Cognitive benefits of mindfulness meditation

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CHAPTER 11

Cognitive Benefits of Mindfulness Meditation

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Given that mindfulness meditation is considered a method for training attention, and cognitive processes associated with it, including memory, can we observe the effects of such mental training with our cognitive science tools? To answer this question, it is important to separate two major styles of meditation practice: focused attention and open awareness. I use *focused attention* here to indicate the process of bringing attention to a particular object of focus and keeping it there, while with *open awareness* I mean the process of observing all salient stimuli as they occur without pursuing them in thought (or action) (Lutz, Slagter, Dunne, & Davidson, 2008). For example, when the thought "I want ice cream" arises, instead of immediately going after this thought of ice cream and creating many subsequent associated thoughts (e.g., about where to get the ice cream, how delicious it has been in the past, how it consoled me when I was little), I just watch the thought and allow it to pass (and get back to writing this chapter).

Different meditation types vary in the relative amounts of focused attention and open monitoring, and mindfulness practice can include both at, for example, different stages of practice. In this chapter I review the cognitive benefits of meditation while keeping this distinction in mind. Figure 11.1 outlines the effects of meditation on cognition that I discuss here. This chapter is not intended to be exhaustive, but I discuss a few representative studies in depth. Chiesa, Calati, and Serretti (2012) and Sedlmeier and colleagues (2012) provide extensive reviews of the effects of mindfulness training on cognition.

Figure 11.1 shows that meditative focused attention is theorized primarily to impact attention and, through that, memory and perception. Open awareness is theorized to impact cognitive monitoring and attention allocation, and through these, cognitive control and self-serving memory biases. Solid lines reflect links supported

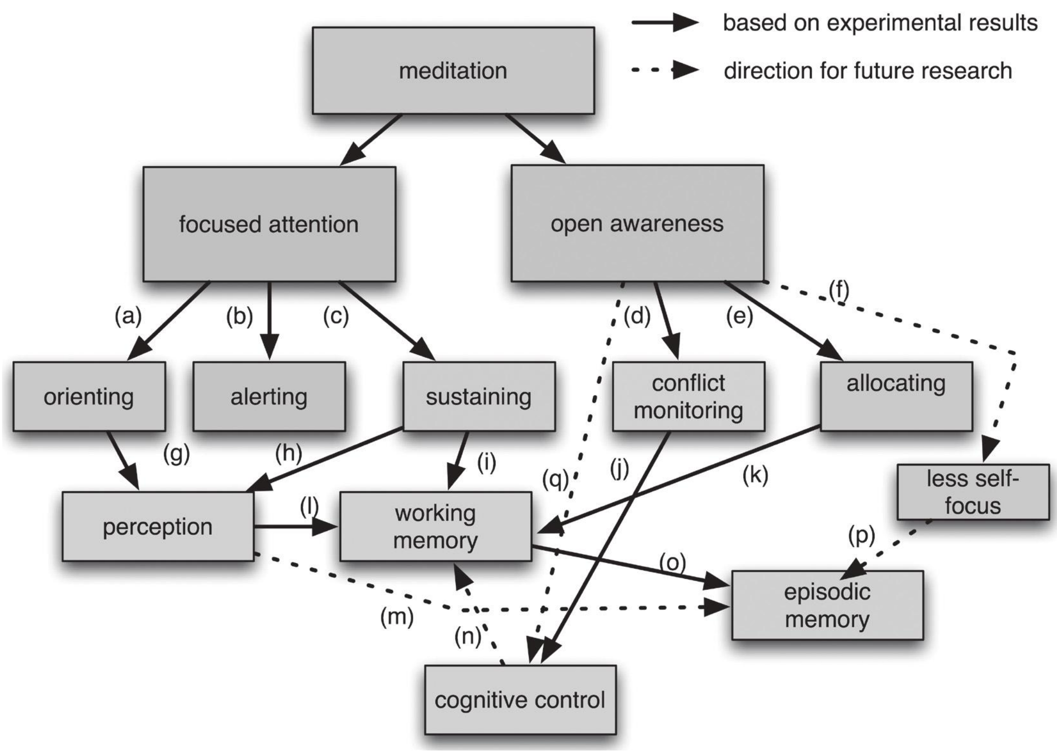

FIGURE 11.1. Conceptual overview of how the two main forms of meditative practice are associated with different parts of the cognitive system. Solid lines reflect links supported by evidence; dashed lines represent hypothesized links.

by data, whereas dashed lines represent hypothesized links to be tested in future experiments.

In this discussion, I pay special attention to an emerging approach to studying the effects of meditation on cognition that emphasizes computational modeling. Mathematical models, upon which this approach is built, can play an important role in clarifying mechanisms through which meditation practice affects cognition. Those models posit detailed mechanisms through which processes such as memory and decision making occur, then formalize those processes in equations or computer algorithms and make predictions about the behavior of people in certain (task) conditions. There is quite a lot of confusion in the literature about what processes compose meditation (e.g., Dunne, 2011), partly arising from the fact that the same words tend to be used for quite different processes by different authors, so using the less ambiguous mathematical models may be clarifying in this regard.

