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INTENSIVE MEDITATION IS ASSOCIATED WITH LONG-TERM BRAIN NETWORK MODULATION IN REGULAR PRACTIONER OF MEDITATION

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Abstract

Regular practices of meditation were associated with the reduction of default-mode network (DMN) activity in resting-state conditions. In addition, the DMN activity was also found to be anticorrelated with the central-executive network (CEN) during meditation practices whereas the salience network (SN) responded to the awareness aspects of meditation. However, it is still not clear whether those benefits remain longer or if they are only transient and punctual effects. This session refers to prompt-meditation scanning (PMS). The third MRI session occurred ten months after PMS related to a late-meditation scanning (LMS). Here, we employed longitudinal functional MRI to assess the brain networks of an expert meditation (1) before a 10-days meditation retreat, (2) just

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after this intensive meditation, and (3) ten months later. In addition, we also compared the brain networks resulting from these three time-points with 25 volunteers without prior regular practices of meditation. Comparisons between Expert Meditator (EM) and Healthy Volunteers (HV). In resting-state conditions, DMN was significantly lower in EM than HV. However, anterior and posterior brain regions within the DMN presented opposite patterns. In the SN, functional connectivity was bilaterally higher in EM than HV within the superior frontal gyrus. In the CEN, EM had higher connectivity than HV in the right middle frontal gyrus. Longitudinal intra-subject comparisons. In resting-state conditions, DMN significantly increased from baseline scanning (BS) to PMS. SN decreased significantly from BS to PMS. CEN presented an opposite pattern faced to the SN. During the meditation task, the DMN had a similar pattern at the resting-state, although the levels of connectivity within this network under the task were higher than in resting-state. SN decreased significantly from BS to PMS, but it did not recover to original connectivity levels as it happens at the resting-state. In CEN, significant differences were found only between BS and PMS in which the level of connectivity reduced.

Introduction

Meditation is a mental and physical practice characterized by focal attention actively sustained and controlled. Several techniques of meditation have been proposed in which the vast majority is organized in two stages. The first one aims to mitigate external influences on an individual's thoughts by holding persistent attentional processes. The second stage goals to implement an in-depth body exploration by which the meditator seeks to observe consciously every sensation emerging from the region explored. In this stage, the focal-guided attention is progressively displaced from one area already evaluated to another one to be accessed. Once the individual body is wholly scanned, the process loops back iteratively.

The regular practice of meditation has been associated with mental health and well-being benefits; however, it is still unclear the mechanism contributing to such putative benefits [1]. Regarding the mental states, prior studies have suggested improvements in memory and attention [2], [3], whereas other studies have also evidenced behavioral changes, especially those behaviors associated with affective and nociceptive processes [4], [5]. In addition, neurobiological phenotype differs between meditations and non-meditations with respect to volumes of brain structures within the medial and frontal lobes [6]. Similarly, functional differences were also observed in the anterior cingulate and adjacent regions of the medial frontal gyrus [7], which also explain the changes in functional connectivity that have been observed within distinct brain networks, such as the default-mode (DMN), salience (SN) and central-executive (CEN) networks. Indeed, regular practices of meditation were associated with a reduction of DMN activity in resting-state conditions [8]. In addition, the DMN activity was also found to be anticorrelated with the CEN during meditation practices [9] whereas the SN responded to the awareness aspects of meditation [10].

Taken together, these findings have posed pieces of evidence about a dynamic and topographic brain organization in which at least three distinct networks play a capital role [11]. Alike the morphophysiological brain change observed in healthy volunteers and its putative association with high scores in quality of life [12], employing meditation as a complementary therapy for depression and anxiety also improved significantly the symptoms of these conditions [13]. However, it is still not clear whether those benefits remain longer or if they are only transient and punctual effects. Indeed, although regular meditation enhances morphophysiological changes, the neurobiological mechanisms underlying these effects are still unknown [11]. To address this gap, we employed longitudinal functional MRI to assess the brain networks of an expert meditation (1) before a 10-days meditation retreat, (2) just after this intensive meditation, and (3) ten months later. In addition, we also compared the brain networks resulting from these three time-points with 25 volunteers without prior regular practices of meditation.

