Attention regulation and monitoring in meditation

Antoine Lutz\textsuperscript{1}, Heleen A. Slagter\textsuperscript{1}, John D. Dunne\textsuperscript{2} and Richard J. Davidson\textsuperscript{1}

\textsuperscript{1}Waisman Laboratory for Brain Imaging and Behavior, Department of Psychology, University of Wisconsin, Madison, WI 53705, USA
\textsuperscript{2}Department of Religion, Emory University, Atlanta, GA 30322, USA

Meditation can be conceptualized as a family of complex emotional and attentional regulatory training regimes developed for various ends, including the cultivation of well-being and emotional balance. Among these various practices, there are two styles that are commonly studied. One style, focused attention meditation, entails the voluntary focusing of attention on a chosen object. The other style, open monitoring meditation, involves non-reactive monitoring of the content of experience from moment to moment. The potential regulatory functions of these practices on attention and emotion processes could have a long-term impact on the brain and behavior.

Meditation as an explanandum

Despite a large number of scientific reports and theoretical proposals \cite{1–5}, little is known about the neurophysiological processes involved in meditation and the long-term impact of meditation on the brain. The lack of statistical evidence, control populations and rigor of many of the early studies, the heterogeneity of the studied meditative states and the difficulty in controlling the degree of expertise of practitioners can, in part, account for the limited contributions made by neuroscience-oriented research on meditation. The absence of a clear operational definition of meditation limits this research. Here, we offer a theoretical framework, based on traditional meditation texts and modern neuroscientific conceptions, in which some standard meditations are grouped into two broad categories: focused attention (FA) and open monitoring (OM) meditation (Boxes 1,2; Table 1). These categories are used to delineate the specific psychological processes implicated in these two practices and to derive neurofunctional predictions. We also present key findings illustrating how meditation might affect mental processing and the brain.

The overall purpose of this framework is to produce an operational definition for FA and OM meditative practices that can be adopted in the scientific study of effects of meditation training on the mind and the brain \cite{6–8}.

The term ‘meditation’ refers to a broad variety of practices, ranging from techniques designed to promote relaxation to exercises performed with a more far-reaching goal, such as a heightened sense of well-being. It is thus essential to be specific about the type of meditation practice under investigation. Failure to make such distinctions would be akin to the use of the word ‘sport’ to refer to all sports as if they were essentially the same. For example, the overly generic description of meditation as a mere relaxation technique \cite{9} becomes extremely problematic when one attends to the details of many practices \cite{4,10,11} (Boxes 1,2). By contrast, here, we conceptualize meditation as a family of complex emotional and attentional regulatory strategies developed for various ends, including the cultivation of well-being and emotional balance \cite{7}. To narrow the explanandum to a more tractable scope, we use Buddhist contemplative techniques and their clinical secular derivatives as a paradigmatic framework \cite{7,6,7}. Among the wide range of practices within the Buddhist tradition, we further narrow this review to two common styles of meditation, FA and OM (Boxes 1,2), which are often combined, whether within a single session or over the course of a practitioner’s training. These styles are found with some variation in several meditation traditions, including Zen, Vipassana and Tibetan Buddhism \cite{4,12,13}. Both styles are also implicated in secular interventions that draw on Buddhist practices, such as mindfulness-based stress reduction \cite{14}. The first style, FA meditation, entails voluntary focusing attention on a chosen object in a sustained fashion. The second style, OM meditation, involves nonreactively monitoring the content of experience from moment to moment, primarily as a means to recognize the nature of emotional and cognitive patterns. A functional characterization of these states is proposed in Table 1.

Neuroscientific study of focused attention meditation

The selective nature of attention and its importance for guiding goal-directed behavior has been one of the most extensively studied areas of Western psychology and neuroscience. Notably, there are remarkable parallels between the processes involved in FA meditation, as described in many meditation texts (Table 1), and recent cognitive (neuro)science conceptualizations of attention. Both Western scientists and Buddhist scholars recognize that the ability to focus and sustain attention on an intended object requires skills involved in monitoring the focus of attention and detecting distraction, disengaging attention from the source of distraction, and (re)di-
Box 1. FA meditation

A widespread style of Buddhist practice involves sustaining selective attention moment by moment on a chosen object, such as a subset of localized sensations caused by respiration. To sustain this focus, the meditator must also constantly monitor the quality of attention. The first involves the ability to redirect focus promptly to the chosen object. Progress in this form of meditation is measured, in part, by the degree of effort required to sustain the intended focus. The novice contends with more distractions, and the three regulative skills are frequently exercised. As one advances, the three regulative skills can be developed to the point that, for example, advanced practitioners have an especially acute ability to notice when the mind has wandered. Eventually, FA induces a trait change, and the attention rests more readily and stably on the chosen focus. At the most advanced levels, the regulative skills are invoked less frequently, and the ability to sustain focus thus becomes progressively ‘effortless.’