The study of the effects of meditation on cognition started with the idea that, at least in the beginning stages of the practice, the meditation instructions emphasize focused, or concentrated, attention (e.g., "Pay attention to your breath"; Austin, 2009; Wallace, 2008). For this reason, studying attention system processes in meditation seems a reasonable place to start. While the focused attention meditation style has a direct link to attention, the open awareness meditation style may be just as important in generating cognitive benefits of meditation, but it has been discussed much less in conceptualizations of meditation, especially in the context of cognitive science. In the latter, one practices nonattachment toward one's sensory and perceptual experiences, which results in an openness to the complete spectrum of one's conscious experience. It is easy to imagine that this changes not only the quality of attention but also how one remembers objects and events, and how one experiences one's life. In particular, being more open to the full spectrum of experience may make people more cognitively flexible and less susceptible to strong emotions. For example, in the earlier situation in which a thought of ice cream occurred in her or his mind, a practitioner of open monitoring would not completely focus his or her attention on ice-cream-related stimuli (i.e., a state of craving in which other thoughts are crowded out). Instead of being able to remember only things related to summer, eating, and ice cream, the practitioner would also be able to retrieve other memories, for example, about the next thing he or she was going to do, or about the person sitting next to him or her. Thus, these two meditation styles are thought to have differing implications for both attention and memory and, as we will see, other cognitive processes as well.

Benefits of Meditation for Attention

Given that the first instructions in mindfulness meditation and related forms are typically some variant of paying attention to the breath (or some other perceptual object), attention was the initial target for studies on the cognitive benefits of meditation. One of the first studies of the effects of meditation on attention came from Jha, Krompinger, and Baime (2007), who asked whether both short-term and long-term attentional training affected performance on a test assessing three key cognitively and neurally distinct aspects of attention, namely, the Attentional Network Test (ANT; Fan, McCandliss, Sommer, Raz, & Posner, 2002). The ANT indexes attentional orienting, alerting, and executive control. *Orienting* refers to voluntarily bringing attention to a particular object, as one does in locating one's luggage on an airport conveyer belt. *Alerting* refers to the ability to detect salient targets outside one's focus of attention, as one does in shifting focal attention to a prominent slippery floor warning sign. *Conflict monitoring* is the ability to prioritize among conflicting stimuli and responses, as one does in selectively attending to a stimulus from among multiple stimuli on a highway traffic sign. Jha and colleagues (2007) found that conflict monitoring was better for a group of experienced meditators compared to groups of controls and novice practitioners (path [d] in Figure 11.1; note that all future references to *path* refer to Figure 11.1). However, the novice practitioners showed improvements in orienting over the course of an 8-week mindfulness-based stress reduction (MBSR; Kabat-Zinn, 1990) training program (path [a]). In contrast, the experienced practitioners improved in alerting over the course of an intensive retreat (path [b]). The difference in conflict monitoring (path [d]) between experienced practitioners and controls was later replicated by van den Hurk, Giommi, Gielen, Speckens, and

Barendregt (2010), who further showed that the practitioners and controls also differed in orienting scores (path [a]).

The difference between these studies may be related to the different meditation practices in which the respective participants engaged. In the study by Jha and colleagues (2007), the practitioners came primarily from a Tibetan tradition, whereas those studied by van den Hurk and colleagues (2010) were primarily practitioners of Vipassanā meditation, which traditionally emphasizes long periods of formal practice in focused attention. Until recently, there has been little discussion in the literature about the differences between the cognitive capacities trained in different meditation traditions (but see Sedlmeier et al., 2012). However, meditation traditions, and various practices within those traditions, differ in the amount of emphasis placed on focused attention and open awareness meditation, which may therefore have different effects on cognition and emotion. Orienting and alerting may improve as the ability to focus on a single stimulus improves, whereas conflict monitoring (also called *executive function*) improvement may primarily be related to a reduction in stimulus attachment, which would make it easier to switch between competing responses.

In another early study in this vein, Slagter and colleagues (2007) examined the role of meditation training in ameliorating the temporal limits of attention using a rapid serial visual presentation task that can be used to measure the attentional blink (Raymond, Shapiro, & Arnell, 1992). In this task, participants try to detect two targets in a stream of very rapidly appearing stimuli (e.g., the targets might be two digits that appear in a stream of letters). The canonical observation is that people are unable to detect a second target when it follows the first target in close succession—that is, with only a few intervening stimuli. This has been termed the *attentional blink*, which is thought to result from an overinvestment of attentional resources in the first target (Shapiro, Arnell, & Raymond, 1997). If this is the case, and if meditation practice leads to an increase in attentional resources, then the attentional blink should decrease in meditators over the course of training. This is indeed what they found: The magnitude of the attentional blink decreased for meditators after a 3-month retreat, from a roughly 20% drop in performance for stimuli that occur close together in time to only a 10% drop in performance (path [e]). This improvement was not seen for nonmeditator controls.

