

Mood repair in long-term meditators is predicted by rsfMRI functional connectivity of the insula and correlates with FA of the uncinate fasciculus

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Synopsis

We used rsfMRI and diffusion imaging to study functional and structural brain changes underlying the psychological trait mood repair in long-term meditators. Results of connectome-based predictive modeling showed that measured “mood repair” scores in meditators could be successfully predicted from rsfMRI data during meditation. The highest degree node in the underlying network was in the anterior ventral insula. Diffusion imaging data further revealed a role of the uncinate fasciculus in the mood repair trait in meditators. The uncinate fasciculus is part of the limbic network, connecting anterior temporal lobe with the inferior prefrontal cortex.

Purpose

There is now ample evidence that meditation may strongly affect the brain functional and structural connectivity¹. However, most of these studies have been conducted in participants with only limited meditation experience and lack psychological profiling of the meditators. The aim of the present study was to use resting state fMRI (rsfMRI) and diffusion imaging (DI) in combination with psychological profiling in a large group of highly experienced meditators in order to assess long-term changes in brain structure and function and how these relate to psychological variables.

Methods

Participants.

Fifty meditators (44.0±5.6 y; 24F) and 37 age- and sex-matched non-meditator controls (44.2±7.5 y; 21F). Mean number of years of meditation practice: 17.2±6.2 y (range 6-29 y). Care was taken to match controls and meditators for life style factors that could affect results.

Psychological profiling.

Participants filled in a number of personality questionnaires to assess dispositional traits including interoceptive awareness, emotional coping, anxiety, depression, and impulsiveness. “Mood Repair” was assessed using the Trait-Meta Mood Scale (TMMS)².

MRI scanning.

Participants were scanned on a 3T Philips Achieva scanner. The MRI session included one anatomical sequence (T1-weighted), one eyes-closed rsfMRI scan, one Diffusion Imaging (DI) sequence, and one fMRI scan with participants in a meditative state. The T1-weighted anatomical image was obtained with a gradient-echo sequence with an inversion prepulse acquired in the sagittal plane with TR=9.1ms, TE=4.6ms, flip angle=8°, 150 slices, slice thickness=1mm, in-plane resolution reconstructed in 0.75x0.75mm². DI images were acquired using a spin echo planar sequence: TE=83ms, TR=6422ms, 70 slices, slice thickness=2mm, in-plane resolution=2x2mm²,

55 directions. A reference b_0 image and 55 $b=800$ s/mm² image were acquired. Resting-state and meditation fMRI images were acquired using repeated single-shot echo-planar imaging: TE=30ms, FA=90°, in plane resolution=3.44x3.44mm², 35 slices, slice thickness=3.44mm, TR=2000ms and number of TR=200 (acquisition length=6min40s).

MRI Preprocessing.

Preprocessing of the fMRI data included linear trend removal to exclude scanner-related signal drift, temporal high-pass filter to remove frequencies lower than 0.005 Hz and correction for head movements. Data was corrected for slice-timing differences, co-registered to the T1w-reference and normalized in the MNI space. Additional preprocessing steps were added to remove non-neural artifacts from the BOLD signals. Regression analyses were performed to remove artifacts due to residual motion (the six movement regressors were obtained via rigid body correction of head motion and changes in ventricles). Original data were smoothed in the spatial domain (Gaussian filter: FWHM=5mm). We used BrainVoyager and a customized Matlab code to calculate pairwise correlations between the average time-course signals, extracted from 246 ROIs defined by the Brain-netome atlas³ and 34 from suit⁴. All matrices were kept signed and unthresholded. Using connectome-based predictive modeling (CPM), we tested for predictive models of brain-behavior relationships from connectivity data using cross-validation⁵. This implies four consecutive steps: 1) feature selection, 2) feature summarization, 3) model building, and 4) assessment of prediction significance. This produces a generalizable model with as input brain connectivity data and that generates predictions of behavioral measures in novel subjects, accounting for a large amount of the variance in these measures. DI preprocessing pipeline included brain extraction⁶, denoising⁷, susceptibility artifact correction⁸ and Eddy-current and head-motion correction⁹. The diffusion tensor model from Dipy was used to generate fractional anisotropy (FA) maps^{10,11}. FA maps were normalized in the MNI space and opened in BV where a whole brain correlation was made with mood repair. The resulting map was corrected at $p<0.05$ for multiple comparison using cluster-size thresholding (size=370mm³).