In advanced practitioners, FA practices create a sense of physical lightness or vigor, and the need for sleep is said to be reduced. Advanced levels of concentration are also thought to correlate with a significant decrease in emotional reactivity. FA practices typically involve a relatively narrow field of focus, and as a result, the ability to identify stimuli outside that field of focus might be reduced. Indeed, and engaging attention to the intended object. These capacities have been associated with dissociable systems in the brain [15–17]. A first, straightforward prediction is therefore that the specific neural systems associated with conflict monitoring (e.g. the dorsal anterior cingulate cortex and dorsolateral prefrontal cortex [17–19]), selective attention (e.g. the temporal-parietal junction, ventrolateral prefrontal cortex, frontal eye fields and intraparietal sulcus [15]) and sustaining attention (e.g. right frontal and parietal areas and the thalamus [16,20]) are involved in inducing and maintaining the state of FA meditation. In addition, sustained activity might be observed in areas representing the object of attention [21]. These neurophysiological changes induced by meditation training should be correlated with improvements in behavioral measures of sustained attention, such as functioning in continuous performance tasks or binocular rivalry tasks, and of selective attention, such as performance in the Posner cueing task (see later) [22]. A second prediction concerns the long-term changes in mental and brain function that FA meditation might produce. Buddhist descriptions of the development of this practice indicate that although the processes of voluntary sustaining and orienting initially have an important role in focusing attention, and expertise in the deployment of these processes might strengthen as a function of practice, with more practice the need for these processes is greatly reduced, resulting in a form of ‘effortless concentration’ (Box 1). In expert meditators, one might therefore expect reduced activation in neural systems implicated in regulating attention, which might be associated with optimized performance in sustained and selective attention tasks.

Several recent studies have reported expertise-related changes in attentional processing [23–25] and brain structures [26,27] in those proficient in FA meditation. For instance, Carter et al. [23] found that Tibetan Buddhist

Table 1. Schematic descriptions of FA and OM meditations

<table>
<thead>
<tr>
<th><strong>FA meditation</strong></th>
<th><strong>OM meditation</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Directing and sustaining attention on a selected object (e.g. breath sensation)</td>
<td>Nonreactive meta-cognitive monitoring (e.g. for novices, labeling of experience)</td>
</tr>
<tr>
<td>Detecting mind wandering and distractors (e.g. thoughts)</td>
<td>Nonreactive awareness of automatic cognitive and emotional interpretations of sensory, perceptual and endogenous stimuli</td>
</tr>
<tr>
<td>Disengagement of attention from distractors and shifting of attention back to the selected object</td>
<td></td>
</tr>
<tr>
<td>Cognitive reappraisal of distractor (e.g. ‘just a thought’, ‘it is okay to be distracted’)</td>
<td></td>
</tr>
<tr>
<td>No explicit focus on objects</td>
<td></td>
</tr>
</tbody>
</table>

Although varied, OM practices share several core features, including in particular the initial use of FA training to calm the mind and reduce distractions. As FA advances, the well developed monitoring skill becomes the main point of transition into OM practice. One aims to remain only in the monitoring state, attentive moment by moment to anything that occurs in experience without focusing on any explicit object. To reach this state, the practitioner gradually reduces the focus on an explicit object in FA, and the monitoring faculty is correspondingly emphasized. Usually, there is also an increasing emphasis on cultivating a ‘reflective’ awareness that grants one greater access to the rich features of each experience, such as the degree of phenomenal intensity, the emotional tone and the active cognitive schema (Box 3).

Although the enhancement of the monitoring awareness continues until no explicit focus is maintained, the monitoring itself does not create any new explicit focus. Thus, unlike FA, OM involves no strong distinction between selection and deselection. For example, the FA monitoring faculty detects the emotional tone of a state as a background feature of the primary focus, but in OM the emotional tone is detected without it, or any other object, becoming an explicit or primary focus. It is as if emotional tone, the quality of attention, and other such phenomenal features remain in the background, even though there is no contrasting cognitive foreground. In this way, the ‘effortful’ selection or ‘grasping’ of an object as primary focus is gradually replaced by the ‘effortless’ sustaining of an awareness without explicit selection.