They also showed that this reduction in attentional blink was accompanied by a decrease in the investment of mental effort, as indicated by the P3 event-related potential measured with scalp electroencephalography (EEG). In a second report on the same sample, Slagter, Lutz, Greischar, Nieuwenhuis, and Davidson (2008) showed that the meditators were more ready to process the second target, as indicated by a phase locking of brain oscillations in the 4–9 Hz theta frequency to this second target. Increased phase locking has been associated with better processing of a stimulus present at the time. This improved allocation of mental resources is likely to primarily result from the nonattachment aspect of meditation, in which the practitioner learned to see that perceptions, thoughts, and emotions are transient and fleeting, and is therefore less inclined to follow them. Nonattachment to perceptual stimuli should reduce the attentional blink, since it is essentially mental attachment to the first target stimulus (in an effort to remember this stimulus) that causes the attentional blink (see Taatgen, Juvina, Schipper, Borst, & Martens, 2009, for a detailed discussion and a computational model of the cognitive mechanisms behind the attentional blink). In fact, recently van Vugt and Slagter (2013) showed that the attentional blink was selectively reduced for open monitoring relative to focused-attention meditation.

Another facet of attention is the ability to sustain it over time. This aspect of attention is often measured by examining how attention declines over the course of a long and boring task. Typically, responses slow and errors increase in such tasks as time progresses. Better sustained attention is associated with less decline in performance. The ability to sustain attention for longer periods of time is likely to be the result of improvements in focused attention rather than open monitoring. In a study of the role of meditation on sustained attention (path 1 [c]), 30 people were randomized to a 3-month shamatha (a meditation practice which emphasizes focused attention) training retreat, whereas 30 others were wait-listed and completed the retreat 3 months later. MacLean and colleagues (2010) measured participants' sustained attention with a task in which they had to decide whether a vertical bar was long or short, and respond only to a short bar. The difference in length of the two bars was calibrated such that participants were only correct on 75% of the trials. This ensured that the task was sufficiently difficult to detect variability in responses. Vigilance was assessed by setting up the task such that participants only had to give a response (to long bars) on about 30% of the trials, while on 70% of the trials they did not (short bars). This meant they had to "do nothing" most of the time except to pay attention to appearing stimuli. While performance tends to deteriorate on this task over time, MacLean and colleagues found that attention could be sustained much longer at the end of the training retreat than at the beginning, and this effect persisted up to 5 months later (cf. Lutz et al., 2009).

In summary, it is clear that meditation impacts various components of attention, although the precise effects may depend on the meditation style practiced and the level of experience of the practitioner. Whereas initially mindfulness and other meditation trainings tend to train primarily focused attention, with less emphasis on developing awareness of the direction of attention (what is being attended to), later practices typically cultivate nonattachment, in which attention "broadens" to encompass more of the moment-to-moment perceptual field. Synthesizing the previous findings, it may be that initially the cultivation of focused attention results in improved ability to direct attention, measured by orienting scores in the ANT (path [a]; Jha et al., 2007). With greater experience in meditation practice, particularly through longer periods of meditation, one also trains sustained attention (path [c]; Lutz et al., 2009; MacLean et al., 2010; Pagnoni, 2012) and learns to allocate attention more effectively in space (path [e]) and time (path [b]). If one practices a meditation style emphasizing open monitoring, such as Tibetan Dzogchen and Mahamudra and Zen training, and perhaps also through the use of visualization, as in certain Tibetan practice traditions, one may develop nonattachment, and be better able to attend to and effectively respond when confronted with conflicting pieces of information (path [d]). Precisely mapping out how different types of meditation impact different aspects of attention is an important challenge for the coming years.

From Attention to Perception

Having established that meditation affects the attentional system, even though substantial variability may exist between different types of meditation and different levels of experience, a logical next step has been to examine whether meditation practice also affects perception (this section) and memory (following sections). *Perception* refers to the process by which we build representations of the external world through our sense organs. Perception is heavily influenced by what we pay attention to, and by what we expect to see (e.g., Summerfield & Egner, 2009). Interestingly, some of the most consistent reports from the meditative traditions themselves suggest that meditation practice can dramatically alter one's perception; it is said to become more vivid, more clear, and more intense (Wallace, 1999). In part, this may be a result of the improvements in attentional focus and quality (i.e., the amount of amplification of perceived stimuli due to directing attention to them). An obvious question is whether we can measure this clarity of perception objectively. The MacLean and colleagues (2010) study, discussed already in the context of sustained attention, can give some clues in this respect. They asked their participants to perceive very fine differences in length between two lines. And indeed, even halfway through their 3-month retreat, participants in this study showed an increased ability to perceive subtle differences in length of the lines. In addition, their discrimination ability covaried with the number of hours of practice completed by these participants (path [h]).

van Vugt and Jha (2011) also investigated perception, albeit indirectly, in the context of memory for face stimuli. Examining a sample of experienced practitioners beginning a 1-month meditation retreat in a Tibetan tradition, training primarily in focused attention, we asked them to perform a visual working memory task in which they had to remember sets of three very similar faces. They were then shown another face (the "probe") and asked whether it was identical to one of the face stimuli in the to-be-remembered list.