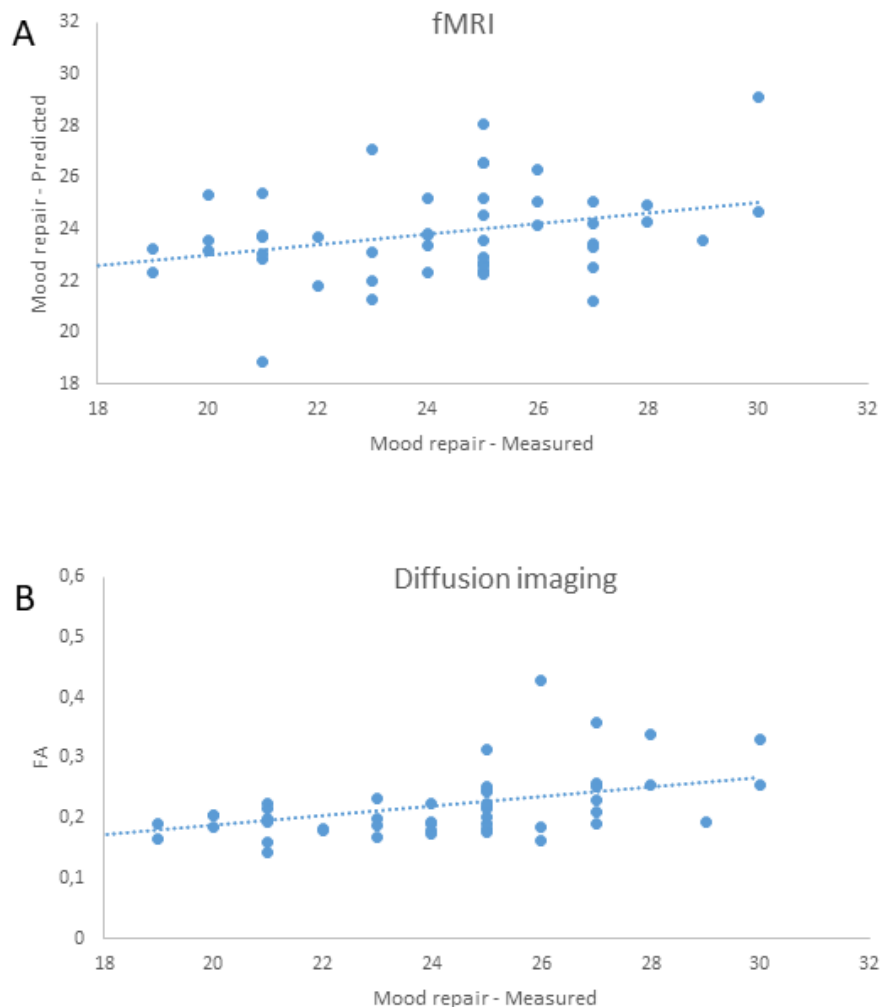


Figure 1: A. Correlation between measured mood repair (TMMS) and predicted mood repair. B. Correlation between FA values in uncinate fasciculus and measured mood repair (TMMS).

Results

CPM revealed that mood repair scores could be predicted from rsfMRI FC during meditation in the meditator group. The correlation between the predicted and measured values of mood repair scores was 0.37 ($p=0.009$) (Figure 1A). The prediction significance of this correlation, based on 2,000 permutations, resulted in a p value of 0.01. The highest degree node was in the right ventral agranular insula (Figure 2). Within the group of meditators, the FC values of the right ventral agranular insula with amygdala, hippocampus, nucleus accumbens, precuneus, posterior cingulate cortex, and parieto-occipital sulcus were significantly higher during meditation as compared to the non-meditation resting-state condition. Likewise, a between-group comparison revealed significantly higher FC values of the right ventral agranular insula with the parieto-occipital sulcus, amygdala, hippocampus, precuneus and posterior cingulate cortex in meditators compared to control subjects. The whole brain correlation between FA values and mood repair revealed 2 clusters, one in the right uncinate fasciculus ($r=0.475$; $P<0.00056$; Figure 1B), in a region connected to the ventral agranular insula, and a second cluster in the right superior longitudinal fasciculus. A group comparison revealed a non-significant trend for higher FA values in the uncinate fasciculus in meditators compared to controls ($p=0.065$).

Discussion

The present data reveal that mood repair, a psychological trait positively involved in cognitive emotion regulation and coping with negative life events, can be predicted by connectome-based modelling of fMRI FC during meditation. The highest degree node was found in the right ventral agranular insula. Within the group of meditators, the FC of this area with other brain areas involved in emotion regulation, memory and cognitive control was significantly higher during meditation as compared to rest. The DI data revealed the implication of the uncinate fasciculus in mood repair. The uncinate fasciculus is part of the limbic system linking the anterior temporal lobe with the inferior prefrontal cortex. This pathway matures slowly and continues to develop until the age of 30¹². Lesions to the uncinate fasciculus are linked to cognitive, socio-emotional, and behavioral difficulties¹³.

