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Clinical paper

Brain activity in near-death experiencers during a meditative state☆

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ABSTRACT

Aim: To measure brain activity in near-death experiencers during a meditative state.
Methods: In two separate experiments, brain activity was measured with functional magnetic resonance imaging (fMRI) and electroencephalography (EEG) during a Meditation condition and a Control condition. In the Meditation condition, participants were asked to mentally visualize and emotionally connect with the "being of light" allegedly encountered during their "near-death experience". In the Control condition, participants were instructed to mentally visualize the light emitted by a lamp.
Results: In the fMRI experiment, significant loci of activation were found during the Meditation condition (compared to the Control condition) in the right brainstem, right lateral orbitofrontal cortex, right medial prefrontal cortex, right superior parietal lobule, left superior occipital gyrus, left anterior temporal pole, left inferior temporal gyrus, left anterior insula, left parahippocampal gyrus and left substantia nigra. In the EEG experiment, electrode sites showed greater theta power in the Meditation condition relative to the Control condition at FP1, F7, F3, T5, P3, O1, FP2, F4, F8, P4, Fz, Cz and Pz. In addition, higher alpha power was detected at FP1, F7, T3 and FP2, whereas higher gamma power was found at FP2, F7, T4 and T5.
Conclusions: The results indicate that the meditative state was associated with marked hemodynamic and neuroelectric changes in brain regions known to be involved either in positive emotions, visual mental imagery, attention or spiritual experiences.

1. Introduction

A "near-death experience" (NDE) refers to an altered state of consciousness usually occurring during an episode of unconsciousness resulting from a life-threatening condition (e.g., cardiac arrest, perioperative complications, intracerebral haemorrhage, septic or anaphylactic shock, near-drowning or asphyxia, electrocution, attempted suicide). Typically, a NDE includes a sense of detachment from the body (out-of-body experience), transcendence of space and time, seeing a tunnel, feelings of peace and bliss and an encounter with a "being of light" (often interpreted as a deity).[1] Improvements in resuscitation techniques have significantly increased the frequency of NDE. Recent studies indicate that near-death experiences (NDEs) are reported by 10–18% of cardiac arrest survivors.[2–4]

A number of biological theories have been proposed to explain the core features of a NDE. It has been advanced that the NDE is caused by cerebral anoxia,[5] cerebral hypoxia,[6] hypercarbia[7] or an abnormal stimulation of the temporal lobe involving neuronal hypersensitization.[8] It has also been suggested that the NDE results from a massive release of endorphins[9] or a marked liberation of glutamate accompanied by the blockade of NMDA receptors.[10] Further, a few non-biological theories have been propounded. For one of these theories, the NDE constitutes a psychological reaction to approaching death.[11] For another theory, the NDE is a form of transcendental state of consciousness in which mind and self-function independently from the unconscious body.[12]

NDE is often associated with life changing effects such as increased positive affect, sense of meaning in life, increased capacity for unconditional love and disappearance of fear of death.[1,13] There is some evidence that the encounter with a "being of light" is one of the components of the NDE that is most closely correlated with these major psychological changes.[13]

In the study reported here we recruited near-death experiencers (NDErs) who purportedly encountered a "being of light" during their NDE. These NDErs claim that since their NDE, they are able to mentally visualize and emotionally connect with this "being of light" during a state of meditation. In this context, the aim of this

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study was to measure – during such a meditative state – brain activity in these NDErs using functional magnetic resonance imaging (fMRI) and electroencephalography (EEG) (fMRI and EEG data were acquired separately). We hypothesized that the brain patterns measured during this spiritual type of meditation would show similarity to those noted in Carmelite nuns during another form of spiritual meditation,[14,15] given the relative phenomenological similarity between the two states. Specifically, we predicted that the meditative state in NDErs would be associated with increased blood oxygen level dependent (BOLD) activation in the temporal lobe, extra-striate visual cortex, inferior and superior parietal lobules, and limbic/paralimbic regions as well as greater theta and gamma power.