We then studied the clarity and quality of perception through fitting a mathematical model to the behavioral data that described performance in this task on the basis of stimulus similarities. This approach consisted of first fitting the behavioral data to a computational model that simulated the task with well-defined psychological mechanisms such as computing stimulus similarities, encoding items in memory, and so forth. During this fitting, various parameters of the model were adjusted to optimize the correspondence between the observed data and the model predictions. One could then see which parameters had to be adjusted to explain the differences in behavior between the practitioner and control groups, which would indicate something about the cognitive mechanisms involved (Forstmann, Wagenmakers, Eichele, Brown, & Serences, 2011).

The noisy exemplar model (Kahana & Sekuler, 2002; Figure 11.2[a]) explains recognition decisions (i.e., deciding "Have I seen this item before?") as follows. Participants implicitly compute a sum of the similarities between the probe and all study items, where similarity is a number that becomes higher as two items are more similar. As this "summed similarity" increases, participants are more likely to indicate they have seen the probe item before. This means that for list items that are identical

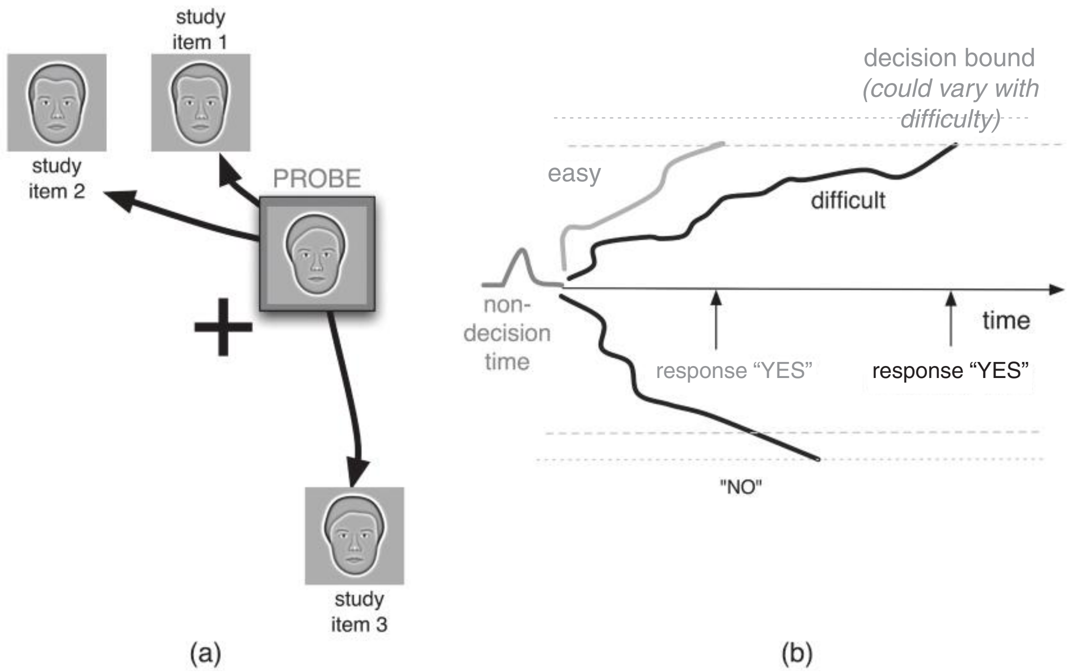

FIGURE 11.2. Models of cognition. (a) Noisy exemplar model of recognition memory. According to this model, the participant computes the probability endorsing a probe item (indicated by a square around the image) as a previously seen item (other faces) on the basis of the sum of the similarities between the probe and all study items (the other images). If this "summed similarity" is high enough (i.e., one of the study items is in the same location or very close to the probe), the participant will say, "Yes, this item was part of the studied list." (b) Drift diffusion model of decision making, which conceptualizes decisions between two alternatives as a noisy evidence accumulation that moves towards one of the decision thresholds corresponding to the response options (in this case, left and right). As soon as a decision threshold is reached, the participant makes the corresponding response.

to the probe, the similarity is very high, and the probability of saying "yes" (in that case the correct answer) also increases. However, if there are many list items that are similar, but not identical to the probe, this also increases the probability of saying "yes," which thereby causes a false alarm.

A strength of this model is that it exploits the similarity structure of the stimuli to make predictions about participants' behavior and can therefore offer insight into how people process stimuli that are highly similar visually. In this way, the model is an index of how clear the participants' mental representations of the stimuli are, and with how much detail they can encode and retrieve visual stimuli. Using the noisy exemplar model, van Vugt and Jha (2011) found that practitioners were able to discriminate between two very similar faces, which was captured by a parameter in the model that describes how sensitive behavioral judgments of similarity are to stimulus properties (see Figure 11.2[a] and Figure 11.1 path [g]).

This is one example of how mathematical models, which are abundant in psychophysics, and the study of perception can help to clarify exactly what components of the cognitive system are impacted by meditation practice.