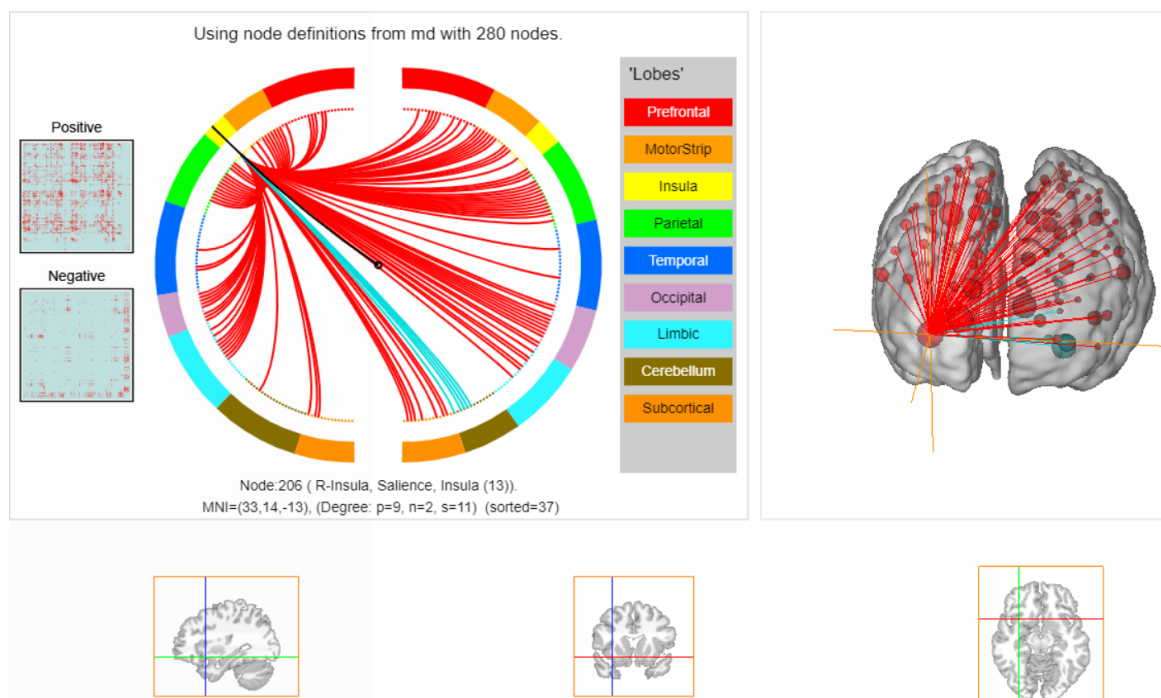


Figure 2: Results of CPM analysis, showing the highest degree node in the right ventral agranular insula.

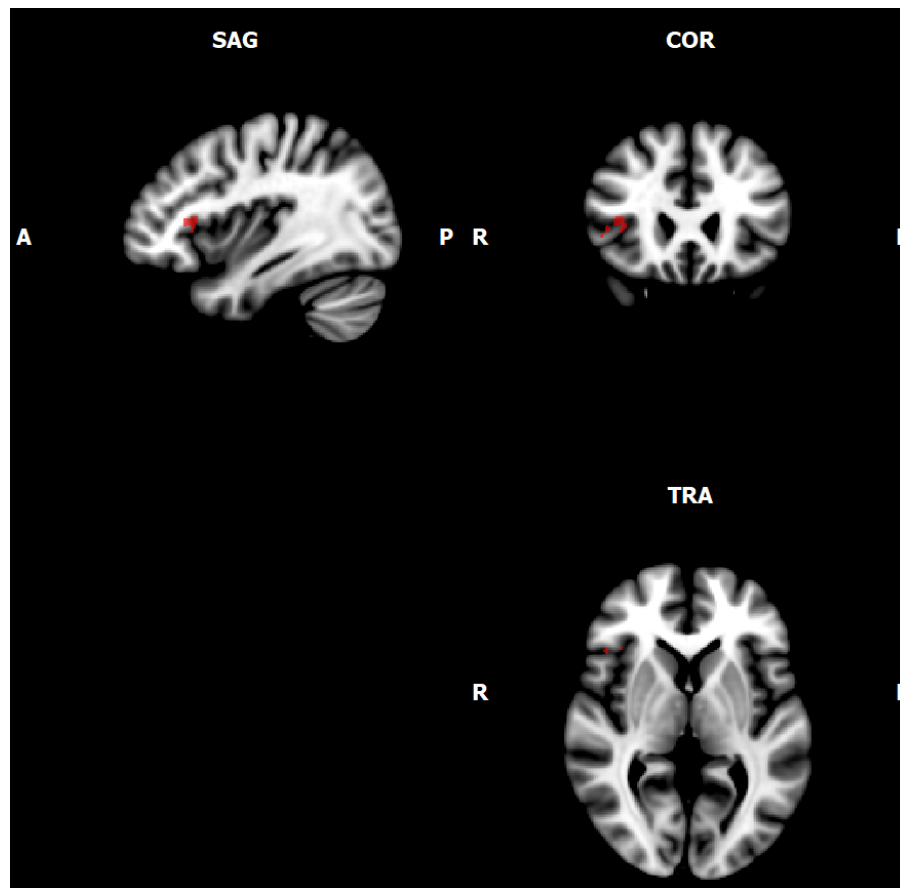


Figure 3: Area within the uncinate fasciculus correlating with measured mood repair scores (TMMS).

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