**ON MIND WANDERING, ATTENTION, BRAIN NETWORKS, AND MEDITATION**

Amit Sood, MD, 1,* and David T. Jones, MD 2

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Human attention selectively focuses on aspects of experience that are threatening, pleasant, or novel. The physical threats of the ancient times have largely been replaced by chronic psychological worries and hurts. The mind gets drawn to these worries and hurts, mostly in the domain of the past and future, leading to mind wandering. In the brain, a network of neurons called the default mode network has been associated with mind wandering. Abnormal activity in the default mode network may predispose to depression, anxiety, attention deficit, and posttraumatic stress disorder.

Several studies show that meditation can reverse some of these abnormalities, producing salutary functional and structural changes in the brain. This narrative review presents a mechanistic understanding of meditation in the context of recent advances in neurosciences about mind wandering, attention, and the brain networks.

**Key words:** Meditation, mind wandering, default network, attention

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**INTRODUCTION**

The human mind wanders. Anyone who has meditated or tried to focus while reading a bedtime story to a child can attest to experiencing mind wanderings. Studies show that mind wandering decreases happiness1,2 and may interfere with learning.3 Exciting developments in the neurosciences have identified areas of the brain associated with our mind’s wanderings, providing an anatomical basis for their perpetuation. 4

In this review we will explore the regional association of the large-scale brain network level dynamics that underlie meditation practice in the context of mind wandering and human attention investigated from the high-spatial resolution perspective of magnetic resonance imaging (MRI). A basic knowledge of human attention and brain networks is critical to understanding the values and pitfalls of meditation. This will allow for the development of insights into what we as clinicians can do to decrease stress and enhance resilience in manner that will allow for healthier patterns of organization in neural networks.

**ATTENTION AND SALIENCE**

Consider these two scenarios. In the first case, you check into a wilderness resort in Mesa, Arizona. It is dinner time and you are in your room, savoring a large order of burritos and tostadas, with a margarita on the side, while watching the Super Bowl. Suddenly you notice company in the room—a three-foot rattler is climbing up the wall behind the wide-screen TV. Where would your attention be focused—the TV, the food, or the snake?

For the next scenario, imagine driving to work on a familiar road on a Monday morning. In the downtown, you notice a large Asian elephant jaywalking on the road close to your office building. How likely are you to remember this adventure for the rest of your life?

These two experiences have one common feature that draws human attention—salience. Salience is the characteristic of an entity that makes it stand out relative to neighbors.5 Salience is not just a physical attribute; it could be guided by emotional, cognitive, or motivational factors. In the aforementioned examples, noticing the unexpected visitors offers survival advantage, or in the case of the elephant, at the very least, is interesting.

Human attention is constantly presented with large volumes of data. Of this vast information, at a particular moment, attention ferries one selected input to the working memory—winner takes it all.7,8 How does attention decide which input to choose? Attention picks the most salient input. The three entities of greatest salience are threat, pleasure, and novelty. All seven billion of us pay greater attention to the input that has at least one of these characteristics, with threat being the predominant focus.9 This threat focus is evolutionarily preserved because of its obvious survival value. A pertinent question is where are most of our threats in the modern times?

An average urban or suburban dweller of today, living in a low-crime and war-free neighborhood, likely experiences lower physical threats than a forest dweller a few thousand years ago. The external physical threats of the past are, however, replaced by another challenge—worries and emotional hurts. These worries and hurts, often related to regrets and fears, are housed in the domains of the past and the future. Given our threat focus, with the bulk of the threats in the mind, the human attention gets rerouted to spend inordinate amounts of time inside the head—busy brooding and worrying, away from the present moment.10 The explosion in the number of choices and our phenomenal ability to imagine increases the mind’s inward focus—a perfect recipe for mind wandering.

