Using First-Person Reports during Meditation to Investigate Basic Cognitive Experience

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Abstract This chapter describes a line of research that seeks to incorporate first-person subjective input into the analysis of meditation-related brain activity and connectivity, as a way to better define and understand everyday mental functions. I present a basic model of naturalistic cognitive fluctuations between mind wandering and attentional states derived from the practice of focused attention meditation. This model proposes four phases in a cognitive cycle: mind wandering, awareness of mind wandering, shifting of attention, and sustained attention. We developed a paradigm to leverage the common experience of awareness of mind wandering during this style of meditation, using subjective reports to drive the analysis of brain imaging data. Results revealed activity in specific brain networks associated with each cognitive phase. Further, participants with more meditation experience exhibited altered patterns of neural activity and resting state functional connectivity compared to participants with less experience. These neural patterns may be involved in the development of cognitive skills such as maintaining attention and disengaging from distraction that are often reported with meditation practice, and suggest mechanisms for how benefits may transfer "off the cushion." Implications for neurophenomenological investigations are discussed, as well as future directions and possible extensions of the model.

Introduction

As evidenced by the present volume, as well as an exponentially increasing number of scholarly and lay publications, research on the mechanisms and effects of meditation is burgeoning. These investigations are undertaken with a variety of goals, but most often in an attempt to understand how meditation "works" – that is, how does meditation practice lead to its frequently-reported benefits, including reduced stress, increased clarity, and a general enhancement of well-being? These pursuits are of great value, particularly for clinical applications, and the results of such investigations have been artfully summarized elsewhere (Chen et al. 2012; Chiesa and Serretti 2011; Chiesa and Serretti 2009; Rubia 2009). The goal of this chapter is to outline another use of contemplative practice in research – one that leverages the cognitive experiences that occur during meditation, coupled with the finely honed ability of practitioners to provide subjective report on these experiences, to gain a better understanding of the neural correlates of basic mental processes. This approach has great potential to advance cognitive neuroscience, and deepen our understanding of the human mind and the possibilities for its transformation. Facilitated in part by the work of Francisco Varela and colleagues (Varela et al. 1991), there has been a recent upsurge of interest in incorporating subjective information regarding mental states into neuroscientific explorations of the human mind. In this chapter, I describe one method for studying cognition based on this neurophenomenological perspective, and discuss implications and possible extensions of the approach.

Most forms of meditation employ fundamental cognitive processes that are also involved in many everyday experiences. For example, processes such as focused attention, detection of distraction, disengagement from ongoing thoughts, logical analysis, emotional engagement, cognitive re-framing, and meta-awareness are all used in various forms of meditation currently being taught in western contexts. Indeed, the goal of any given meditation is often to train one or more of these particular capacities, with the assumption that these skills will transfer “off the cushion” to be available in daily life. In addition, repeated meditation practice results in an increased familiarity with and ability to report on subtle changes in mental state in the practitioner (Lutz et al. 2008; Lutz and Thompson 2003). Thus, contemplative practice, when carefully understood and studied, can yield insights into these other processes in a more refined way.

The advent of non-invasive technologies such as functional magnetic resonance imaging (fMRI) has allowed for investigation of brain activity associated with human cognition in real time. Many studies have used such neuroimaging techniques to investigate brain activity during meditation, and while much has been learned and some consistencies are emerging (Chiesa and Serretti 2010; Chiesa 2009, 2010; Fell et al. 2010; Green and Turner 2010; Rubia 2009), theoretical and methodological limitations have often made results difficult to interpret. For example, the theoretical assumption that meditation is a single mental state that is achieved and maintained has supported a methodological approach of averaging brain activity over a block of time spent “in meditation” (often several minutes) and interpreting the static picture that results as a representation of brain activity during meditation. However, this underlying assumption is likely only accurate in the case of advanced practitioners, and only when the style of meditation has a goal of a single-pointed stable mental state. Rather, novice and intermediate practitioners often experience dynamic fluctuating cognitive states, even when trying to remain stably engaged in focused attention practices, oscillating between mind wandering and focused states. Thus, the common statistical practice of averaging brain activity over extended periods of time introduces caveats not commensurate with subjective experience.

It would seem advisable, given the aforementioned limitations, for researchers to find ways of leveraging the ability of meditators to report on their cognitive experience and adjust their methodological approaches to include this information. Cognitive models of meditation that incorporate subjective report can provide a framework from which to design and analyze experiments with finer sophistication, yielding deeper insights into the mental processes involved. Herein, I describe a simple model that begins to examine the cognitive processes involved in the practice of focused attention (FA) meditation in greater detail.

A Basic Cognitive Model

FA meditation is intended to help the practitioner enhance awareness of his/her cognitive states while developing attentional control (Lutz et al. 2008). Indeed, research has demonstrated that FA meditation improves attentional skill in several domains (Jha et al. 2007; Lutz et al. 2009; MacLean et al. 2010; van Leeuwen et al. 2012; Zeidan et al. 2010). During FA practice, an individual attempts to maintain focus on a single object (e.g., the sensation of breathing), bringing attention back to the object whenever the mind wanders (Gunaratana 2002; Wallace 2006).

In line with many traditional accounts, our model proposes that during FA meditation, particularly for novices, one's subjective experience follows the general structure outlined in Figure 1. When attempting to sustain focus on an object, an individual inevitably loses this focus and experiences mind wandering. At some time during mind wandering, the practitioner becomes aware that his/her mind is not on the object, at which point he/she disengages from the current train of thought and shifts attention back to the object, where it stays focused again for some period of time. In our original analysis, we termed these states MIND WANDERING (representing loss of focus), AWARE (representing the awareness of mind wandering), SHIFT (representing disengaging and shifting of focus back to the breath) and FOCUS (representing maintenance of attentional focus on the breath). The subjective experience of these states is a cycle that iterates repeatedly throughout a session of FA meditation. Thus, the practice of FA meditation is not a single cognitive state, except perhaps in very advanced practitioners. Instead, it involves a dynamic fluctuation between states of FOCUS and MIND WANDERING, incorporating the more transitory states of AWARE and SHIFT.

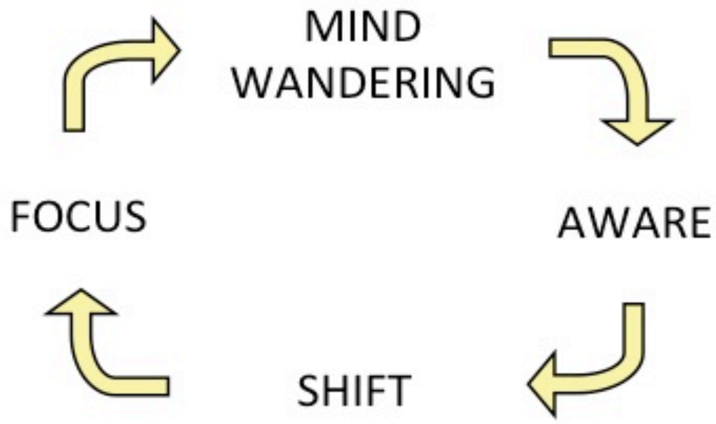

Fig. 1 Basic cognitive model of FA meditation. A theoretical model of dynamic cognitive states experienced by a non-expert practitioner during a session of FA meditation. When attempting to sustain focus on an object (FOCUS), an individual inevitably loses this focus and experiences wandering of attention (MIND WANDERING). At some time during mind wandering, the practitioner becomes aware that his/her mind is not on the object (AWARE), at which point he/she disengages from the current train of thought and shifts attention back to the object (SHIFT), where it stays focused again for some period of time (FOCUS). The cycle iterates repeatedly over a session of FA meditation.

