37 (5), 357–373.

Sudsuang, R., Chentanez, V., Veluvan, K., 1991. Effect of Buddhist Meditation on serum cortisol and total protein-levels, blood-pressure, pulse-rate, lung-volume and reaction-time. Physiology & Behavior 50 (3), 543–548.

Tang, Y.Y., Ma, Y.H., Wang, J., Fan, Y.X., Feng, S.G., Lu, Q.L., Yu, Q.B., Sui, D., Rothbart, M.K., Fan, M., Posner, M.I., 2007. Short-term meditation training improves attention and self-regulation. Proceedings of the National Academy of Sciences of the United States of America 104, 17152–17156.

Toma, K., Honda, M., Hanakawa, T., Okada, T., Fukuyama, H., Ikeda, A., Nishizawa, S., Konishi, J., Shibasaki, H., 1999. Activities of the primary and supplementary motor areas increase in preparation and execution of voluntary muscle relaxation: an event-related fMRI study. The Journal of Neuroscience 19 (9), 3527–3534.

Toneatto, T., Nguyen, L., 2007. Does mindfulness meditation improve anxiety and mood symptoms? A review of the controlled research. Canadian Journal of Psychiatry—Revue Canadienne De Psychiatrie 52 (4), 260–266.

Tooley, G.A., Armstrong, S.M., Norman, T.R., Sali, A., 2000. Acute increases in night-time plasma melatonin levels following a period of meditation. Biological Psychology 53 (1), 69–78.

Travis, F., Tecce, J.J., Guttman, J., 2000. Cortical plasticity, contingent negative variation, and transcendent experiences during practice of the Transcendental Meditation technique. Biological Psychology 55 (1), 41–55.

Travis, F.T., Tecce, J., Arenander, A., Wallace, R.K., 2002. Patterns of EEG coherence, power, and contingent negative variation characterize the integration of transcendental and waking states. Biological Psychology 61, 293–319.

Vedamurthachar, A., Janakiramaiah, N., Hegde, J.M., Shetty, T.K., Subbakrishna, D.K., Sureshbabu, S.V., Gangadhar, B.N., 2006. Antidepressant efficacy and hormonal effects of Sudarshana Kriya Yoga (SKY) in alcohol dependent individuals. Journal of Affective Disorders 94 (1–3), 249–253.

Vitiello, B., Swedo, S., 2004. Antidepressant medications in children. New England Journal of Medicine 350 (15), 1489–1491.

Walton, K., Pugh, N.D., Gelderloos, P., Macrae, P., 1985. Stress reduction and preventing hypertension: preliminary support for a psychoneuroendocrine mechanism. Journal of Alternative and Complementary Medicine 1, 263–283.

Wu, Z., Guo, A., 1999. Selective visual attention in a neurocomputational model of phase oscillators. Biological Cybernetics 80 (3), 157–225.

Young, S.N., Leyton, M., 2002. The role of serotonin in human mood and social interaction. Insight from altered tryptophan levels. Pharmacology, Biochemistry and Behaviour 71 (4), 857–865.

Young, J.D., Taylor, E., 2001. Meditation as a voluntary hypometabolic state of biological estivation. News in Physiological Sciences 13, 149–153.

Zylowska, L., Ackerman, D.L., Yang, M.H., Futrell, J.L., Horton, N.I., Hale, S., Pataki, C., Smalley, S.L., 2008. Mindfulness meditation training in adults and adolescents with ADHD: a feasibility study. Journal of Attention Disorders 11 (6), 737–746.