**MIND WANDERING**

We live in two parallel worlds: perceptual and conceptual.11 The perceptual world is the external reality perceived by the five senses. The conceptual world is the inner environment, the col-
lecion of our thoughts and emotions. The two worlds are linked and influence each other—a calming environment changes our thoughts; our thoughts change the perception of the world.

Broadly, our thoughts are of two types: focused and goal directed (such as planning a trip), or undirected and spontaneous (such as the drifting mind during a boring presentation). The internally directed cognitions that typically process the past and the future are generally unfocused and random, sometimes labeled mind wandering. Mind wandering is thinking about something other than what one is currently intending to think about, or thoughts without a clearly identified proximate intention which initiated the thoughts. A mind typically wanders into one’s own private thoughts and feelings, often without any awareness that it has wandered. Mind wandering occupies up to a third to half of the awake time in healthy adults. These thoughts can be benign, nonworking thoughts; fanciful daydreaming; or damaging catastrophizing exploration of what transpired or is in the offing. Mind wandering is ubiquitous—96% of Americans report daydreaming each day. Given the nearly universal presence of mind wandering, the word “REST” has been labeled by a group of neuroscientists as Random Episodic Silent Thinking.

Knowledge of mind wandering is of particular importance because although mind wandering may contribute to low state of vigilance, the mind that wanders is less happy and predisposed to psychopathology and chronic stress with their related adverse outcomes. The content of the inner dialogue is biased toward negative ruminations. Excessive ruminations predispose to increased risk of depression. A wandering mind also interferes with learning.

Understanding mind wandering in the context of the brain structure and function is particularly helpful. On the basis of functional and structural brain imaging, the prevailing wisdom is that, like most large-scale complex structures, our brain is organized as a network, an observation of great relevance to mind wandering, stress, and neurodegenerative disorders.

**BRAIN NETWORKS**

Most large-scale complex structures in our society are organized as networks. We live our life as part of multiple networks—professional, social, financial, and political. At a microscopic level, a single cell in our body is also organized as a coordinated network of different organelles; at a macroscopic level, our entire ecosystem works as a network. The human brain with its one hundred billion neurons also operates as a coordinated complex network with an intricate interconnected architecture extending from the cellular level to the larger functional systems.

The topography of the large-scale system level organization of the brain’s network architecture can be investigated using functional magnetic resonance imaging (fMRI). This technique can be used to observe this architecture whether a subject is performing a task in the MRI machine or is resting comfortably without performing any task directed by the investigator; the latter experimental paradigm is referred to as resting-state fMRI or task-free fMRI. In essence, the very “alive” brain is never at rest and continually maintains a complex network activity. The properties of this architecture are typically defined by characterizing the synchronized behavior of low-frequency fluctuations (<0.1 Hz) in the blood oxygenation level-dependent signal measured during the fMRI session. Areas of the brain that show synchronous activity in this frequency range are considered to be within the same large-scale neural network and have been termed intrinsic connectivity networks. During the last decade, studies have consistently shown that the regions within intrinsic connectivity networks show similar fluctuations in fMRI signals and are structurally related. The regions of the brain that exhibit correlated activity correspond to well-described functional systems, such as language, motor, visual, and auditory cortices.

Interestingly, a few areas of the brain are anticorrelated—the signal in one region seesaws with the signal in the other (Figure 1). The anticorrelated systems of interest to the current discussion are known as the task-positive and the task-negative networks. Regions of the task-positive network help with focused attention and selecting behaviorally relevant stimuli. These task-positive regions can be subdivided into two components: the executive control network (superior frontal cortex and intraparietal cortex that directs attention and working memory) and salience network (insula and anterior cingulate cortex [ACC] that helps with selection of behaviorally relevant stimuli).

These regions are anticorrelated to regions of the task-negative network, a distributed set of neurons close to the midline that increase activity when we are not externally focused. These neurons, some of which are associated with mind wandering, are the ones we default to when not task-focused; hence their name—default network or default mode network (DMN).