As a practitioner gains fluency and expertise, the processes of vigilance and adjustment become more automated, allowing one to rest in an "effortless" state of concentration or awareness (Lutz et al. 2008). In contrast, the present model is concerned with early stages of practice, which are more closely related to everyday experiences of attention and distraction.

Two Large-Scale Neural Networks

The mental processes of mind wandering and attention are increasingly becoming associated with activity in different distributed brain networks (Figure 2). A task-negative, or default mode network (DMN) has been associated with task-independent, spontaneous thought processes, also known as mind wandering (Buckner et al. 2008). Mind wandering processes are directed away from a primary task and toward personal goals, and cover a broad range of mental functions, including memory, planning, and theory of mind (Smallwood and Schooler 2006). The DMN consists of hubs in the medial prefrontal cortex and posterior cingulate cortex, and also includes inferior parietal and lateral temporal regions (Buckner et al. 2008). The medial prefrontal cortex has been specifically implicated in self-related cognitive processing (Northoff and Bermpohl 2004), which is arguably a central feature of much mind wandering experience.

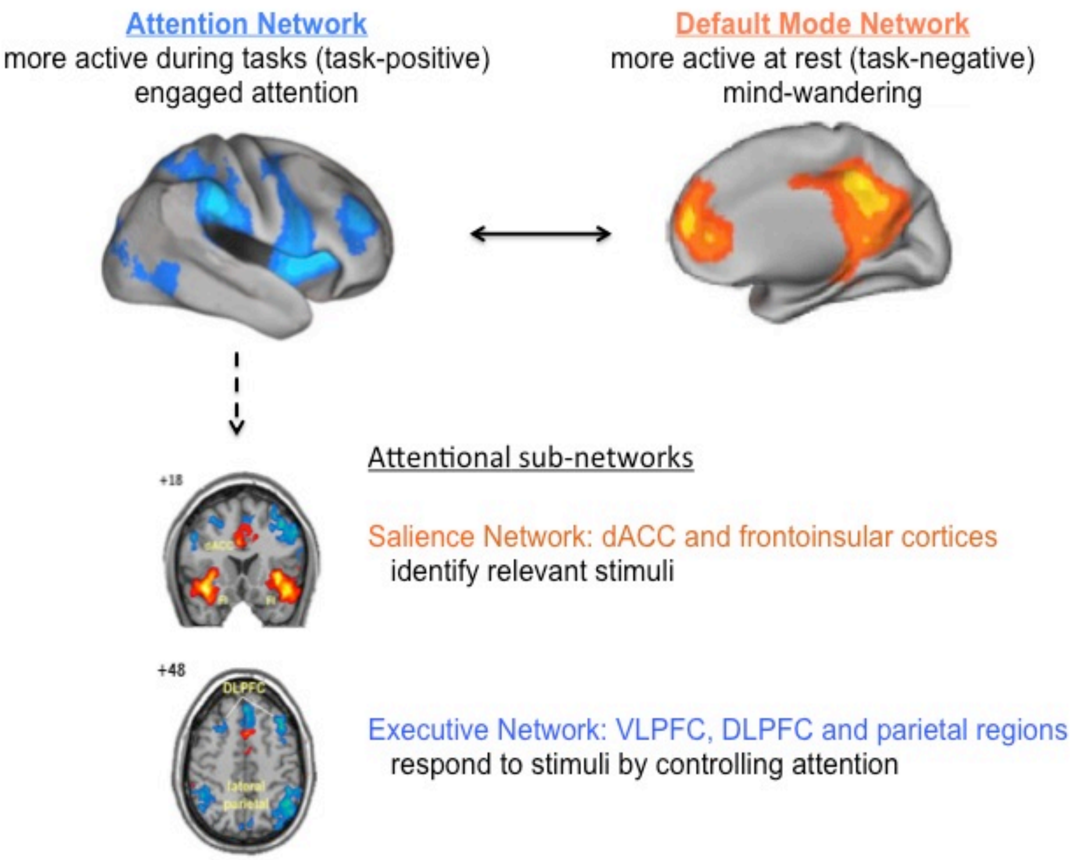

Fig. 2 Brain networks associated with mind wandering and attention. The brain can be divided into two large-scale distributed networks – the *default mode network* (top right), activity in which is associated with mind wandering states, and the *attention network* (top left), activity in which is associated with focused states demanding attentional resources. Within the larger attention network, multiple sub-networks can be identified. Two shown here are the *salience network*, comprised of the dorsal cortex (dACC) and bilateral insula, and the *executive network*, comprised of the dorsal and ventral prefrontal cortex and parietal regions. The salience network is thought to be involved in identifying relevant and salient stimuli in one's environment that require attention; the executive network is involved in disengaging and reorienting attention to these identified stimuli. (Images modified from Buckner et al. 2008 and Seeley et al. 2007.)

Conversely, a task-positive network has been associated with various attentional, present moment, and task-related processes, and is active during rest in an anti-correlated manner with the DMN (Fox et al. 2005; Fransson 2005). This large task-positive attention network can be subdivided in several ways to yield smaller and more distinct subnetworks. One such division distinguishes the salience and executive networks (Seeley et al. 2007). The salience network is thought to be involved in the immediate, present moment processing or detection of relevant stimuli, and involves the dorsal anterior cingulate cortex and bilateral anterior insula (Craig 2009; Seeley et al. 2007). The executive network, also referred to as the frontoparietal attention network, consists of dorsolateral prefrontal cortex (dlPFC) and posterolateral parietal regions, and is involved in controlling attentional resources to deal with immediate or future demands (Corbetta et al. 2008; Corbetta and Shulman 2002; Seeley et al. 2007)[1].

Attentional Sub-Processes in FA Meditation

The processes of detecting salience and controlling attention are highly relevant in the context of FA meditation (Figure 3). Broadly speaking, the goal state, set by the intention of the practitioner via executive management systems in the brain, is to keep attention stably placed on an object. Ongoing regulation of this attention proceeds as a thermostat or feedback system, monitoring the environment – in this case, the internal, mental environment – for variation from the goal state (i.e., error detection). This could also be described as the process of conflict-monitoring, where the current state is in conflict with the goal state (Alexander and Brown 2010; Posner and Rothbart 2009). In this case, the primary relevant "target" that is to be detected becomes any mental state in which the object has been lost to attention. In the model here, the mental process of MIND WANDERING represents such a salient target. The meta-cognitive ability to monitor the contents of one's mind allows for detection of the MIND WANDERING target, and strengthening this ability is one of the main endpoints of FA training (Lutz et al. 2008). With continued practice, it would be hypothesized that detection of such target states would become increasingly rapid and sensitive. Indeed, this aligns well with subjective report of many practitioners, as well as traditional guides (Wallace 2006). Once the target is detected, attentional disengagement and re-orienting must be employed in order to re-engage with the object (Posner and Petersen 1990; Posner et al. 1984). Again, it is expected that these processes of attention management are trained and improved by FA practice. The result of training in these attentional processes allows for longer and more stable retention of focus on the object, and thus, reduced object loss and faster recognition and re-orienting when object loss does occur.

[1] See also the chapter by Austin in this volume.