From Attention to Working Memory

Another process that depends strongly on attention is memory. If one pays more attention, one can better remember the stimuli to which one attended (e.g., Chun & Turk-Browne, 2007). One form of memory, *working memory*, refers to the items in episodic memory that are in the current attentional spotlight (e.g., Oberauer, 2008). If this attentional spotlight is more flexible (as suggested by the just-discussed studies of Jha et al. [2007] and Slagter et al. [2007]), then it may be able to store more stimulus items. Moreover, being better able to sustain attention, through meditative practice, for example (Lutz et al., 2009; MacLean et al., 2010; Pagnoni, 2012), may make the representations in working memory more stable and less subject to interference or decay. How does meditation practice affect working memory?

In a seminal study, Jha, Stanley, Kiyonaga, Wong, and Gelfand (2010) examined the effects of mindfulness practice emphasizing open monitoring on working memory capacity in a cohort of predeployment military personnel (U.S. Marines). Over the course of the predeployment period, working memory capacity as assessed by the operation span task (OSPAN; Unsworth, Heitz, Schrock, & Engle, 2005) decreased in the control group that did not receive mindfulness training—perhaps due to the considerable stress that Marines experience during this period. Notably, mindfulness training seemed to prevent this working memory capacity decline. Moreover, working memory capacity at the end of the predeployment period was predicted by the amount of mindfulness practice in which participants engaged (path [k]). Focusing on a different type of working memory, Zeidan, Johnson, Diamond, and Goolkasian (2010) showed that for the "symbol digit modalities test," a complex visuospatial working memory task (Smith, 1982), participants showed performance increases immediately after a brief mindfulness intervention of 20 minutes' duration (relative to a control group that did not undergo such an intervention). In this task, participants have to decode a series of numbers on a piece of paper and match them to a set of geometrical figures. Their score is the number of correctly decoded symbols. The participants in the mindfulness intervention were thus able to manipulate these digits and geometrical figures in their minds more quickly, which is likely to be related to improvements in both focused attention and open awareness. If one can focus better, it is probably easier to keep items in memory, while allocating attention more flexibly can improve one's ability to manipulate information, which lies at the core of working memory.

Further evidence for the effect of meditation on working memory comes from Chambers, Lo, and Allen (2008), who showed that after a 10-day Vipassanā retreat, meditators improved more than a control group in a backward digit span task, wherein they were asked to remember sequences of digits and repeat them back in reverse order, suggesting that their practice of sustaining attention improved the representation of items in their working memory.

While Jha and colleagues (2010), Chambers and colleagues (2008), and Zeidan and colleagues (2010) studied working memory capacity, van Vugt and Jha (2011) instead focused on the entire sequence of cognitive operations underlying visual working memory, from encoding to response. In the previous tasks (OSPAN, backward digit span, symbol digit modalities), stimuli could be easily verbally encoded, while the stimuli in our study required perception and encoding of stimuli with substantial detail. Just like Lutz and colleagues (2009), we showed that after a retreat, meditation trainees showed a smaller and less variable response time, which may be another instance of the improvement in visuospatial working memory that Zeidan and colleagues observed.

Importantly, we used computational modeling to understand this decreased variability in response time. Since participants were making yes–no decisions, we could apply the drift diffusion model of decision making (see Figure 11.2(b); Ratcliff, 1978; Wagenmakers, van der Maas, & Grasman, 2007) to these data. While the noisy exemplar model explains how participants process stimulus similarity, the drift diffusion model explains how participants use evidence (either similarity-based or other) to make decisions. This model showed that the observed decrease in response time variability was associated with an increase in "drift rate" in the recognition decisions these participants made. In a drift diffusion model, participants accumulate evidence for each of their response options (in this case, "Yes, this face was in the list I had to remember" and "No, this face was not in the list I had to remember"). They make a response once they reach a decision threshold that corresponds to the response option. Drift rate is the model parameter that is thought to reflect the quality of evidence that participants accumulate in the decision process, which in our study was higher after a meditation retreat than before (Figure 11.1 path [l]). Since the quality of evidence in this case is based on the summed similarity that the noisy exemplar model describes, I posit that the improvement in working memory is at least partially mediated by improvements in perception.

The modeling approach that van Vugt and Jha (2011) took in these studies went beyond the directly observable behavioral data because it showed the mechanism by which behavior was changed rather than simply the behavior change by itself. Why is this useful? If we measure response time in a perceptual decision-making task, for example, it can not only increase because of increases in task difficulty, but also, for example, because of an increase in response caution by the participant. The drift diffusion model is able to disentangle these possibilities. If the task difficulty is the underlying cause, then the drift diffusion model fits would show a decrease in the drift rate parameter, while an increase in response caution would be associated with an increase in the decision threshold parameter (Figure 11.2 [b]).