**DEFAULT MODE NETWORK**

The discovery of the DMN is a story of great serendipity in neurosciences. The DMN was discovered as a result of include...
ing rest control conditions during functional imaging studies. When scientists found cortical midline areas (medial prefrontal cortex and precuneus/posterior cingulate cortex) activating during rest control, they first considered it confound, such as activity involved in hosting the brain’s processing needs to fixate on a cross hair. However, during the last decade, since its first description in 2001, the DMN has emerged from being considered annoying noise to the central focus of investigation for many neuroscientists. Far from being a distraction, the DMN is now believed to host several operations, such as constructing mental models or adaptive simulations to guide future behavior, processing internal cognition to imagine alternative scenarios, self-referential processing, particularly the anterior node of DMN (medial prefrontal cortex); and imagining the future. An important consideration is that DMN hosts the “theory of the mind”—our ability to imagine from the self to the other persons’ perspective. Overall, the DMN constructs the mental models of personally significant events.

However, the DMN also has a dark side to it. With its hosting of self-referential processing and constructing mental models to guide future behavior, specific DMN activity can produce mind wandering. Inability to suppress DMN activity can lead to attentional lapses and impairs task performance. Excess mind wandering. Inability to suppress DMN activity can lead to difficulty in shifting and sustained attention, greater executive network activation. As hypothesized by the investigators, the DMN activated during rest suggest that meditation has the potential to transform even the nonmeditation time.

Several additional studies show that meditators, compared with the nonmeditator groups, are more likely to activate task-positive brain regions (and not DMN) that are involved in conflict monitoring, working memory, and cognitive control. These changes are noted both during meditation and at rest. In a study involving 24 meditation experts, focused attention meditation enhanced anticorrelation between the task-positive and default networks.

Even brief meditation training can alter DMN connectivity. Zen practitioners were noted to have reduced duration of the neural response linked to conceptual processing in regions of DMN. In another study, PCC deactivation occurred during awareness of thoughts, feelings, and body sensations compared with assessing the personal meaning of words. After training in an eight-week Mindfulness-Based Stress Reduction training course, compared with waiting controls, the trained participants showed increased functional connectivity within auditory and visual networks and between auditory cortex and areas associated with attentional and self-referential processes, stronger anticorrelation between auditory and visual cortex, and stronger anticorrelation between visual cortex and areas associated with attentional and self-referential processes.

In an elegant study, Hasenkamp et al proposed four intervals in a cognitive cycle in the context of meditation: mind wandering, awareness of mind wandering, shifting of attention, and sustained attention. Fourteen meditation practitioners underwent fMRI scanning while performing breath-focused meditation. As hypothesized by the investigators, the DMN activated during mind wandering; salience network activated when the participants became aware of the mind wandering; and during shifting and sustained attention, greater executive network activation was observed.

A few studies have evaluated changes in the brain network organization during rest periods, even when meditation is not being practiced. Sustained changes were noticed in long-term meditators in the Brewer study noted above. In addition, Jang et al compared 35 meditation practitioners with 33 healthy controls and performed 4.68 minutes of task-free fMRI. Meditation practitioners had greater functional connectivity within the DMN in mPFC than the controls. The long-term meditation prác-
The aforementioned changes in network activity are dynamic and continue to evolve with practice. Bréczynski-Lewis et al assessed the effect of duration of meditation practice on regions involved in sustained attention. In focused attention meditation and age-matched participants, expert meditators with an average of 19,000 hours of practice had more activation in regions of sustained attention than novices. However, meditators with an average of 44,000 hours of practice had less activation. The influence of hours of practice on the brain networks supports the concept of plasticity in the changes.