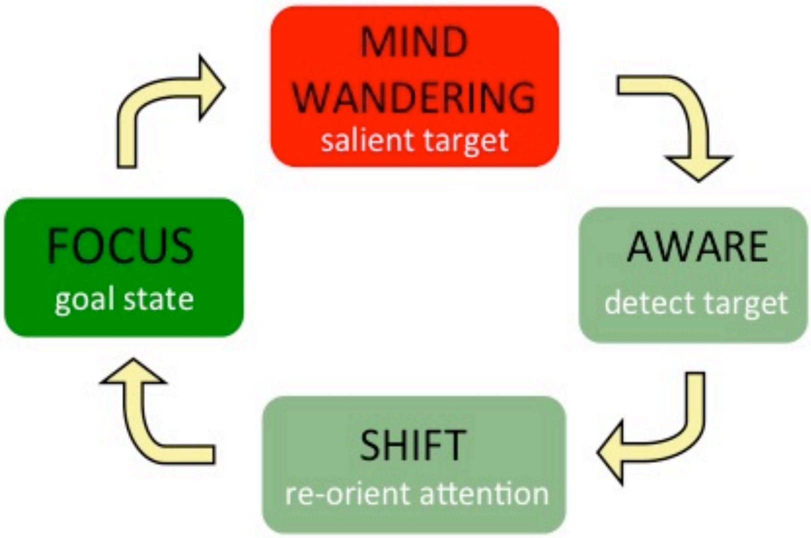

Fig. 3 **Attentional sub-processes in FA meditation.** During the practice of FA meditation, the goal state is one in which attention rests stably on the object of choice (FOCUS). In order to maintain this state, one must monitor one's own mental state and detect any attentional deviation from the object. In this case, the state of MIND WANDERING – one in which the object of attentional focus has been lost – becomes a salient target to be detected by monitoring systems. Once detected (at the AWARE moment), one must then disengage and re-orient attention (SHIFT) back to the chosen object. Green coloring represents top-down regulatory processes (subserved by the attention network) and red coloring represents bottom-up processes (subserved by the default mode network).

This cycle also represents an interesting dynamic fluctuation between top-down and bottom-up mental processes, where attention systems are responsible for top-down management (e.g., setting the goal, sustaining attention, conflict monitoring, detection of salient targets/error detection, disengagement and re-orienting), and the natural tendency towards mind wandering or distraction is a bottom-up process (Corbetta and Shulman 2002). For example, as you read this chapter, your top-down brain systems (e.g., attention regulation networks) set the goal of reading and processing the words on these pages. However, bottom-up processes related to your immediate surrounding environment (e.g., a colleague knocking at your door), internal bodily state (e.g., the strong desire for coffee), or other mental demands (e.g., the need to plan for a lecture tomorrow) will likely create distractions, sensory or cognitive in nature, intermittently pulling your focus away from the content of these pages. Top-down systems then regain the upper hand; meta-cognitive monitoring allows you to realize you have lost focus, and then you must disengage from the distraction, re-orient your attention towards the chapter and re-engage with the information content. When considered in the larger context of daily life, this endless dance between focus and distraction forms the undercurrent of much of our subjective experience.

Incorporating Subjective Input into Neuroimaging Research

In order to incorporate subjective input into analytical cognitive models, we must first identify reportable cognitive states, that is, those that are accessible to conscious awareness. Throughout the process of FA meditation, perhaps the most consistently reportable moment is the experience of becoming aware of mind wandering (i.e., AWARE). Subjectively, this is a highly salient moment of meta-awareness, and also a necessary step in order to transition back to FOCUS.

In the experiment described here, intermediate level meditation practitioners performed 20 minutes of breath-focused FA meditation while undergoing whole-brain fMRI scanning, pressing a button each time they realized their mind had wandered (signifying the AWARE moment), and then returning their focus to the breath. This temporal information given by the button press allowed for separation of the data into subjectively meaningful epochs around AWARE, based on the model above. We used this information to construct the four intervals of AWARE, SHIFT, FOCUS and MIND WANDERING around the button presses, in 3-second epochs (for a detailed explanation of the analysis, see Hasenkamp et al. (2012).[2] Results show activity in brain regions associated with the task-positive attention network during AWARE, SHIFT and FOCUS phases (Figure 4). Below, we briefly summarize these results; for a full discussion and deeper consideration of the findings, please see the original publication (Hasenkamp et al. 2012).

[2] Briefly, the TR containing the button press, as well as the preceding TR, constituted the AWARE phase, corresponding to awareness of mind wandering (3 sec total). The two TRs (3 sec) before the AWARE phase were cognitively defined as MIND WANDERING, representing loss of focus. The two TRs (3 sec) following the AWARE phase made up the SHIFT phase, representing the shifting of attention back to the breath. Finally, the two TRs (3 sec) following the SHIFT phase made up the FOCUS phase, representing maintenance of FA on the breath.

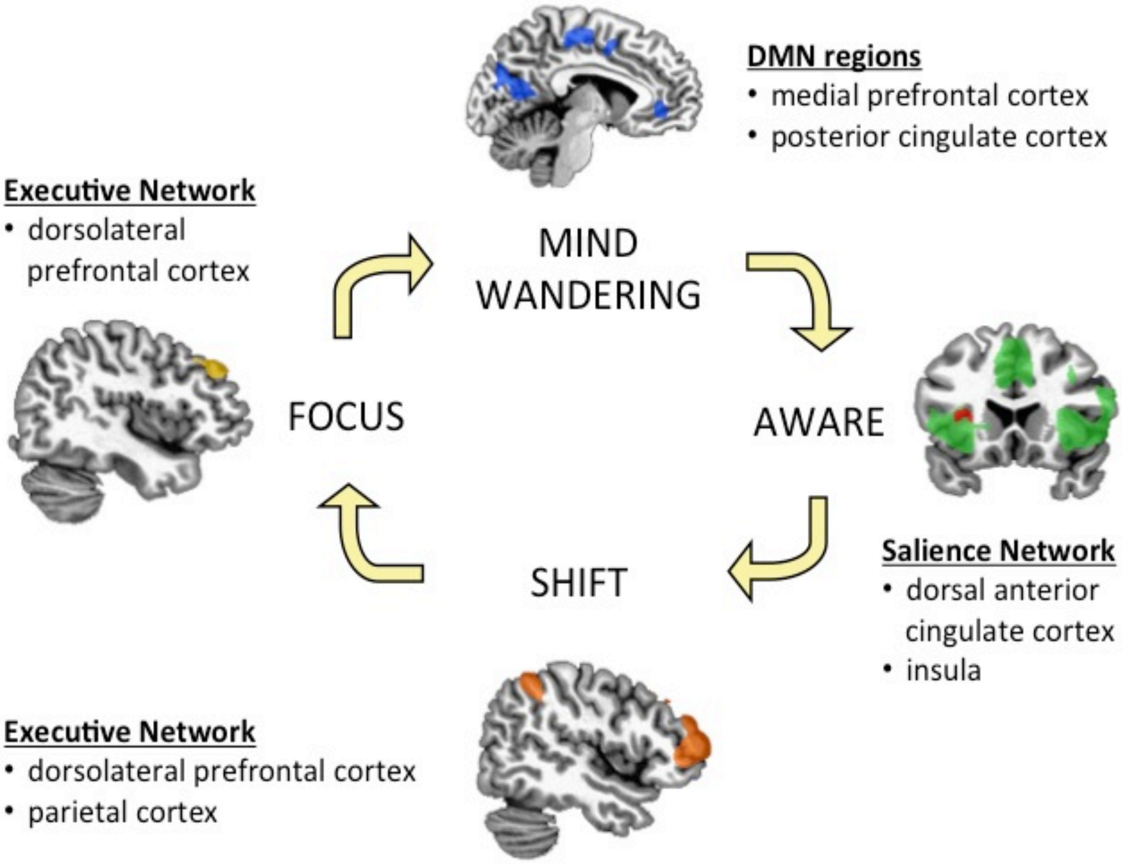

Fig. 4 Summary of brain activations during the four cognitive phases of FA meditation. Determined by subjective input (a button press at the moment of AWARE), we constructed temporal windows to represent the four phases of FA meditation (3 seconds each), and calculated brain activity for each phase across participants. During MIND WANDERING, we saw activations in default mode regions, including the medial prefrontal cortex and the posterior cingulate cortex. At the moment of awareness of mind wandering (AWARE), we observed highly robust activations in the salience network, specifically in the dorsal anterior cingulate cortex and bilateral insula (red areas indicate activity during a simple button-pressing task, as control for purely motor effects). Following AWARE, during the SHIFT phase when participants were disengaging and re-orienting their attention, we saw activations in the executive network, consisting of right lateralized dorsolateral prefrontal cortex and parietal cortex. Finally, during sustained attention in the FOCUS phase, activation persisted in the right dorsolateral prefrontal cortex. The known function of these brain areas corresponds well with the mental processes associated with each of the phases (see text for description).