Participants and Methods

Population

This study included 26 healthy volunteers. One of them is a 55 years old man who has practiced one-hour meditation twice a day for the last 12 years. In addition to the daily practice, this expert meditation participant (EM) has attended a yearly program of intensive meditation training since 2007 that cumulated up to 6,000 hours before the MRI experimentation. The remaining healthy volunteers (HV) had no particular meditation practice neither any prior history of neurological nor psychiatric disorders. The HV group was assembled with 10 men and 15 women aged from 40 to 80 years old.

Meditation protocol

Vipassana meditation was employed on the 10-days intensive meditation training. The technique is composed of two parts: focalization and scanning. Both are recommended to be performed alone, in absolute silence, and without any external communication. In the first part, the meditator was instructed to focus on the physiological sensations emerging around the philtrum, a small area between the upper lips and the base of the nose. This anatomic region provides thermomechanical information associated with the airflow when one breathes. Therefore, it assisted the meditator in tracking its respiration. Moreover, the surface of this region is supplied by the superior labial artery, and it is monitored by the trigeminal nerve via enervations arising from a branch of the infraorbital nerve. In the present study, the focalization part took the initial four days of the intensive meditation and it targeted to eliminate individual's thoughts that may disrupt attention as well as to prepare one's mind for a series of mental body scans. The second part occurred during the remaining six days of the intensive meditation. It consisted of displacing the focus of attention successively through all regions of the body. No limited amount of time was set to explore a single body region; however, the EM was instructed to perform a deep mental exploration within the region under evaluation, seeking to recognize every emergent regional sensation but without reacting to the sense perceived. Vipassana meditation was also employed in the daily practices, however, the amount of time spent in a single session was adapted to one hour. Whereas the focalization part occurs within 20 minutes, the body scan part takes 40 minutes to be completed.

MRI data acquisition

Structural and functional MRI data were acquired on a Skyra 3T scanner (Siemens Healthcare) using a 32-channel head coil. Axial T1-weighted images with high spatial resolution were obtained using the following parameters: gradient-echo sequence with TR/TE=1700/2.54ms; flip angle=9; matrix size=512x512; FOV=250x250mm and thickness=1mm. For functional MRI, T2*-weighted axial echo-planar images were acquired in a bottom-up interleaved mode by using a gradient-echo sequence with TR/TE=2000/20ms; flip angle=90; matrix size=9494; voxel size=225mm3 with no gap and number of slices=32. These parameters were identical for the resting-state and meditation-task acquisition. In the former, subjects were scanned twice with each run lasting 6 minutes and 10 seconds. They were also instructed to rest with their eyes closed and not to think of anything in particular. In the latter, only the EM underwent a meditation task which lasted 10 minutes split into three stages: one-minute resting followed by three minutes of focalization and six minutes of mental body scanning. In addition, EM underwent longitudinal MRI sessions encompassing three-time points. The first represents the baseline scanning (BS) and it had occurred one week before EM attended the intensive meditation retreat. The second MRI session was performed one week after the intensive meditation retreat. This session refers to prompt-meditation scanning (PMS). The third MRI session occurred ten months after PMS related to a late-meditation scanning (LMS).

Data analysis

MRI dataset was preprocessed according to our prior studies [14]. Briefly, structural images were oriented according the MNI standard-space using the FSL toolbox (https://fsl.fmrib.ox.ac.uk) [15]. Field inhomogeneities were corrected using the ANTs software (https://stnava.github.io/ANTs) [16] and noise was reduces using the AFNI software (https://afni.nimh.nih.gov) [17]. Remaining images were registered to the MNI space using the Symmetric Diffeomorphic Image Registration algorithm, a robust nonlinear registration approach that is implemented in ANTs that outcomes an affine transformation matrix and Jacobian images. Functional images were initially corrected for the slice-timing and for the head motion. The parameters of rotation and translation were stored to be used as nuisance factors. An average image was computed across time-points and registered into the native-space of the structural image. The linear transformation estimated here was concatenated with the prior spatial transformation and applied on the aligned functional dataset. Then, independent component analysis (ICA) was permed according to our previous study [14]. This procedure identifies spatial components with similar signal fluctuations. A single component may reveal an independent brain network. In this study, we employed a Goodness-of-Fit algorithm to select components with the highest probability of matching the default-mode network (DMN), salience network (SN) and central-executive network (CEN) [18]. These maps were used independently to perform intra and intergroup comparisons by employing the two-sample permutation test. Finally, correction for multiple comparison were applied and only outcomes with pcorrected¡0.05 were reported.