We (van Vugt & Jha, 2011) then used another model to further probe this drift rate effect after meditation training. According to the noisy exemplar model of recognition memory (Figure 11.2[a]; Kahana & Sekuler, 2002; Nosofsky & Kantner, 2006), the drift rate increase should reflect a decrease in the "noise" with which stimuli are encoded. In the model, each item is encoded with noise to reflect the fact that our mental representations of stimuli are never completely veridical, but always some corrupted versions of the presented stimuli, particularly when those stimuli are relatively complex. The noise accounts for fluctuations in behavior in response to otherwise identical trials. Again, using a mathematical modeling approach, van Vugt and Jha (2011) found that meditators showed a decrease in a model parameter that reflects noise in the encoded mental representation of the stimuli. This suggests that meditators' memory becomes more accurate and vivid after intensive meditation practice (path [l]). Although I suggest here that this improvement is primarily related to improvements in focused attention, we do not yet know whether it depends on the type of practice in which participants engage.

In summary, we have shown that meditation not only trains attention but also affects working memory for both verbal (Jha et al., 2010) and nonverbal materials (Zeidan et al., 2010) even in novice practitioners. In more experienced practitioners, we showed that the quality of mental representations of the to-be-remembered stimuli increased after a meditation retreat (paths [i and l]; van Vugt & Jha, 2011). How this increased quality of representations relates to the working memory capacity results is an important question for future research. It may be the case that meditation improves the ability to encode stimuli, or it may increase the number of stimuli that can be held at the same time, or it may decrease degradation of the memories over time. Carefully designed studies with different types of practitioners and different tasks should address these questions. In particular, I expect that the strongest effects on visual working memory will come from forms of meditation that emphasize focused attention, while the capacity of working memory for more verbalizable materials may be more affected by practices that depend heavily on open monitoring and emphasize nonattachment, thereby promoting more flexibility in allocating attention (path [k]).

Episodic Memory: Changing Associative Patterns

If meditation affects attention and working memory, it may as a consequence also affect long-term episodic memory (path [o]). Episodic memories are those that are encoded with a particular temporal context associated with them. The relation between working memory and episodic memory is described in detail by computational memory models (e.g., Raaijmakers & Shiffrin, 1981), many of which posit that items sit in a working memory buffer in the process of being encoded into long-term episodic memory. As a result, if items are encoded with more fidelity into working memory (van Vugt & Jha, 2011), they can also be encoded into episodic memory with more detail. Can such improvements indeed be observed? And are there other effects of meditation on episodic memory? For example, does more clarity in perception lead to different encoding in episodic memory (path [m])?

One of the few studies reporting how meditation affects episodic memory was that of Lykins, Baer, and Gottlob (2012), who showed that meditators from a mixture of traditions recalled a larger number of words in a California Verbal Learning Test, in which participants are asked to learn and recall a list of words repeatedly over several trials. Nevertheless, this is only a very coarse index of episodic memory, and more research will be needed to probe whether meditation affects episodic memory, and if so, whether that effect depends on the type of meditation practiced. For example, does the content of episodic memory differ? If meditation reduces attachment, and especially attachment to the self (Sahdra, Shaver, & Brown, 2010), then meditators might tend to remember less self-related content and more other-related content (path [p]). In addition, the organization of memory recall may change. For example, it has been shown that free recall of word lists is more structured and organized for participants with higher working memory capacity (Spillers & Unsworth, 2011). Given that some types of meditation have been related to increased working memory capacity, this improvement in episodic memory organization may occur as well.

Another way of examining recall organization is on the basis of the valence of the remembered stimuli. For example, participants' recall of longer sequences of negative-valence stimuli may reflect a tendency toward depressive ruminations, which are trains of predominantly negative thoughts. We made use of this idea in a recent study (van Vugt, Hitchcock, Shahar, & Britton, 2012). While most studies of free recall focus on memory of the number of words of different types that participants remember, in that study we instead focused on the *mechanism by which* memory retrieval takes place, that is, how participants proceed from recalling one item of a particular valence to the next. Memory retrieval is driven by the patterns of association between memories: for example, "I should finish writing this chapter," which reminds me that "I should look up this new paper about meditation research." Considering that most of our thinking is driven by sequential patterns of associations, these determine to a large extent whether we are able to think of new things or we instead attend to habitual patterns of thought (which can lead to rumination; Lyubomirsky & Nolen-Hoeksema, 1993). They also determine whether we spend most of our time thinking happy thoughts (when we habitually keep recalling positive thoughts after recalling one positive thought) or alternatively, keep thinking unhappy thoughts (when we get "stuck" in recalling negative thoughts). Given that meditation is a practice in which one gets to know one's mind, including one's habitual patterns of mentation, it seems likely that episodic memory retrieval processes would change as a function of meditative practice. Instead of directly going with the dominant pattern of associations (e.g., Facebook—"I want to check whether my friend John has posted an update"), we can decide to instead focus on thoughts or actions that may be more productive (e.g., "I need to write this chapter"). Being aware of habitual patterns can therefore create a cognitive opening to pursue adaptive trains of associations.