AWARE. Analysis of the AWARE phase revealed robust activations in bilateral anterior insula and dorsal anterior cingulate cortex (Figure 4, green). These regions are consistent with the subdivision of the attention network known as the salience network, described above (Seeley et al. 2007). Anterior insula and dorsal anterior cingulate have been implicated in a diverse range of cognitive processes, including conflict monitoring and error detection, interoceptive-autonomic arousal, the moment of perceptual recognition, self-regulation, emotional aspects of pain, empathy, musical chills, pleasurable touch, and present moment awareness (reviewed in Craig 2009; Seeley et al. 2007; Singer et al. 2009). Detection of relevant or salient events is important in each of these processes, which has led to the suggestion that these brain regions act together to comprise a general salience network (Seeley et al. 2007). Interestingly, while most paradigms have implicated this network in the detection of external salient events such as visual targets, the detected event in this paradigm—a state of mind wandering—was internally generated and purely cognitive in nature. This extends the scope of the salience network and supports recent suggestions that it may indeed function to detect general salience, regardless of environment or modality (Corbetta et al. 2008; Craig 2009; Seeley et al. 2007).

SHIFT. During the SHIFT phase, we observed significant activation in lateral PFC (dorsal and ventral) and lateral inferior parietal cortex, with larger clusters and more robust activation in the right hemisphere (Figure 4, orange). These frontoparietal regions are consistent with the subdivision of the task-positive attention network known as the executive network, which acts on relevant stimuli (thought to be identified by the salience network) by re-orienting or directing attention while maintaining a goal (Corbetta et al. 2008; Corbetta and Shulman 2002; Seeley et al. 2007). Thus, what is known about the function of this network corresponds well with the hypothesized cognitive processing occurring in this phase: shifting or re-orienting attention from mind wandering back to the breath.

FOCUS. During maintenance of attention in the FOCUS phase, a cluster in the dorsolateral prefrontal region of the executive network remained active from the SHIFT phase (Figure 4, yellow-orange). This may represent persistent neural activity underlying working memory, or "keeping a goal in mind," to maintain sustained attention on the focal object (Curtis and D'Esposito 2003; D'Esposito 2007). The DLPFC has been specifically implicated in active rehearsal, which consists of "the repetitive selection of relevant representations or recurrent direction of attention to those items" (D'Esposito 2007). Active rehearsal would be central to the sustained attention we hypothesize is occurring in the FOCUS phase, providing repetitive selection of, or attention to, the object (e.g., the breath).

Mind wandering. During the MIND WANDERING phase, we detected activity in posterior cingulate cortex, medial PFC, posterior parietal/temporal cortex and parahippocampal gyrus (Figure 4, blue); these regions have been repeatedly associated with the DMN in prior studies (Buckner et al. 2008). This pattern supports recent work associating the DMN with mind wandering processes (Buckner et al. 2008; Christoff et al. 2009; Mason et al. 2007).

Overall, activations in these phases were consistent with results from previous research showing that the respective attentional brain areas are associated with awareness (salience), disengagement and re-orienting (executive control), and maintenance (sustained attention). We also detected activity during MIND WANDERING in brain regions frequently associated with the DMN, mentalizing and self-related processing. This pattern of network activations is consistent with cyclic alternation between default mode and task-positive networks, in which DMN activity is associated with mind wandering, and attentional subnetworks are associated with awareness, shifting attention, and maintaining attention.

Effects of Meditation Experience

We also sought to investigate whether there was an effect of practice time on these activation patterns – that is, does brain activity look different during these epochs dependent on the amount of time a person has meditated over their lifetime? By correlating estimated lifetime practice hours (see Hasenkamp and Barsalou 2012 for algorithm) with each of these activation maps, we identified several brain regions where activity varied according to meditation experience, particularly during the SHIFT phase. One region we chose to examine further was the ventromedial prefrontal cortex (VMPFC), a region in the DMN, which has been particularly implicated in self-related processing. In this area, activity returned to baseline more quickly following the button press in participants with more meditation experience than in those with less experience (Figure 5). This suggested a possible increased ability in individuals with greater meditation experience to disengage from self-related or DMN processing upon awareness of MIND WANDERING. Research is increasingly suggesting that neuroplastic changes occur following repeated meditation practice (Baron Short et al. 2010; Brefczynski-Lewis et al. 2007; Farb et al. 2007; Farb et al. 2012; Hölzel et al. 2011; Tang et al. 2010; Xue et al. 2011; Zeidan et al. 2011), in a similar manner to other forms of experience-dependent plasticity. In this case, perhaps disengaging from ongoing thought content (as is required during FA meditation during the SHIFT interval) intentionally and repeatedly, induces neural changes that facilitate this process. This would correspond with the subjective experience of many practitioners and descriptions in practice manuals.

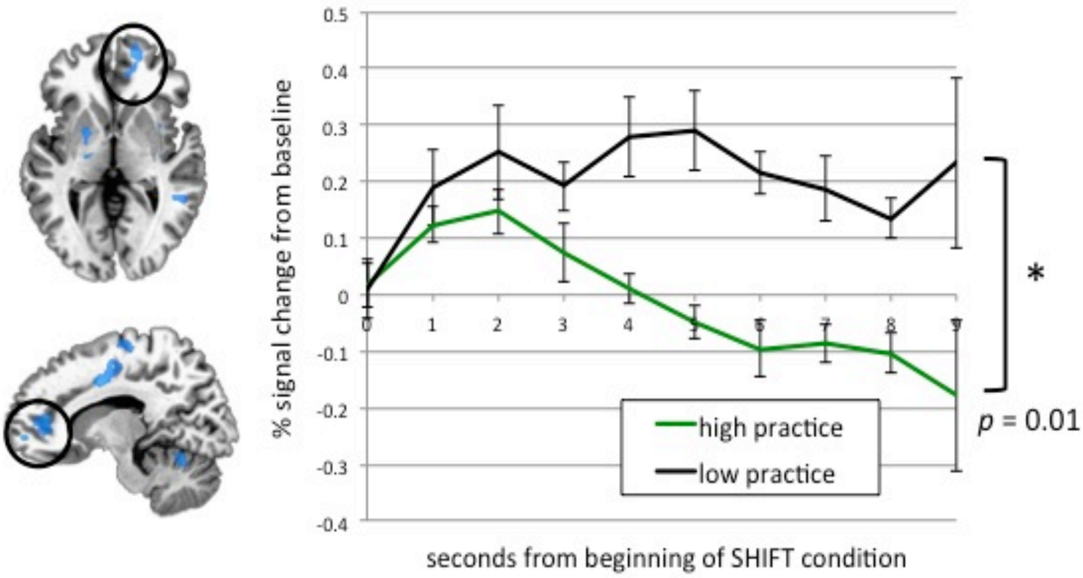

Fig. 5 Correlations of brain activity with lifetime meditation experience. Left: Activity during the SHIFT phase was negatively correlated with practice time in several brain regions (shown in blue). The VMPFC cluster that was examined at right is circled. Right: Time courses from the VMPFC cluster were extracted and hemodynamic response functions were calculated from the onset of the SHIFT phase for each subject. Percent signal change (from MIND WANDERING, mean ± s.e.m.) over time is plotted for high (n=5) and low (n=9) practice participants. Activation in this cluster was significantly reduced in high practice compared to low practice participants across the modeled time series. * Main effect of group over time by repeated-measures ANOVA, $p = 0.010$.

