Variations among meditative and concentrative states: a case study

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Introduction

Meditation is a state of consciousness that varies according to technique, person, and session, as well as the depth achieved. The tradition we are studying recognizes different levels of absorption, starting with concentration, to sensory withdrawal, and to different stages of meditation, making it harder to identify the brain circuitries expected to be used in meditation. Some studies report activations in the orbitofrontal areas, prefrontal cortex, insula, anterior cingulate, cerebellum, caudate, parietal and temporal regions (Lazar et al., 2000; Cahn and Polich, 2006). The purpose of our study was to characterize the circuitry of different levels of absorption.

Methods: Task and Subject

Task

The meditator was asked to perform three different meditative procedures. The first consisted in concentrating on his breath (concentration) for 256s. The second consisted in meditating on a written verse (visual meditation). The verse was displayed on a screen in the fMRI for 2 minutes and the meditation lasted 10 minutes. The last absorption consisted in meditating on an aural presentation of verses chosen and pronounced by his teacher (auditory meditation). The words were taped and played through an MRI compatible headphone system. The tape lasted 1 minute. The auditory meditation also lasted for 10 minutes.

Subject and School

The meditator was selected from a small school in Rome, *Scuola Maya*. There are about 200 students in the school. About 30 students have visible effects after this type of meditation. After experiencing deeper states of meditation, they are unable to walk, or move for about 30 minutes to 1 hour. During the meditation, they seem to undergo seizure-like events. They feel that meditation is beneficial to them. They are unable to describe their experiences during the deeper absorptions. Before entering deeper absorptions they report no sensory perception and no sense of time. The meditator is a 40 year old Italian healthy subject. He has no history of psychiatric illnesses.

Methods: Scanning Procedure and Preprocessing

All MRI scans were collected on a 3T Phillips Achieva system at the University of California, Irvine Research Imaging Center. The scanning session consisted of: a localizer scan as needed to identify the AC-PC axis; software shimming of the images to reduce ghosting in the EPI acquisitions; a 3D T1-weighted scan (MPRAGE, TI=1100ms, TR/TE=11/3.3ms, flip angle=18, 24 cm FOV,1 mm slice thickness, 150 slices as needed to cover the entire head, sagittal orientation); The functional scans were T2*-weighted gradient echo EPI sequences with 3 mm slice thickness, 1mm gap, 2.5mm*2.5mm in-plane resolution, TR/TE=2000/30ms. The subject repeated the entire scanning session on five different days.

Methods: Analysis

The preprocessing steps included motion detection and correction, co-registration and normalization to a Montreal Neurological Institute template (Montreal Neurological Institute, Montreal, Quebec, Canada) by using an automated algorithm implemented in the statistical software, and smoothing with an 8 mm FWHM 3D Gaussian filter. The preprocessing steps were performed with the SPM5 software (http://www.fil.ion.ucl.ac.uk/spm/software/spm5/).

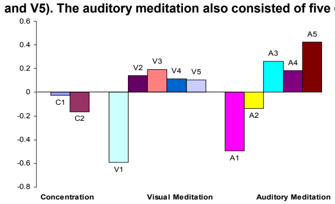
The analyses used PLS version 5.0803181 (http://www.rotman-baycrest.on.ca/).
PLS identifies areas of the brain presenting the same activations at the same time (covariance) (McIntosh et al., 2004). A Singular Value Decomposition on the covariance matrices within each task generates three matrices expressing a singular image, a correlational profile and an observed singular value.

- The *singular image* identifies the distribution of covarying voxels in the brain (saliences).
- The *correlational profile* is the particular relationship between brain BOLD signal change and each condition.
- The *observed singular values* expresses the strength of the relationship.

The significance of the singular value is determined by permutation sampling, while the reliability of the saliences are determined by the bootstrap method (McIntosh et al., 2004).

Results: Concentration vs Visual vs Auditory – all phases

Figure 1. First Latent Variable. (a) The correlational profile describes the correlation between the activation levels and the task. Each epoch consisted of two minutes. Therefore, the concentration task consisted of two epochs (C1 and C2). The visual meditation task consisted of five epochs (V1, V2, V3, V4 and V5). The auditory meditation also consisted of five epochs (A1, A2, A3, A4 and A5)



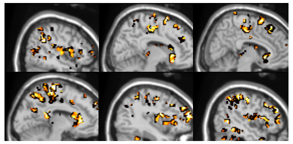
Very similar patterns appeared to be engaged during both visual and auditory meditation.

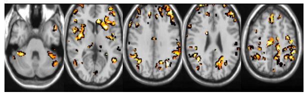
Concentration did not correlate with this pattern.

The early phases of meditation were strongly correlated with this pattern.

Results: Concentration vs Visual vs Auditory - Early and Late Phases

Figure 2. First Latent Variable. (a, b) The singular image identifies the voxels covarying during the task in sagittal and axial orientations (shown with L = R, radiological convention). (b) The correlational profile describes the correlation between the voxels and the task. Yellow areas in (a) represent regions that are positively correlated with the profile. For both visual and auditory meditation, the first and last two minutes - Early and Late Phases - are compared.