This distinction between the ‘effortful’ and the ‘effortless’ points to the contrast between skills employed during the state and traits developed as practice progresses [54]. For example, initially the practitioner frequently ‘grasps’ objects in a way that requires the skill to disengage that focus deliberately; however, eventually a trait emerges such that one can sustain the ‘non-grasping’ state, which has no explicit focus.

A central aim of OM practice is to gain a clear reflexive awareness of the usually implicit features of one’s mental life. It is said that awareness of such features enables one more readily to transform cognitive and emotional habits. In particular, OM practice allegedly leads one to a more acute, but less emotionally reactive, awareness of the autobiographical sense of identity that projects back into the past and forward into the future. Finally, heightened sensitivity to body and environment occurs with a decrease in the forms of reactivity that create mental distress.

Box 2. OM meditation
monks were able to perceive a stable, superimposed percept of two dissimilar, competing images presented to separate eyes for a longer duration both during and after FA meditation, but not a form of ‘compassion’ meditation. These behavioral findings obtained using a ‘binocular rivalry’ task support the hypothesis that extensive training in FA meditation might improve the practitioner’s ability to sustain attention on a particular object for a prolonged period of time. Another study [24] used functional magnetic resonance imaging (fMRI) to interrogate the neural correlates of FA meditation in experts and novices. In this study, FA meditation on an external visual point compared with a rest condition was associated with activation in multiple brain regions implicated in monitoring (dorsolateral prefrontal cortex), engaging attention (visual cortex) and attentional orienting (e.g. the superior frontal sulcus and intraparietal sulcus). Although this meditation-related activation pattern was generally stronger for long-term-practitioners compared with novices, activity in many brain areas involved in FA meditation showed an inverted u-shaped curve. Whereas expert meditators with an average of 19,000 hours of practice showed stronger activation in these areas than do the novices, expert meditators with an average of 44,000 practice hours showed less activation. This inverted u-shaped function resembles the learning curve associated with skill acquisition in other domains of expertise, such as language acquisition [28], and provides support for the notion that after extensive FA meditation training, minimal effort is necessary to sustain attentional focus. A direct comparison between experts in FA and OM meditation will be important here to distinguish effortless concentration from objectless meditation. In addition, expert meditators showed less activation than did novices in the amygdala during FA meditation, and activation in this affective region correlated negatively with hours of practice in life (Figure 1a). This finding is unlikely to be due simply to the long-term practitioners ignoring the stimuli more than controls because auditory processing regions (e.g. superior temporal gyrus) were more significantly activated to sounds in the practitioners compared with controls [24]. This finding is also in line with a previous behavioral study showing a reduction in habitual responding on the Stroop task following a 20-minute meditation practice [29] and might illustrate the notion that training in FA is associated with a significant decrease in emotionally reactive behaviors that are incompatible with stability of concentration. Such inhibition of automatic responses provides preliminary support for earlier proposals, and an earlier FA electroencephalography study [30], that concentrative meditation leads to partial ‘deautomatization’ of the mental processes that shape and interpret perceptual stimuli [8,31]. Collectively, these findings underscore the view that at least several subcomponents of attention are best regarded as the product of trainable skills, and that FA meditation represents a family of mental practices that are explicitly designed to train such attentional skills.