Implications

The study described above reveals several important findings, not only for understanding neural correlates of cognitive fluctuations during FA meditation, but also for research methodology. By incorporating subjective input into the analytical design, we were able to obtain a fine-grained picture of cognitive states that were occurring in real time during FA meditation. The neural activations shown in Figure 4 occurred over a total period of only 12 seconds. Thus, the conventional method of averaging brain activity over several minutes would surely have obscured the richness of these subjective experiences and associated neural activations. As described above, these mental states also occur in daily life during other tasks where focused attention is required. This means that similar methodologies could be implemented to examine general processes of mind wandering and attention monitoring and regulation.

Another implication with regard to neuroimaging study design is the somewhat paradoxical outcome that by reducing the time window of analysis (3 seconds in this study), but basing the precise temporal location of that window on relevant subjective input, the researcher actually *gains* statistical power. Indeed, the activations at the moment of the button press (AWARE) in the above study were so robust that the *p*-value threshold had to be lowered to 5.0×10^{-6} in order to obtain a meaningful activation map. By comparison, standard block-design neuroimaging paradigms utilize periods of 30 seconds or more. For tasks where the mental processes involved are consistent (although this is always an assumption, even in standard tasks), this approach increases power tremendously, making block designs preferable. However, for tasks such as FA meditation with non-advanced participants, where mental processes are inherently variable, incorporating subjective input and reducing the time window around self-reported events may impart a statistical advantage. Event-related designs increase power in a similar way, examining narrow temporal windows around experimenter-defined events. The difference here is that the *participant* determines the events based on their own experience. An initial concern is the necessarily variable number of events across subjects, with irregular and unpredictable temporal spacing. Researchers traditionally take great pains to avoid this kind of experimental variability; however, the above study suggests that such variability is not a hindrance when the experimenter can be more certain about conserved mental states.

Examining Brain Activity "Off the Cushion"

Detailed temporal analyses such as those described above are clearly useful in understanding the moment-to-moment cognitive shifts underlying the subjective experience of focused attention. However, to understand how cognitive skills gained during such meditation practice may be transferred "off the cushion," we must also investigate brain states more reflective of daily life. One way to assess non-task related neural activations is to examine "resting state" brain activity. The nature of the brain's resting state has generated much interest among neuroimaging researchers in recent years (Lee et al. 2012; Snyder and Raichle 2012). These investigations focus on brain activity and functional connectivity when people are asked to rest quietly and not engage in any particular mental activity. Functional connectivity in particular has been examined as an indicator of brain areas that oscillate in a highly correlated pattern over time. Strong functional connectivity is often taken to suggest that brain regions are acting together, or have increased ability to communicate as compared to regions with weak functional connectivity. Changes in resting state functional connectivity have been identified after learning or practice paradigms (Leavitt et al. 2012; Schultz et al. 2012; Wang et al. 2012), and can be interpreted as an outcome of re-wiring or neuroplastic processes.

We reasoned that the networks identified as being involved in FA meditation (Figure 4) are likely candidates for experience-dependent plasticity resulting from repeated practice. Thus, these regions may express differential resting state functional connectivity depending on the amount of meditation experience a person has accumulated. To investigate this possibility, we created seeds[3] to represent the activation patterns seen in each of the four conditions above. We then used these seeds to perform functional connectivity analysis on resting state data from the same participants. Participants were dichotomized into groups with high and low levels of lifetime meditation practice, and results were compared between groups to evaluate the effect of meditation experience on the functional connectivity of these networks. We hypothesized that participants with more meditation experience would exhibit increased functional connectivity of attentional networks, possibly reflecting plasticity induced by repeated engagement of these networks during contemplative practice.

Figure 6 shows representative findings from this analysis (for full results, see Hasenkamp and Barsalou 2012). Functional connectivity to the DLPFC, which was active during sustained attention in the FOCUS phase, was increased to several regions in the right insula in the high practice group. The insula has been implicated in a vast array of tasks, including present moment awareness and sensation of internal states (Craig 2009; Hasenkamp et al. 2012). Increased coherence of signal between right DLPFC and right insula at rest suggests that individuals with more meditation experience may have an enhanced awareness of present moment experience and more access to internal bodily states when employing executive processes in daily life. In addition, the VMPFC region found to have reduced activity during the SHIFT phase in high practice participants (Figure 5) showed increased functional connectivity to bilateral regions of the inferior parietal lobule in these same participants. These parietal regions are part of the executive network, and have been specifically implicated in attentional disengagement (Posner et al. 1984). This finding supports conclusions from our previous analysis (Figure 5); with increased coherence between these regions, experienced meditators may have improved capacity for disengagement of thought content mediated by the medial PFC region.

[3] In functional connectivity analysis, the term "seed" is used to refer to the distinct brain area to which all other brain activity is compared. Brain activity over time is plotted in the seed region, and temporal data from all other points in the brain is correlated with this pattern. If the correlation is strong, a given area is said to have strong functional connectivity with the seed region.

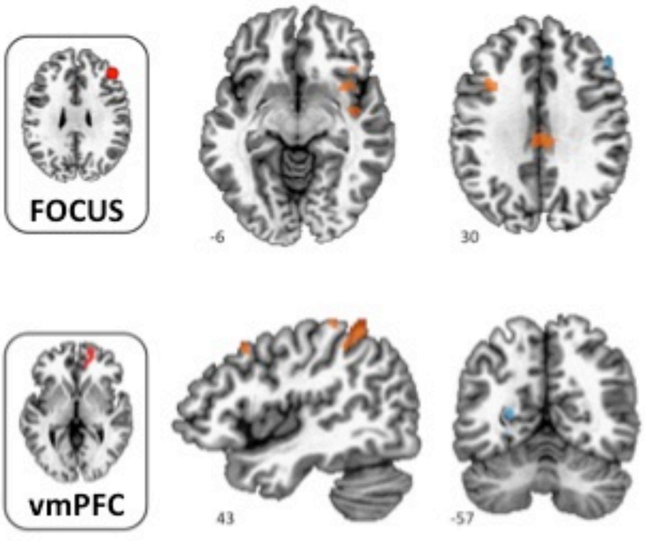

Fig. 6 Functional connectivity differences between participants with high and low levels of meditation experience. Upper: Increased functional connectivity in high practice participants between the right DLPFC (active during the FOCUS phase, red) and several attentional brain regions, including right insula, left DLPFC and mid-cingulate. Lower: Increased functional connectivity in high practice participants between the VMPFC (correlated with practice time, red, see Figure 5) and left inferior parietal lobule. Orange indicates increased functional connectivity with more meditation experience; blue indicates reduced functional connectivity with more meditation experience.