(a)


(b)

The analysis decoupled early and late phases of meditation. In this pattern, the same brain regions appeared to be engaged during both visual and auditory meditation. Yellow areas represent areas that are engaged during the latest phases of both meditation types. Concentration did not correlate with the regions shown.

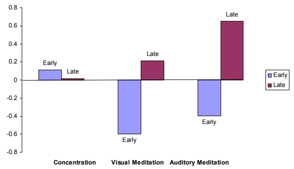


Table 1 (a-e): Significant clusters for Concentration vs Visual meditation vs Auditory Meditation

Frontal Areas	*Positive X Y Z (cluster) [BSR]*
Superior Frontal Gyrus	
BA 8	-4 32 48 (19) [14.7]
BA 9	-8 50 27 (7) [6]
BA 10	-36 70 -5 (324) [30.9] 26 74 0 (289) [18.5]
BA 11	-28 47 -23 (998) [27.1] 30 49 -24 (26) [12.1]
Middle Frontal Gyrus	
BA 6	24 -9 52 (25) [17.8]
BA 10	-46 55 5 (456) [60.1]
BA 47	53 54 -14 (38) [13.1]
Medial Frontal Gyrus	
BA 6	10 3 53 (22) [8.1] 6 -24 58 (6) [7]
BA 8	8 27 41 (90) [19.5]
BA 9	2 42 26 (261) [19.7] 22 35 30 (5) [10]
BA 10	12 57 6 (65) [11.1] -16 49 14 (53) [25.9] -6 72 9 (6) [7.4]
Inferior frontal	
BA 9	-42 7 25 (39) [11.8]
BA 10	61 42 -5 (14) [17.9]
BA 44	-50 -1 20 (58) [18.5]
BA 45	61 31 6 (30) [16.1]
BA 46	-55 41 0 (47) [17.6] 44 33 8 (39) [21]
BA 47	-59 27 -5 (38) [15.9] 50 40 -15 (15) [7.6]
Precentral Gyrus	
BA 4	24 -23 49 (34) [22.2] -18 -23 51 (8) [7.4]
BA 6	34 5 29 (59) [39.4]
Rectal Gyrus	
BA 11	12 36 -22 (120) [46.6] -2 28 -27 (47) [17.8]

Limbic Lobe	*X Y Z (cluster) [BSR]*
Cingulate Gyrus	
BA 24	-10 -7 44 (1021) [13.7] 8 -6 26 (190) [14.9] 2 -19 40 (55) [20.1] 8 -6 41 (19) [9.9] -4 -4 28 (8) [9.8]
BA 31	18 -41 35 (53) [18.9] 16 -33 42 (39) [22.8] -2 -31 37 (22) [9.2]
BA 32	20 15 38 (136) [25.4]
Anterior Cingulate Gyrus	
BA 24	-10 22 21 (7) [6.4]
BA 25	-2 13 -9 (62) [14.1]
BA 32	12 35 -8 (58) [16.7] 14 39 13 (8) [6.1]
Parahippocampal Gyrus	
BA 19	40 -48 2 (12) [9.8] -42 -43 -5 (14) [8.1]
BA 28	-14 -18 -16 (22) [6.7]
BA 30	-16 -37 -7 (271) [20.9]
BA 34	12 -14 -18 (19) [10.4]
BA 35	30 -20 -19 (19) [7.7]
BA 36	-34 -28 -24 (16) [11]
Insula – BA 13	-40 13 -4 (181) [18.5]
Uncus – BA 20	32 -15 -28 (17) [8.1]

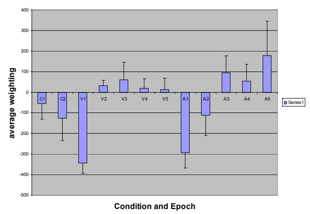
Other Areas	*X Y Z (cluster) [BSR]*
Thalamus	-10 -27 -4 (40) [40.9]
Lentiform Nucleus - Putamen	32 -4 -5 (506) [38.7] 18 14 1 (18) [13.2]
Claustrum	28 -16 23 (35) [13.7] -36 -10 -1 (14) [10.8]
Cerebellum	
Tonsil	-38 -33 -45 (84) [9.4] 38 -31 -44 (72) [13.1] -53 -49 -41 (69) [9]
Declive	34 -61 -19 (49) [11.1] -22 -74 -15 (13) [7.7]
Culmen	2 -70 -12 (15) [9.6] -50 -48 -28 (30) [6.1] 44 -44 -23 (15) [7.7] -32 -42 -21 (12) [10.2]
Striatum Caudate Body	-14 5 22 (20) [11.3] 6 4 11 (6) [10.7]
Caudate Tail	38 -42 9 (209) [30.8]