In addition to the functional changes already noted, diffusion tensor imaging has been helpful in assessing white matter tract integrity and connectivity. Increased white matter tract integrity was observed in the dACC in experienced meditators compared with controls. Improved white matter tract integrity was observed in the ACC after 11 hours of integrated body—mind training meditation. In other studies, increased gray matter concentration in the PCC has been noted after mindfulness training, greater gray matter density has been noted in the inferior temporal gyrus in experienced meditators; callosal thickness was greater in long-term meditation practitioners, compared with controls, particularly involving anterior corpus callosum; and larger cortical gyrification was observed in meditators compared with controls in the left precentral gyrus, right fusiform gyrus, right cuneus, as well as left and right anterior dorsal insula.

It will be helpful to summarize our findings so far before concluding the review with its clinical implications. Human attention selectively focuses on salience, particularly threats; modern times offer more psychological than physical threats; attending to these threats, the human mind wanders away from the present moment; a network of neurons called the DMN has been associated with mind wandering; and meditation practices are associated with increased activity of the task-positive regions. In the last section of this article we will explore clinical implications of this emerging research.

CLINICAL IMPLICATIONS

The network model of the brain provides interesting correlations and insights into many common medical conditions. Abnormal DMN connectivity, particularly inability to suppress the DMN and altered anticorrelation between the networks, has been associated with anxiety, depression, attention deficit, and posttraumatic stress disorder. DMN abnormalities have also been linked with schizophrenia, autism, and Alzheimer’s dementia. The clinical corollary of DMN—mind wandering, has been linked with increased risk of unhappy thoughts and decreased learning ability.

Patients with Alzheimer’s dementia have decreased task-induced deactivations and fragmented functional coupling among the anterior and posterior default network components, and the amount of time spent in brain configurations is biased toward anterior or posterior DMN regions. The abnormalities in the DMN have been reported in carriers of APOE4 allele in the absence of measurable Alzheimer’s pathology or atrophy. Similar changes have also been noted in cognitively intact individuals with occult amyloid pathology. These changes in neuronal activity may be conducive to pathological changes.

Meditation, FA or OM, and related practices offer an interesting approach to train attention, one benefit of which may be to reduce mind wandering. Mechanistically, for example, it makes sense to help patients with depression decrease their ruminative thinking. In a study with mindfulness training compared with wait-list controls, in response to sadness provocation, participants in the meditation arm showed greater right-lateralized recruitment, including visceral and somatosensory areas associated with body sensation. The greater somatic recruitment was associated with decreased depression scores. The lower emotional density with meditation may be related to both down-regulation of the left amygdala during emotional processing in the beginners and deactivation of DMN areas in the more advanced meditators, with the latter experiencing greater acceptance and enhanced present-moment awareness.

In the context of Alzheimer’s dementia, particularly for patients with a high risk of future dementia (such as carriers of APOE4 allele), a hypothesis worth exploring is whether controlling DMN activity might slow disease progression. Further, with better characterization of the changes in the connectivity of the brain networks, particularly in the early stages of dementia, fMRI might provide a sensitive tool for early diagnosis of dementia. Pharmacotherapy to treat depression and attention deficit-hyperactivity disorder decreases DMN activity. Attention training exercises that can enhance task-positive network activity and improve anticorrelation between the two networks might be optimal behavioral approaches for these conditions. A common challenge with meditation is an inability to control the mind wandering. We thus speculate that external focus, away from the wandering mind, with greater task-positive network activity might offer a more optimal meditation approach for the minds of the twenty-first century.

As hunter-gatherers, we foraged for food. Now we forage in our mind. This mental foraging comes at a cost, that of excessive stress. Neuropsychology studies show that excess activity and abnormal connectivity in the default network predisposes to mind wandering. Mind wandering itself might predispose to the same activity. Could depression, anxiety, excessive stress, and Alzheimer’s dementia simply be an outcome of excessive default network activity, perhaps in individuals with vulnerable brains? Although currently speculative, it is likely that one therapeutic approach to help influence brain networks will be the attention training approach such as meditation, which might influence disease progression and at the same time decrease stress and enhance joy.

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