These results add to growing evidence that the amount of time an individual spends practicing meditation is associated with activity and connectivity changes in the brain, particularly in attentional regions (Baron Short et al. 2010; Brefczynski-Lewis et al. 2007; Hasenkamp et al. 2012; Saggar et al. 2012). In this analysis, we utilized seed regions that were identified through the use of subjective input provided during meditation, and examined connectivity during the resting state in the same participants. This approach arguably allowed us to examine specific regions that would be most likely to have undergone plasticity from repeated meditation practice. Compared to selecting brain regions based solely on the literature, the leveraging of subjective input enabled a directed approach that likely increased the probability of detecting meditation-related changes.

Extending the Model

While the basic model we propose above is useful as a starting point for this research, it is clearly an over-simplification of experience, and could be extended in many ways. I outline some possibilities here in the hopes of stimulating future research that incorporates a neurophenomenological approach (see Figure 7). In doing so, I reconsider the labels of the four cognitive states as well as the processes that enable them (denoted by arrows). It should be noted that other useful models of this process have been proposed (Tang et al. 2012; Vago and Silbersweig 2012), and the present re-formulation is offered as only one possible next step.

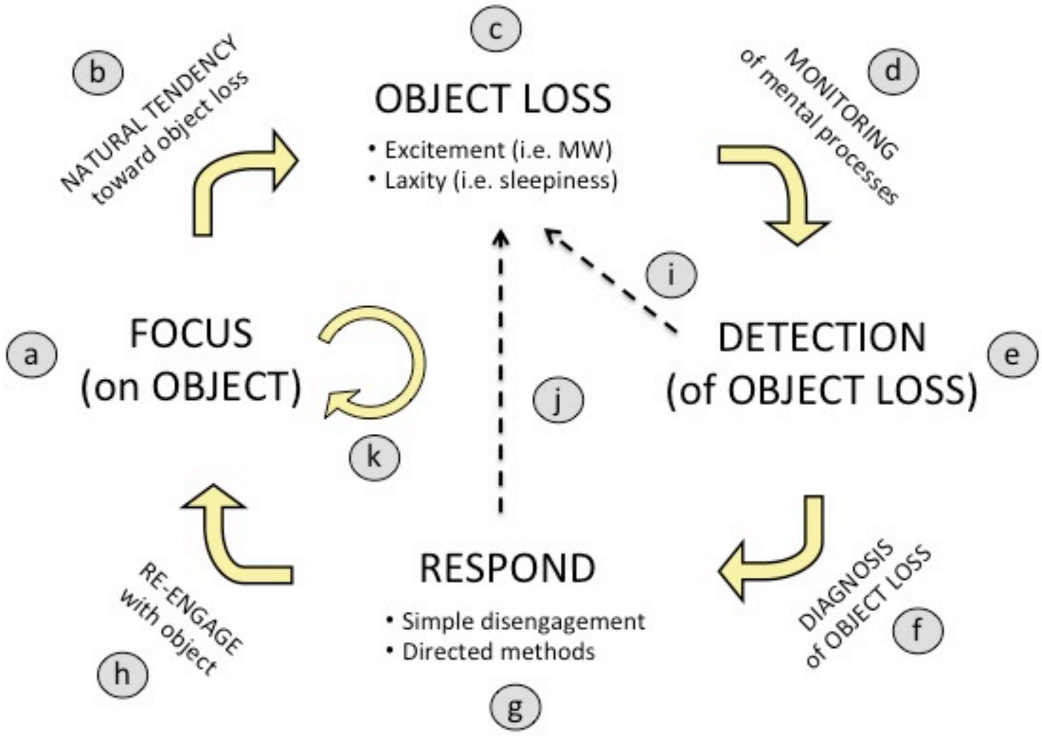

Fig. 7 Possible extensions to the cognitive model of FA meditation. In this expanded model of focused attention practice, the main phases have been re-labeled (a, c, e, g) to reflect a more general fluctuation between retention and loss of the object. In addition, the transitions between states have been labeled as processes (b, d, f, h) that enable each successive state. Finally, multiple exceptions to the serial nature of the four-phase model have been noted, including derailment (i, j) and parallel awareness/passing thoughts (k). For a full description of each point, see the text.

First, it may be more generalizable in future research to broaden the MIND WANDERING state so that it encompasses all possibilities in which attention is "off" the chosen object of focus. This is denoted in Figure 7 as OBJECT LOSS. This classification allows for more possibilities within the OBJECT LOSS state than just mind wandering; indeed, attention can also drift from the object into a state of dullness or sleepiness (Figure 7c). This is a different subjective experience than the more engaged and energized state of mind wandering. In traditional Buddhist accounts, these mental states are referred to as "excitement" (meaning active thinking, roughly equivalent to mind wandering) and "laxity" (meaning a state of dullness or sleepiness; Wallace 2006). Furthermore, the arrow indicating the transition from FOCUS to OBJECT LOSS can be labeled to reflect that this process seems to be a natural tendency of the untrained mind (Figure 7b).

Moving forward in the cycle, the previously named AWARE moment could be more generally described as DETECTION of object loss (Figure 7e), to more clearly reflect the target detection function of the salience network that performs this process. Moreover, the process that enables this detection can be described as monitoring of attention, or meta-awareness (Figure 7d). Once the DETECTION has been made, there may or may not be a process of diagnosis – that is, determining how the attention was off the object (e.g., via excitement or laxity; Figure 7f). This process can also be referred to as "labeling," or "noting." Whether this process is engaged in will depend on the intention of the practitioner. It is also debatable whether diagnosis occurs simultaneously with detection or sequentially. It may be that in the early stages of learning, the processes are quite distinct, and with greater experience they become more indistinguishable such that the act of DETECTION automatically incorporates some level of diagnosis.

Once DETECTION occurs and a diagnosis is made (or even if none is made), one can then RESPOND to the state of OBJECT LOSS (Figure 7g). This can be done in many ways, and will also depend on the manner of OBJECT LOSS. For example, in the case of excitement, one may simply disengage with the thought content that has arisen, "dropping" the thoughts in order to return to FOCUS. This is a common instruction in western styles of practice (Gunaratana 2002; Kabat-Zinn 1990; Wallace 2006). Another approach that is encouraged in some practices is to counteract the nature of the OBJECT LOSS through physical and/or mental strategies; for example, if laxity has occurred, one can open the eyes, look up, take a deep breath, perform certain visualizations, or find another way to increase energy and support vigilance (Gunaratana 2002; Wallace 2006). Whatever strategy is used, be it mere disengagement or a more directed approach, this is the beginning of the attentional response. Following this initial adjustment, one must then re-engage with the chosen object by directing attention through the process of re-orienting (Figure 7h). This re-engagement enables the FOCUS state to once again be obtained (Figure 7a). Maintenance of this state will require working memory and executive systems.

Another area where this model could be extended is in the serial nature of the cycle that is implied by the arrows. In reality, of course, one's subjective experience does not always proceed in such a clean and step-wise fashion. Rather, there are times when the cycle can "short circuit" after OBJECT LOSS before a successful return to FOCUS is achieved. For example, upon DETECTION, it is possible to simply return to the distracted or dull state of OBJECT LOSS without fully disengaging or re-engaging (Figure 7i). Similarly, one can begin to RESPOND with disengagement and re-engagement, but not return to FOCUS before another state of OBJECT LOSS emerges (Figure 7j). Lastly, based on the subjective report of many practitioners, there can be a sense of parallel mental states[4], whereby one retains some amount of FOCUS on the object, but passing thoughts or brief states of dullness can co-arise, and be experienced without full OBJECT LOSS (Figure 7k).