In our study (van Vugt et al., 2012) of 52 depressed patients, we asked whether patterns of remembering positive-valence, negative-valence, and neutral words would change after participation in an 8-week mindfulness-based cognitive therapy (MBCT; Segal, Williams, & Teasdale, 2002) course. We measured how likely a person would continue recalling a word of a particular valence category given that he or she had just recalled a word from that category. Continuing to recall negative words could be the mechanism behind rumination, whereas continuing to recall positive words would reflect more healthy patterns of thoughts. We found that those patients who completed the MBCT course were more likely to repeatedly recall positive words once they were already recalling positive words, and they were less likely to "get stuck" in recalling negative words than were depressed patients in the control condition receiving treatment as usual. In addition, we found that MBCT may have protected them against the anxiety induced by the Trier Social Stress Test (TSST) that was administered to provoke rumination. We measured this by looking at the first recall a participant made. This gave us an idea of the mental context of the person at the start of recall because that context is what drives memory retrieval. In our study, this first recall occurred right after the TSST. While control patients increased in the probability of starting recall with a negative word, indicating that they were sensitized to the negative affect that is known to be induced by the TSST (Kirschbaum, Pirke, & Hellhammer, 1993), participants in the MBCT program did not do so (path [p]).

These findings indicate that free recall is a very useful tool to clarify how meditation practice affects the associations from one memory to another. Free recall can be used to track how our trains of thought may change as a function of meditation practice. For example, if meditation practice reduces attachment to the self, as it is claimed to do (e.g., Wallace, 2008), I would expect that presenting participants with stimuli related to the self would evoke shorter trains of self-related memories in meditators than in controls. Such a change in the dynamics of memory retrieval would particularly be associated with effects of meditative practice on (non)attachment. Importantly, these changes in the dynamics of memory associations may help prevent people from engaging in ruminative thinking and thereby enhance their mental health, potentially reducing the risk for depressive relapse (Mathew, Whitford, Kenny, & Denson, 2010).

Another reason for using free recall to study the cognitive benefits of meditation practice is that detailed computational models exist for this cognitive process (e.g., Howard & Kahana, 2002; Polyn, Norman, & Kahana, 2009). These models describe the cognitive processes involved in memory storage and retrieval, and can therefore provide insight into how these component processes may be modified by the practice of meditation. For example, according to these models, memories are associated with a temporal context that drifts over time. This temporal context includes the environment, mood, and other factors that were present at the time the memories were encoded. The temporal context is used as the main cue to retrieve the memories (Howard & Kahana, 2002). The speed of contextual drift is determined by the rate of incoming stimuli, with an increasing rate of stimuli leading to an increased rate of contextual drift. Would this context drift more slowly in meditators because they experience more cognitive control (i.e., are less distracted), and hence experience fewer incoming stimuli from mind wandering processes? The computational models also indicate how recall is organized by the temporal and semantic associations between stimuli. For example, items occurring in adjacent positions on the to-be-remembered list tend to be recalled together, just like semantically related items. Future studies should investigate whether and how the drift and recall organization change with meditative practice, and whether such change differs between types of meditation (e.g., path [n]).

Is Meditation an Exercise in Cognitive Control?

Anyone who has ever practiced meditation knows that a meditation session can be something like a battle for control of attention ("I want to go and eat that piece of pie"; "No, I should sit on this cushion"; "Where was I? I was supposed to pay attention to my breath."). Hence, an obvious hypothesis is that meditation teaches cognitive control: being aware of what one is thinking of and moving attention to a different focus if necessary. This also follows from the effects of meditation on conflict monitoring discussed in the section on attention. Since open awareness involves dealing with many different stimuli, I propose that improvements in cognitive control are primarily a result of the open awareness form of meditation practice. Cognitive control further involves monitoring and resisting temptations, such as the temptation to stop meditating and eat a piece of the pie about which one is thinking.

Cognitive control is operationalized in different ways, including the ability to deal with competing response options. For example, in the Stroop task (Stroop, 1935), participants see color names printed in different colors and must indicate the color of the ink. Sometimes the color of the ink and the word agree (no interference); at other times they conflict (interference). Moore and Malinowski (2009) found that mindfulness meditators (who practice predominantly open awareness) made fewer errors in trials where the color of the word and ink did not agree than in trials in which they agreed. In other words, meditators showed a reduced interference effect compared to nonmeditators (path [j]). It should be noted that in this study the observed effect may be confounded by demand characteristics because they were comparing a meditator group to a control group, with the former perhaps motivated to show there were beneficial effects of meditation. Nevertheless, Chan and Woollacott (2008) showed a similar effect in a different sample of meditators, in which the magnitude of the reduction in interference covaried with the amount of participants' meditation practice, and this held for both open awareness and focused attention meditation styles.

Another measure of cognitive control is the ability to inhibit responses. Sahdra and colleagues (2011) examined response inhibition in a sample of meditators on a 3-month retreat. In a task very similar to that of MacLean and colleagues (2010), participants were asked to judge the length of two similar lines. They had to respond to the majority of the stimuli (70%), which were long lines, and inhibit responses (i.e., withhold a button press) to short lines. The authors showed that after the 3-month retreat, people were better at inhibiting responses than before, and compared to a wait-list control group (path [j]). Interestingly, this improvement in performance was accompanied by self-reported increases in adaptive psychological functioning, an aggregate self-report measure that included anxious and avoidant attachment style, trait mindfulness, ego resilience, empathy, five broadband personality traits, emotion regulation capacities, depressive symptoms, anxiety, and psychological well-being. Yet these analyses cannot indicate whether adaptive functioning *caused* better cognitive control, or vice versa. As such, this study shows how intertwined the cognitive system and the emotional system are. In fact, the previously discussed effects of meditation practice on working memory could be related to improvements in cognitive control as well (path [n]).