Results

Intergroup comparisons between Expert Meditator and Healthy Volunteers

In resting-state condition, DMN was significantly lower in EM then HV (Figure 1A). However, anterior and posterior brain regions within the DMN presented opposite patterns. Whereas the functional connectivity peaked within the medial frontal gyrus for EM (z-scores=13.69, MNI=[-7,64,5], Broodman Area 10 [BA10]), it was significantly lower than HV within precuneus (z-score=-6.85, MNI=[0,-66,28], BA39). In addition, a regional feature was also observed within the frontal gyrus of EM, in which significant reduction of activity was observed within the frontal orbital gyrus (z-score=-4.84, MNI=[0,58,-7], BA10r).

Alike DMN, similar anterior-posterior patterns were also observed within the SN (Figure 1B). Indeed, functional connectivity were bilaterally higher in EM than HV within the superior frontal gyrus. This difference achieved z-score=13.24 (MNI=[-29,54,26], anterior BA9) for left hemisphere and z-score = 7.30 (MNI=[21,50,29], posterior BA9) for the right connectivity within both insula were also higher in EM than HV achieving z-score=6.01 (MNI=[-36,16,3], left middle insula) and z-score=5.02 (MNI=[31,22,6], right anterior ventral insula). Finally, EM had lower connectivity than HV within the left intraparietal area (z-score=4.86, MNI=[-40,-64,50], BA7). All of these differences were remarkably observed on left hemisphere whereas, although being statistically significant, only residual outcomes were revealed in the right hemisphere. Similar lateralization was also observed in the CEN (Figure 1C). EM had higher connectivity than HV in the right middle frontal gyrus (z-score=14.68, MNI=[31,23,52], BA8av), right superior orbital gyrus (z-score=10.19, MNI=[36,61,0], BA47r / BA9-46v), inferior parietal lobe (z-score=15.72, MNI=[52,-42,52], area PFm complex) and contralateral cerebellum (z-score=8.07, MNI=[-38,-71,-43], Pyramis). Finally, EM connectivity within the left medial intraparietal area (z-score=-7.13, MNI=[-29,-74,58], BA7) was lower in EM than HV.

Discussion

A growing interest in employing meditation as a regular practice for improving mental heathy has motivated several studies to investigate the neural mechanism underlying the dynamics of the brain network [11]. In this pilot study, we initially validated our method by performing independent comparisons of DMN, SN, and CEN between an expert meditation (EM) and health volunteers (HV). First, by contrasting the DMN in EM faced to the HV, we observed increased connectivity within both middle frontal gyri and a reduction of connectivity within precuneus. Our findings reproduce and corroborate with prior studies [19], [20]. More specifically, Garrison et al observed that connectivity in the precuneus was even more reduced during mediation task than in other cognitive conditions, and in the Crewell's et al. study, increased connectivity in the pre-frontal cortex explained about 30% of the variability of circulant interleukin, a blood marker for neuroinflammation that was claimed to be associated with the health benefits. Although the present study did not investigate meditation in HV nor analyzed blood samples, our neuroimaging outcomes fit those studies.

Similar validation was established for the SN with respect to recent study [21]. Van der Gucht's et al investigated the effect of mindfulness therapy in patients with breast cancer. Besides finding a positive correlation between the SN and practitioners of mediation, they also reported an improvement in patients' quality of life. In our study, we also observed increased connectivity in insula bilaterally, a brain region that plays a key role in pain modulation. Thus, we speculate that pain mitigation might be an important factor supporting the patient's quality of life improvements and also a key element for effective meditation. Finally, the previous studies have associated an increased CEN with the regular practice of meditation [9]. However, our findings identified a hemispherical dominance at the right except for contralateral connectivity increased on the left cerebellum.

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