It is important to note that in neither the original model nor this revised version, do we mean to suggest that each of these cognitive states has a consistent duration. Indeed, significant individual variability undoubtedly exists in the precise temporal nature of the cognitive fluctuations discussed here. In our previous analysis, we used 3-second windows surrounding the button press – an assumption based partly on participant feedback and partly on methodological restrictions. It may be possible in future research to more accurately determine the temporal patterns of these states by incorporating additional subjective input. For example, one approach could be to include an additional button press when the state of FOCUS has been re-achieved. This resulting window between the two button presses would then denote the entirety of the RESPOND process. Similarly, one could envision adding a separate, distinguishable button-press to indicate detection of excitement (button 1) vs. laxity (button 2). While these approaches could provide additional accuracy and would certainly be interesting to investigate, they may also complicate analysis in several ways. For example, the addition of a second button press upon return to FOCUS would result in differing time windows for each cycle, necessitating a more complex analytical model for neuroimaging data. Moreover, the requirement of additional button presses could further interfere with the naturalistic experience of FA meditation, thereby disrupting the very process that is to be investigated. Careful consideration and experimentation is needed to navigate the balance between an approach that reduces complex mental processes to distinct, reportable moments, and one that embraces the totality of phenomenological experience.

Conclusions

In this chapter, I review a recent attempt to incorporate subjective report into the neuroscientific study of cognitive processes associated with FA meditation and the

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[4] This proposal of parallel states of processing may or may not agree with Buddhist theory, depending on tradition. It is proposed here as a result of anecdotal reports collected during the course of the research described herein, as opposed to an attempt to align with any particular textual account.

shifts between attentional states. While still an uncommon approach, other work using subjective report is showing similar success (Christoff et al. 2009; Fox et al. 2012). Moving forward, it is hoped that cognitive science will begin to broaden its view of what constitutes valid evidence, and strive to develop rigorous methods of utilizing first-person information. In addition, the study of meditation in its various forms can be considered not only as a means to understand "mechanism of action," but to more clearly elucidate basic cognitive functions that are involved in everyday mental processes. It is becoming ever clearer that simple, third-person "objective" measurements will not suffice if we are to understand a topic as inherently subjective as the human mind. The marriage of first- and third-person investigations offers great potential for those wishing to more clearly elucidate this deeply important area of our shared experience.

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References

Alexander, W.H., & Brown, J.W. (2010). Computational models of performance monitoring and cognitive control. Topics in Cognitive Science, 2(4), 658–677. doi:10.1111/j.1756-8765.2010.01085.x.

Baron Short, E., Kose, S., Mu, Q., Borckardt, J., Newberg, A., George, M.S., et al. (2010). Regional brain activation during meditation shows time and practice effects: An exploratory fMRI study. Evidence-based Complementary and Alternative Medicine, 7, 121–127. doi:10.1093/ecam/nem163.

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 USA, 104, 11483–8. doi:10.1073/pnas.0606552104.

Buckner, R.L., Andrews-Hanna, J.R., Schacter, D.L. (2008). The brain's default network: anatomy, function, and relevance to disease. Annals of the New York Academy of Sciences, 1124, 1–38. doi:10.1196/annals.1440.011.

Chen, K.W., Berger, C.C., Manheimer, E., Forde, D., Magidson, J., Dachman, L., et al. (2012). Meditative therapies for reducing anxiety: a systematic review and meta-analysis of randomized controlled trials. Depression and Anxiety, 29, 545–62. doi:10.1002/da.21964.

Chiesa, A., & Serretti, A. (2010). A systematic review of neurobiological and clinical features of mindfulness meditations. Psychological Medicine, 40, 1239–52. doi:10.1017/S0033291709991747.

Chiesa, A., & Serretti, A. (2011). Mindfulness-based interventions for chronic pain: a systematic review of the evidence. Journal of Alternative and Complementary Medicine, 17, 83–93. doi:10.1089/acm.2009.0546.

Chiesa, A. (2009). Zen meditation: an integration of current evidence. Journal of Alternative and Complementary Medicine, 15(5), 585–592. doi:10.1089/acm.2008.0416.

Chiesa, A. (2010). Vipassana meditation: systematic review of current evidence. Journal of Alternative and Complementary Medicine, 16(1), 37–46. doi:10.1089/acm.2009.0362.

Chiesa, A., & Serretti, A. (2009). Mindfulness-based stress reduction for stress management in healthy people: a review and meta-analysis. Journal of Alternative and Complementary Medicine, 15, 593–600. doi:10.1089/acm.2008.0495.

Christoff, K., Gordon, A.M., Smallwood, J., Smith, R., Schooler, J.W. (2009). Experience sampling during fMRI reveals default network and executive system contributions to mind wandering. Proceedings of the National Academy of Sciences USA, 106, 8719–24. doi:10.1073/pnas.0900234106.

Corbetta, M., Patel, G., Shulman, G.L. (2008). The reorienting system of the human brain: from environment to theory of mind. Neuron, 58, 306–24. doi:10.1016/j.neuron.2008.04.017.

Corbetta, M., & Shulman, G.L. (2002). Control of goal-directed and stimulus-driven attention in the brain. Nature Reviews Neuroscience, 3, 201–15. doi:10.1038/nrn755.

Craig, A.B. (2009). How do you feel--now? The anterior insula and human awareness. Nature Reviews Neuroscience, 10, 59–70. doi:10.1038/nrn2555.

Curtis, C.E., & D'Esposito, M. (2003). Persistent activity in the prefrontal cortex during working memory. Trends in Cognitive Science, 7, 415–423.

D'Esposito, M. (2007). From cognitive to neural models of working memory. Philosophical Transactions of the Royal Society B: Biological Sciences, 362, 761–772.

Farb, N.S., Segal, Z.V., Anderson, A.K. (2012). Mindfulness meditation training alters cortical representations of interoceptive attention. Social Cognitive and Affective Neuroscience. doi:10.1093/scan/nss066.

Farb, N.S., Segal, Z.V., Mayberg, H., Bean, J., McKeon, D., Fatima, Z., et al. (2007). Attending to the present: mindfulness meditation reveals distinct neural modes of self-reference. Social Cognitive and Affective Neuroscience, 2, 313–22. doi:10.1093/scan/nsm030.

Fell, J., Axmacher, N., Haupt, S. (2010). From alpha to gamma: electrophysiological correlates of meditation-related states of consciousness. Medical Hypotheses, 75(2), 218–224. doi:10.1016/j.mehy.2010.02.025.

Fox, K.R., Zakarauskas, P., Dixon, M., Ellamil, M., Thompson, E., Christoff, K. (2012). Meditation experience predicts introspective accuracy. PLOS One, 7(9). doi:10.1371/journal.pone.0045370.

Fox, M.D., Snyder, A.Z., Vincent, J.L., Corbetta, M., Van Essen, D.C., Raichle, M.E. (2005). The human brain is intrinsically organized into dynamic, anticorrelated functional networks. Proceedings of the National Academy of Sciences USA, 102, 9673–8. doi:10.1073/pnas.0504136102.

Fransson, P. (2005). Spontaneous low-frequency BOLD signal fluctuations: an fMRI investigation of the resting-state default mode of brain function hypothesis. Human Brain Mapping, 26, 15–29. doi:10.1002/hbm.20113.

Green, R., & Turner, G. (2010). Growing evidence for the influence of meditation on brain and behaviour. Neuropsychological Rehabilitation, 20(2), 306–311. doi:10.1080/09602010903172239.

Gunaratana, B. (2002). Mindfulness in Plain English. Somerville, MA: Wisdom Publications.

Hasenkamp, W., & Barsalou, L.W. (2012). Effects of meditation experience on functional connectivity of distributed brain networks. Frontiers in Human Neuroscience, 6. doi:10.3389/fnhum.2012.00038.