Another very exciting avenue to study the effect of meditative practice on cognitive control is the use of decision-making paradigms from the field of neuroeconomics, which permit studies of the ability to control impulses and delay gratification (Glimcher, 2008). Just like perception, this field is based on well-developed cognitive theories, rich with computational models. Kirk, Downar, and Montague (2011) examined meditators' ability to decide rationally using the Ultimatum Game, a social decision-making paradigm. In this game, a sum of money is given and the proposer makes an offer to split up the money (e.g., $10 for you, $10 for me). Although it would be rational to accept any offer if one is the receiving party in this game, it has been found that receivers typically do not accept the offers when they receive less than 20% of the total sum available (Guth, Schmittenberger, & Schwarze, 1982). Kirk and colleagues (2011), however, found that meditators (whose meditation style was not reported) tended to accept larger inequalities in money (and therefore acted more rationally and were less swayed by their emotions) compared to a group of matched controls (path [f and j]). This finding suggests some important potential avenues for future investigations. For example, do meditators respond more optimally in a temporal discounting experiment, wherein participants have to choose between a smaller but earlier reward and a larger but later reward? Moreover, can these effects be explained by a reduction in meditators' attachment to positive outcomes and positive emotions (path [q])?

The Future: Modeling and Integrating Emotion and Cognition

This chapter has explored the emerging science describing how meditation affects cognition (see Figure 11.1 for an overview). Nevertheless, as I have noted, it is becoming clearer that cognition and emotion cannot be disentangled (e.g., Malinowski, 2013; Pessoa, Padmala, Kenzer, & Bauer, 2012), and that the meditation style (focused attention and open awareness) appears to affect both. While focused attention meditation primarily affects cognition, open awareness may also have important effects on cognition. But, notably, open awareness simultaneously affects emotion, suggesting that we should pay more attention to the cognition–emotion interaction in understanding the cognitive effects of meditation. This is even more so because as practice progresses, the focused attention and open awareness aspects of meditation become more and more entangled (or "non-dual"; Dunne, 2011), and therefore perhaps also the effects of the practice on emotion and cognition become more intertwined. These hypothesized distinctions between the open awareness and focused attention meditation styles should be studied more in the future by comparing groups of meditators who selectively focus on one of these meditation modes.

I believe that a real understanding of why meditation is so useful for many people (e.g., Grossman, Niemann, Schmidt, & Walach, 2004) depends on consideration of the effects of meditation on cognition and emotion simultaneously. For example, as discussed by Hölzel and colleagues (2011), changes in perspective on the self may underlie a large portion of the benefits of meditation practice. As one is less focused on oneself, one has more cognitive capacity (or mental resources) left to perform other cognitive tasks that require attention and working memory. At the same time, this shift away from an ego-involved perspective may reduce emotional biases in episodic memory (path [p]) and foster psychological adjustment.

Another important consideration for future studies is the need to distinguish the effects of different meditation styles and levels of experience in terms of effects on cognition (see also Sedlmeier et al., 2012). This volume focuses on mindfulness, the practice of which has been considered to involve both focused attention and open monitoring (Lutz et al., 2008). It is the latter that I predict mindfulness will affect most, with corresponding effects on conflict monitoring in attention tasks, the allocation of attention, cognitive control, and organization of episodic memory (paths [d, e, p]). For improvements in, for example, sustaining attention, I expect that the largest effects will come from shamatha and other meditation practices that emphasize focused attention (path [c]). The less-studied effects of meditation, including mindfulness practice, on the recollective processes that form our sense of self (path [f]) may require considerably more time to develop. For instance, as an individual gains experience with mindfulness and sees the transitory nature of thoughts and emotions more often, slowly the self-relevant associative structures and other habits of thoughts may start to change.

Studying the influence of meditation on the intertwined processes of cognition and emotion can benefit from computational or mathematical modeling to develop more detailed understandings of the *mechanisms* through which meditation exerts its effects. Because computational models describe the processes they model in great detail, they help to make fine-grained predictions about how the set of cognitive–emotional processes involved in meditation changes our habitual ways of processing.

Models can also point to the commonalities between seemingly different tasks. For example, in this chapter I have indicated that the drift diffusion model can be used to describe both response inhibition tasks and recognition memory decisions. And yet these models can also highlight subtle differences between behaviors that are not obvious from the verbal descriptions of the participants (cf. Marewski & Mehlhorn, 2011). By defining precisely what cognitive processes are involved in different tasks, including the task of meditation, this approach may lead to a more detailed understanding of how mindfulness impacts thought and emotion, and why mindfulness has the benefits that research has demonstrated.

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