**The neuroscientific study of OM meditation**

Several predictions concerning the mental processes and brain systems involved in OM meditation can be derived from the description of this form of meditation given in Table 1. A first prediction is that because OM meditation involves no explicit attentional focus, it does not rely on brain regions involved in sustaining or engaging attention onto a specific object, but on brain regions implicated in monitoring, vigilance and disengaging attention from stimuli which distract attention from the ongoing stream of experience (see earlier). Findings from several recent studies of OM meditation [10,11,32–35] provide preliminary support for this idea. For instance, in an early behavioral study, OM meditators showed superior performance on a sustained attention task in comparison with FA meditators when the stimulus was unexpected; however, there was no difference between the two groups of meditators when the stimulus was expected, indicating a more distributed attentional focus in the OM meditators [11]. In another study, a group randomly assigned to five days of meditation training substantially based on OM meditation showed greater improvement in conflict monitoring than did a similarly chosen control group given relaxation [10]. In regard to the second prediction, because OM meditation involves the cultivation of awareness of the subjective features of a given moment, such as its emotional tone (Box 2), it is conceivable that it engages processes involved in interoception, or the perception of internal bodily responses. These processes rely on meta-representations in the brain of homeostatic afferent activity (e.g. temperature change or pain [36]), in particular in the anterior insula, somatosensory cortex and anterior cingulate cortices [36,37]. In line with the idea that OM meditation engages processes involved in monitoring one’s body state, a recent study found greater activity in this neural circuitry during a monitoring state relative to a narrative generation state in participants who attended an eight-week course incorporating OM meditation (the Mindfulness-Based Stress Reduction program [14]) compared with a group of controls [34]. A third prediction concerns the potential regulatory influences of OM meditation on emotional processes through prefrontal regulation of limbic responses. Recent neuroimaging studies have shown that simple verbal labeling of affective stimuli activates the right ventrolateral prefrontal cortex and attenuates responses in the amygdala through activity in the ventromedial prefrontal cortex [38,39]. This strategy of labeling aspects of experience (e.g. ‘this is distressing’) is used in Vipassana traditions to support OM practice and is a central feature of many clinical interventions based on OM meditation, in particular mindfulness-based interventions [14] (here, we use the term ‘OM’ instead of the term ‘mindfulness’, which has received multiple meanings [7]). OM practices that sometimes involve verbal labeling might thus call upon emotion regulation processes instantiated in the ventral prefrontal cortex and disrupt or inhibit automatic affective responses in appraisal systems, diminishing their intensity and duration. Recent experimental [27,40,41] and clinical [42–44] studies of mindfulness meditation, and studies of individual differences in self-reported mindfulness traits [41], provide preliminary support for this possibility.

Long-term practice of OM meditation is also thought to result in enduring changes in mental and brain function. Specifically, because OM meditation fosters nonreactive
awareness of the stream of experience without deliberate selection of a primary object, intensive practice can be expected to reduce the elaborative thinking that would be stimulated by evaluating or interpreting a selected object [8] (Box 2). In line with this idea, Slagter et al. [45] recently found that three months of intensive OM meditation reduced elaborative processing of the first of two target stimuli (T1 and T2) presented in a rapid stream of distracters, as indicated by a smaller T1-elicited P3b, a brain potential index of resource allocation (Figure 1b). Moreover, this reduction in resource allocation to T1 was associated with improved detection of T2 (Figure 1c). Because participants were not engaged in formal meditation during task performance, these results provide support for the idea that one effect of an intensive training in OM meditation might be reduction in the propensity to ‘get stuck’ on a target, as reflected in less elaborate stimulus processing and the development of efficient mechanisms to engage and then disengage from target stimuli in response to task demands. From the description in Box 2, we anticipate a similar improvement in the capacity to disengage from aversive emotional stimuli following OM training, enabling greater emotional flexibility.

Neurodynamic framework
As noted earlier, traditional Buddhist scholars have emphasized the decreased need for voluntary attentional efforts to attain concentration following expertise in FA...
meditation. In addition, some variations of OM meditation advise practitioners to drop any explicit effort to control the occurrence of thoughts or emotions to further stabilize their meditation. These descriptions suggest that some meditation states might not be best understood as top-down influences in a classical neuroanatomical sense but rather as dynamical global states that, in virtue of their dynamical equilibrium, can influence the processing of the brain from moment to moment. Moreover, an important hypothesis that derives from the emphasis on trait-like transformation in these traditions is that with systematic practice, there is an enduring alteration of the ‘baseline’ or ‘default’ mode [46] of brain functioning. In this alternative ‘dynamistic’ view of top-down control, spatio-temporal trajectories of neural activity emerge from complex nonlinear neural interactions following the rules of dynamical theory [47]. These large-scale coherent neuronal ensembles – for instance, which emerge during FA on the breath – can influence other local neuronal processes – for instance, evoked by an external distractor, by entraining local ensembles [48,49]. In this view, the brain goes through a succession of large-scale brain states, with each state becoming the source of top-down influences for the subsequent state. We predict that these large-scale integrative mechanisms participate in the regulatory influence of these meditation states.