Hasenkamp, W., Wilson-Mendenhall, C.D., Duncan, E., Barsalou, L.W. (2012). Mind wandering and attention during focused meditation: A fine-grained temporal analysis of fluctuating cognitive states. NeuroImage, 59(1), 750–760. doi:10.1016/j.neuroimage.2011.07.008.

Holzel, B.K., Carmody, J., Vangel, M., Congleton, C., Yerramsetti, S.M., Gard, T., et al. (2011). Mindfulness practice leads to increases in regional brain gray matter density. Psychiatry Research, 191, 36–43. doi:10.1016/j.pscychresns.2010.08.006.

Jha, A.P., Krompinger, J., Baime, M.J. (2007). Mindfulness training modifies subsystems of attention. Cognitive and Affective Behavioral Neuroscience, 7, 109–19.

Kabat-Zinn, J. (1990). Full catastrophe living: Using the wisdom of your body and mind to face stress, pain, and illness. New York, NY: Delta.

Leavitt, V.M., Wylie, G.R., Girgis, P.A., Deluca, J., Chiaravalloti, N.D. (2012). Increased functional connectivity within memory networks following memory rehabilitation in multiple sclerosis. Brain Imaging and Behavior. doi:10.1007/s11682-012-9183-2.

Lee, M.H., Smyser, C.D., Shimony, J.S. (2012). Resting-state fMRI: A review of methods and clinical applications. American Journal of Neuroradiology. doi:10.3174/ajnr.A3263.

Lutz, A., Slagter, H.A., Dunne, J.D., Davidson, R.J. (2008). Attention regulation and monitoring in meditation. Trends in Cognitive Science, 12, 163–9. doi:10.1016/j.tics.2008.01.005.

Lutz, A., Slagter, H.A., Rawlings, N.B., Francis, A.D., Greischar, L.L., Davidson, R.J. (2009). Mental training enhances attentional stability: Neural and behavioral evidence. Journal of Neuroscience, 29, 13418–13427. doi:10.1523/JNEUROSCI.1614-09.2009.

Lutz, A., & Thompson, E. (2003). Neurophenomenology: Integrating subjective experience and brain dynamics in the neuroscience of consciousness. Journal of Consciousness Studies, 9, 31–52.

MacLean, K.A., Ferrer, E., Aichele, S.R., Bridwell, D.A., Zanesco, A.P., Jacobs, T.L., et al. (2010). Intensive meditation training improves perceptual discrimination and sustained attention. Psychological Science, 21, 829–39. doi:10.1177/0956797610371339.

Mason, M.F., Norton, M.I., Van Horn, J.D., Wegner, D.M., Grafton, S.T., Macrae, C.N. (2007). Wandering minds: the default network and stimulus-independent thought. Science, 315, 393–5. doi:10.1126/science.1131295.

Northoff, G., & Bermpohl, F. (2004). Cortical midline structures and the self. Trends in Cognitive Science, 8, 102–7. doi:10.1016/j.tics.2004.01.004.

Posner, M.I., & Petersen, S.E. (1990). The attention system of the human brain. Annual Reviews Neuroscience, 13, 25–42. doi:10.1146/annurev.ne.13.030190.000325.

Posner, M.I., & Rothbart, M.K. (2009). Toward a physical basis of attention and self regulation. Physics of Life Reviews, 6, 103–20. doi:10.1016/j.plrev.2009.02.001.

Posner, M.I., Walker, J.A., Friedrich, F.J., Rafal, R.D. (1984). Effects of parietal injury on covert orienting of attention. Journal of Neuroscience, 4, 1863–74.

Rubia, K. (2009). The neurobiology of meditation and its clinical effectiveness in psychiatric disorders. Biological Psychology, 82, 1–11. doi:10.1016/j.biopsycho.2009.04.003.

Saggar, M., King, B.G., Zanesco, A.P., Maclean, K.A., Aichele, S.R., Jacobs, T. L., et al. (2012). Intensive training induces longitudinal changes in meditation state-related EEG oscillatory activity. Frontiers in Human Neuroscience, 6, 256. doi:10.3389/fnhum.2012.00256.

Schultz, D.H., Balderston, N.L., Helmstetter, F.J. (2012). Resting-state connectivity of the amygdala is altered following Pavlovian fear conditioning. Frontiers in Human Neuroscience, 6. doi:10.3389/fnhum.2012.00242.

Seeley, W.W., Menon, V., Schatzberg, A.F., Keller, J., Glover, G.H., Kenna, H., et al. (2007). Dissociable intrinsic connectivity networks for salience processing and executive control. Journal of Neuroscience, 27, 2349–56. doi:10.1523/JNEUROSCI.5587-06.2007.

Singer, T., Critchley, H.D., Preuschoff, K. (2009). A common role of insula in feelings, empathy and uncertainty. Trends in Cognitive Science, 13, 334–40. doi:10.1016/j.tics.2009.05.001.

Smallwood, J., & Schooler, J.W. (2006). The restless mind. Psychological Bulletin, 132, 946–58. doi:10.1037/0033-2909.132.6.946.

Snyder, A.Z., & Raichle, M.E. (2012). A brief history of the resting state: the Washington University perspective. NeuroImage, 62(2), 902–910. doi:10.1016/j.neuroimage.2012.01.044.

Tang, Y.Y., Lu, Q., Geng, X., Stein, E.A., Yang, Y., Posner, M.I. (2010). Short-term meditation induces white matter changes in the anterior cingulate. Proceedings of the National Academy of Sciences USA, 107, 15649–52. doi:10.1073/pnas.1011043107.

Tang, Y.Y., Rothbart, M.K., Posner, M.I. (2012). Neural correlates of establishing, maintaining, and switching brain states. Trends in Cognitive Science, 16(6), 330–337. doi:10.1016/j.tics.2012.05.001.

Vago, D.R., & Silbersweig, D.A. (2012). Self-awareness, self-regulation, and self-transcendence (S-ART): a framework for understanding the neurobiological mechanisms of mindfulness. Frontiers in Human Neuroscience, 6. doi:10.3389/fnhum.2012.00296.

Van Leeuwen, S., Singer, W., Melloni, L. (2012). Meditation increases the depth of information processing and improves the allocation of attention in space. Frontiers in Human Neuroscience, 6, 133. doi:10.3389/fnhum.2012.00133.

Varela, F., Thompson, E., Rosch, E. (1991). The embodied mind: Cognitive science and human experience. Cambridge, MA: The MIT Press.

Wallace, B.A. (2006). The attention revolution: Unlocking the power of the focused mind. Somerville: Wisdom Publications.

Wang, D.Y., Liu, D.Q., Li, S.F., Zang, Y.F. (2012). Increased local synchronization of resting-state fMRI signal after episodic memory encoding reflects off-line memory consolidation. NeuroReport, 23(15), 873–878. doi:10.1097/WNR.0b013e3283587c96.

Xue, S., Tang, Y.Y., Posner, M.I. (2011). Short-term meditation increases network efficiency of the anterior cingulate cortex. Neuroreport, 22(12), 570–574. doi:10.1097/WNR.0b013e328348c750.

Zeidan, F., Johnson, S.K., Diamond, B.J., David, Z., Goolkasian, P. (2010). Mindfulness meditation improves cognition: evidence of brief mental training. Consciousness and Cognition, 19, 597–605. doi:10.1016/j.concog.2010.03.014.

Zeidan, F., Martucci, K.T., Kraft, R.A., Gordon, N.S., McHaffie, J.G., Coghill, R.C. (2011). Brain mechanisms supporting the modulation of pain by mindfulness meditation. Journal of Neuroscience, 31(14), 5540–5548. doi:10.1523/JNEUROSCI.5791-10.2011.