Temporal Lobe	*X Y Z (cluster) [BSR]*
Superior Temporal Gyr.	
BA 22	48 -33 7 (161) [40.3] 48 -16 -4 (58) [11.4] -46 -10 -8 (15) [8.3] -50 -38 13 (10) [6.4]
BA 38	48 17 -11 (145) [15.1] -48 -1 -13 (20) [7.4] -20 20 -36 (9) [6.9]
Middle Temporal Gyr.	
BA 21	-61 12 -28 (38) [13.6] 67 -1 -12 (36) [12.4]
BA 39	40 -60 9 (21) [6.9]
Inferior Temporal Gyr.	
BA 20	-59 -16 -16 (25) [6.3]
Transverse Temporal Gyrus	
BA 41	48 -21 12 (10) [7.4]
Fusiform Gyrus	
BA 20	-50 -30 -25 (75) [26] -61 -25 -27 (74) [12.7] 53 -3 -25 (31) [12.8] 44 -30 -22 (25) [9.6] 57 -40 -23 (14) [6]
BA 37	44 -53 -18 (38) [12] -46 -39 -13 (50) [18.9] 50 -53 -9 (40) [7.6]

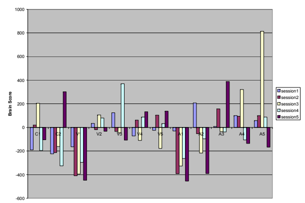
Parietal Lobe	*Positive X Y Z (cluster) [BSR]*
Inferior Parietal Lobule	
BA 40	-46 -36 28 (144) [17.6] -38 -29 36 (6) [8.1] -32 -37 40 (5) [5.9]
Precuneus	
BA 7	-14 -40 46 (23) [6.3]
Post-Central Gyrus	
BA 2	40 -32 27 (82) [9.7]
BA 3	61 -14 21 (97) [20]
BA 40	-51 -22 25 (477) [26]
BA 43	63 -7 13 (6) [6.2]

Results: Intersession Variability

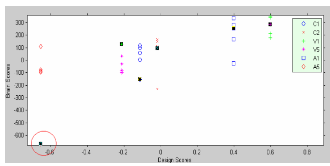
Figure 3(a-c). a) The mean and standard error of the weightings by epoch, reflecting the intersession variability. b) The session by session scores.



(a)


(b)

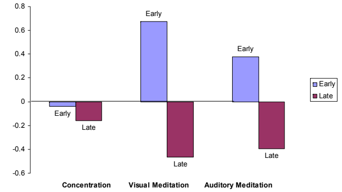
It appeared that there was a significant variability associated with the last phase of the auditory meditation. The last phase of the auditory meditation during the third session may have represented an outlier.



(c)

Results: Replication on Four Sessions

Figure 4. The correlational profile describes the correlation between the voxels and the task. For both visual and auditory meditation, the first and last two minutes are compared.

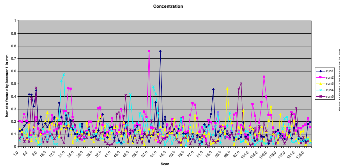


The analysis decoupled early and late phases of the auditory and visual meditation. Concentration did not correlate with this pattern. The brain regions (not shown) appeared very similar to the circuitry detected by the previous analysis with all the sessions.

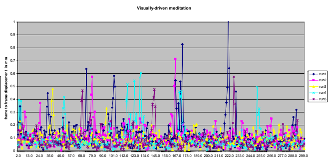
Results: Movement

Figure 5. Summary of frame to frame displacement by session and condition. (a) Movement during the Concentration condition.(b) Movement during the visually driven condition. (c) Movement during the auditorily driven condition.

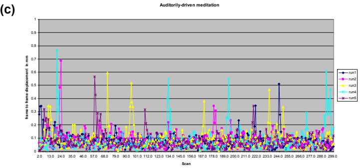
(a)



(b)



(c)



Occasional larger movements were present in all runs and conditions. Frame to frame movement was below 1 mm except for one spike of 1.4 mm in Run 1 during the visual condition. There was significantly less movement in auditory conditions than in the other conditions, and there was less movement in the later sessions than in the first two.

Conclusion

This study showed widespread patterns associated with meditative condition in the prefrontal, insula, cingulate, cerebellum, caudate, temporal and parietal regions. These areas have been previously associated with meditation (Lazar et al., 2000; Cahn and Polich, 2006).

The study showed that different perceived levels of absorption may be reflected in different brain patterns. Meditation based on visual and auditory verses appeared to be different from concentration. In meditation, the main difference was observed between early and late phases. The early (first two minutes) phases showed different activation levels from later (last two minute) phases.

Relative to concentration, the early phases of visual and auditory meditation created a widespread decrease in mean BOLD signal levels, gradually increasing to and slightly above the levels of concentration.

There may have been a certain level of variability among the different sessions; the unusually strong measures in the late auditory phase in the 3rd session was not reflected in head movement levels or other measurements.

The subject's breathing patterns may have accounted for part of the coherence patterns, and are currently under analysis.

Acknowledgements

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References:

Cahn BR, Polich J (2006): Meditation states and traits: EEG, ERP, and neuroimaging studies. *Psychol Bull* 132:180-211.

Lazar SW, Bush G, Gollub RL, Fricchione GL, Khalsa G, Benson H (2000): Functional brain mapping of the relaxation response and meditation. *Neuroreport* 11:1581-5.

McIntosh AR, Lobaugh NJ. Partial least squares analysis of neuroimaging data: applications and advances. Neuroimage 2004; 23 Suppl 1:S250-263