The finding of a high-amplitude pattern of γ-synchrony in expert meditators during an emotional version of OM meditation [50] supports the idea that the state of OM might be best understood in terms of dynamic global states. Lutz et al. [50] studied a group of long-term Tibetan Buddhist practitioners who underwent mental training for 10 000 to 50 000 hours over time periods ranging from 15 to 40 years. Compared with a group of novices, the practitioners self-induced higher-amplitude sustained electroencephalography γ-band oscillations and long-distance phase synchrony, in particular over lateral fronto-parietal electrodes, while meditating (Figure 1d–g). Importantly, this pattern of γ-oscillations was also significantly more pronounced in the baseline state of the long-term practitioners compared with controls, suggesting a transformation in the default mode of the practitioners. Although the precise mechanisms are not clear, such synchronizations of oscillatory neural discharges might have a crucial role in the constitution of transient networks that integrate distributed neural processes into highly-ordered cognitive and affective functions [48,49] and are an important constraint for synaptic plasticity [51]. The combination of neuroimaging and neurodynamic information, in particular with first-person report (Box 3), might thus provide a particularly promising approach to the study of the brain mechanisms underlying meditation.

Future directions
The neuroscientific study of meditation is clearly still in its infancy but the initial findings reviewed earlier promise both to reveal the mechanisms by which such training might exert its effects and to underscore the plasticity of the brain circuits that underlie complex regulatory mental functions. These findings will need to be supplemented with more data, most crucially from longitudinal studies examining changes over time within the same individuals randomized either to meditation training or to an active control group. Such longitudinal studies, which are designed to test a selected effect of a given, clearly defined meditation, are necessary to exclude the possibility that observed training effects are due to pre-existing differences between groups (i.e. experts and novices) and will enable a more precise delineation of the developmental trajectory of the trained abilities. Another important area of future research is to study meditation practices that deliberately invoke an emotional state of empathy, affection and compassion for others. Such practices are often seen as indispensable supplements to FA or OM practices. Despite the importance of these practices, they were not reviewed here, due to the paucity of available empirical data.

Future work will need to address at least three additional types of questions (Box 4). First, the impact of mental training on peripheral biological processes that are
important for physical health and illness is not yet clear. Although several clinical studies have reported changes in, for example, cortisol or immune function as a function of mindfulness-based therapies [40,43], there are no data that mechanistically link changes in the brain that might be produced by meditation, and alterations in peripheral processes – for example, in immune function. At present, relatively few studies have examined how changes in peripheral biology might be related to changes in brain function following meditation [40,52,53]. Second, meditation is always practiced in a particular context, whether it be the context formed by the practitioner’s body and mind (e.g. typically a seated posture; the spine must be kept straight, while the rest of the body should be neither too tense nor too lax) or the wider context formed by ethics, traditions, culture and the environment (e.g. altruistic motivation to practice, ethics of non-harming others and the student–teacher relationship). Future studies will need to examine how this context might modulate the generation of certain mental states. Third, the extent to which, and how, meditation training affects behavior outside of the laboratory and transforms basic mental functions such as emotion and attention in everyday life is another crucial question that needs further study. It is our fervent hope that this review will stimulate additional research in these and other directions.

Acknowledgements

Support for the work described here was provided by NCCAM U01AT002114–01A1, Fyssen foundation, to A.L. and NIMH P50-MH089315 to R.J.D. and by gifts from Adrianne and Edwin Cook-U01AT002114–01A1, Fyssen foundation, to A.L. and NIMH P50-

References

26 Pagnoni, G. and Celig, M. (2007) Age effects on gray matter volume in expert long-term meditation practitioners. Cerebral Cortex 17, 2697–2704
27 Lazar, S.W. et al. (2005) Meditation experience is associated with increased cortical thickness. Neuroreport 16, 1893–1897
Elsevier joins major health information initiative

Elsevier has joined with scientific publishers and leading voluntary health organizations to create patientINFORM, a groundbreaking initiative to help patients and caregivers close a crucial information gap. patientINFORM is a free online service dedicated to disseminating medical research.

Elsevier provides voluntary health organizations with increased online access to our peer-reviewed biomedical journals immediately upon publication, together with content from back issues. The voluntary health organizations integrate the information into materials for patients and link to the full text of selected research articles on their websites.

patientINFORM has been created to enable patients seeking the latest information about treatment options online access to the most up-to-date, reliable research available for specific diseases.

For more information, visit www.patientinform.org