Supplemental Materials

Materials and Methods

Participants' Meditation Background

Participants in this study had primary meditation experience in several Buddhist traditions (Shamatha/breath-focus, Vipassana/insight, and other Tibetan styles such as compassion and tong-len). Several subjects had experience in multiple traditions, as is common with Western lay practitioners. Of the 14 total subjects, 6 primarily practiced Shamatha, 5 practiced other Tibetan styles (compassion, tong-len), and 3 practiced Vipassana. Importantly, all of these styles are built on or incorporate breath-focus meditation. Thus, all participants were very familiar with the cognitive experiences of focused attention and mind wandering, and the shifts between them, that occur during breath-focus meditation.

Motor Control Task

To account for activations due solely to motor activation from pressing a button during the meditation task, a motor control task was also performed. In each block, a dot was presented on a screen at pseudo-random intervals, six times over 21 seconds. Ten blocks were presented, with alternating instructions to either press (motor condition) or not press (visual condition) the button whenever a dot appeared. Activations during these conditions were calculated using a GLM (described in the Methods section). For each individual, activations during visual-only blocks were subtracted from activations during motor control blocks to yield an activation map representing the button press. A conjunction analysis was performed between the activation maps from this task and the AWARE condition (which included the button press) to aid in the interpretation of those results. As this task was intended as a gross functional localizer for motor activations, it should be noted that neural activations and cognitive operations in this task may differ slightly from those during the meditation task. In Figure 2a, green voxels were activated during the AWARE condition alone; voxels that were also activated during the motor control task are shown in red.

Functional MRI Data Acquisition and Pre-Processing

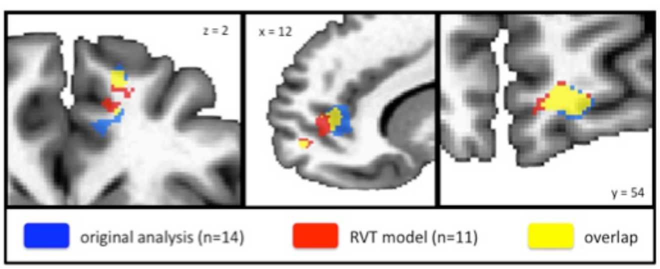
BOLD fMRI scanning was performed on a Siemens 3T MRI scanner, using a Siemens 12-channel head coil and parallel imaging with an iPAT acceleration factor of 2. Head movement was minimized with foam padding around the head. Functional images were obtained using a T2* weighted gradient-echo pulse sequence (TR=1500 msec, TE=30 msec, flip angle=90 deg, FOV=192 cm, 64 x 64 matrix, voxel dimensions=3 x 3 x 4 mm^3), providing whole brain coverage in 18 slices. High-resolution anatomical T1-weighted images were acquired for localization of task-related neural activations (TR=2600 msec, TE=3.9 msec, TI=900 msec, FOV=24 cm, 256 x 256 matrix, voxel dimensions = 1 x 1 x 1 mm^3). Respiration data were collected during scanning using a physiological monitor (In Vivo Research, Orlando, FL) connected to a dedicated computer through a data acquisition board. These data were usable for 11 out of 14 subjects (three subjects' data were unusable due to technical problems).

Initial preprocessing steps of the functional data included slice time correction and motion correction, in which all volumes were registered spatially to the 20^{th} volume in the functional run. The functional data were next smoothed using an isotropic 8 mm full-width half-maximum Gaussian kernel. Finally, the signal intensities in each volume were divided by the mean signal value for the respective run and multiplied by 100 to produce percent signal change from the run mean. All later analyses were performed on these percent signal change data. The anatomical scan was corrected for image intensity non-uniformity, skull-stripped, and then aligned with the functional data. The resulting aligned anatomical dataset was warped to Talairach space using an automated procedure employing the TT_N27 template.

Respiration Analysis

As previous work has found that meditation experience can be correlated with respiration rate (Lazar et al., 2005), we analyzed respiration in several ways in this sample. Respiration rate (breaths/minute) was calculated for each subject during the meditation task, both in the practice session and in the fMRI session. Pearson correlations were then performed between respiration rate and hours of practice. In addition, respiration rate was compared between high and low practice groups using *t*-tests, with alpha set at 0.05.

Respiration can also produce fMRI artifact, particularly in midline areas (Birn et al., 2008). To investigate this possibility, for the 11 subjects with usable respiration data, we calculated nine time-shifted respiration volume per time (RVT) regressors in a manner similar to that described by Birn et al. (Birn et al, 2006). These regressors reflect changes in the rate of breathing, and the time shifted versions of RVT changes allow for variability in the latency, from -20 s to 20 s in 5 s increments. GLMs were run for each subject including the nine RVT regressors, and the resulting betas were used in group analyses and correlations as described in the Methods section. Results from these analyses were extremely similar to those from the main analysis. Supplemental Figure 1 shows an overlay of the results in the vmPFC cluster that was significantly correlated with practice time in Figure 3, both from the original analysis and using the RVT regressors with 11 subjects.

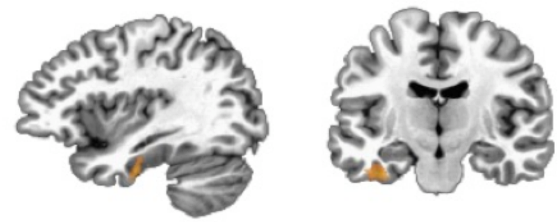


Supplemental Figure 1. Analysis of respiration effects. Overlay of vmPFC cluster examined in Figure 3, using the results of two different analyses. Blue voxels were significantly correlated with practice time in the original analysis (n=14), without controlling for possible respiration fMRI artifact. Red voxels were significantly correlated after regressing out respiration (n=11). Yellow voxels were significant in both analyses. In general, respiration had little effect on these findings.

Discussion

Practice Time Effects: AWARE

During the AWARE condition, a cluster within the left inferior temporal lobe was positively associated with practice time (Table 2), meaning that participants with more meditation experience had higher activity in this region when they became aware of mind wandering.



Supplemental Figure 2. Inferior temporal lobe cluster that was positively correlated with practice time during the AWARE condition. Subjects with more meditation experience tended to have more activity in this region when becoming aware of mind wandering.

This finding is intriguing in light of several recent reports of increased grey matter volume in this region for meditators (Hölzel et al., 2008; Luders et al., 2009). A comparison of coordinates between studies reveals a nearly precise overlap across clusters, lending weight to the suggestion that this region may be of particular importance for meditation. In one study, grey matter volume in this region was positively correlated with meditation experience (Hölzel et al., 2008). Incorporating the knowledge that activity in this region was dependent on practice time specifically during the AWARE condition, it may be that the left inferior temporal lobe is involved in the process of becoming aware of ongoing internal mentation (e.g., mind wandering in the present study). This kind of awareness is one of the main cognitive abilities that many styles of meditation aim to increase (Lutz et al., 2008).