2. Methods

2.1. Participants

Participants were nine men and six women (mean age 47, s.e.m. = 12, range: 27–66 years) with no history of psychiatric, neurological or substance use disorders (according to self-reports). They were not taking any psychotropic drug at the time of scanning. Participants completed two self-report questionnaires a few weeks before the experiments. The NDE scale[16] was used to a measure the "depth" of the NDEs reported by the participants. This scale is a standardised 16-point questionnaire used to evaluate the core components of the NDE. A score of 7 or over is accepted as compatible with a NDE. The mean score on the NDE scale was 19 (s.e.m. = 5). The capacity to emotionally connect with the "being of light" on a regular basis during a meditative state was assessed with a numerical rating scale ranging from 0 (no capacity at all) to 5 (very high capacity). The mean score on this scale was 4.6 (s.e.m. = 0.7). Participants all gave written informed consent and the study was approved by the ethics committee of the Centre de Recherche de l'Institut Universitaire de Gériatrie de Montréal (CRIUGM).

2.2. FMRI experiment

BOLD signal changes were measured during a Meditation condition, a Control condition, and a Baseline condition (resting state, eyes closed). In the Meditation condition, participants were asked to mentally visualize (eyes closed) and emotionally connect with the "being of light" allegedly encountered during their NDE. In the Control condition, participants were instructed to mentally visualize (eyes closed) the light emitted by a lamp (all participants reported being able to generate visual mental images). A blocked-design paradigm was used. Control and Meditation blocks lasted for 1 min and were separated by resting periods (duration: 1 min). The sequence of blocks was as follows: Rest (R)–Control (C)–R–C–R–C–R–C–R–Meditation (M)–R–M–R–M–R–M.[14]

Echoplanar images (EPI) were acquired on a 3 T system (Magnetom Trio, Siemens Electric, Erlangen, Germany). Twenty-eight slices (5 mm thick, voxel size = 3.4 mm × 3.5 mm × 5 mm) were acquired every 2 s in an inclined axial plane. These T2* weighted functional images were acquired using an EPI pulse sequence (echo-space time = 0.8 ms, TE = 30 ms, Flip = 90°, FOV = 215 mm, Matrix = 64 × 64). Following functional scanning, high-resolution anatomical data were acquired using a gradient echo pulse sequence. Ear pad foam cushions surrounding the head of the participants and earplugs were used to significantly reduce perception of the noise generated by the MRI scanner.

Data were analyzed using Statistical Parametric Mapping software (SPM2). The images for all participants were spatially normalized into an MRI stereotactic space. Using a "random-effects model", paired Student's *t*-tests were performed to compare the brain activity associated with the Meditation and Control conditions. An *a priori* search strategy was used and a small volume correction was performed in the brain regions (ROIs) defined *a priori*. For this *a priori* search, a corrected probability threshold for multiple comparisons of $P < 0.05$ corrected was used. A whole-brain *post hoc* analysis was also carried out. For this analysis, a corrected probability threshold of $P < 0.005$ was utilized. Only clusters showing a spatial extent of at least 10 contiguous voxels were kept for image analysis.

2.3. EEG experiment

EEG activity was measured inside a dark, soundproof room (isolated acoustically and electromagnetically) during the same conditions (Meditation, Control, Baseline) as in the fMRI experiment. An infrared camera enabled the experimenters to observe the participants continually. Both Meditation and Control conditions lasted for 15 min while the Baseline condition lasted for 5 min. The experiment always began with the Baseline condition. The order of the Control and Meditation conditions was counterbalanced across participants.

EEG was recorded (Deymed Diagnostic, TruScan 32) from 19 scalp locations (Electro-cap International Inc.) – (FP1/FP2, F7/F8, F3/F4, FZ, T3/T4, C3/C4, CZ, P3/P4, T5/T6, PZ, O1/O2) – based on the International 10/20 System of electrode placement. A linked-ears reference montage was used. EEG data were acquired and amplified within a bandpass of 0.1–75 Hz (128 samples/s) with a 60-Hz Notch filter. EEG recordings were imported into the software Neuroguide (version 2.4), which calibrated EEG signals coming from the current amplifier. Each participant's EEG samples were plotted, visually examined and then edited to remove artifacts. Power spectral analysis was performed with a fast Fourier transform (FFT). Overall, absolute power (mV2) was computed in five frequency bands (delta: 1–4 Hz, theta: 4–8 Hz, alpha: 8–12 Hz, beta: 12–30 Hz, gamma: 30–40 Hz). EEG activity associated with the Meditation and Control conditions was compared with paired *t*-tests.

2.4. Self-report questionnaires

For both experiments, the degree to which participants thought having succeeded in both Meditation and Control conditions was measured using a numerical rating scale ranging from 0 (no success at all) to 5 (very high level of success). This scale was administered immediately at the end of these two conditions. Qualitative interviews were also conducted at the end of each experiment to obtain additional information regarding the nature of the subjective experiences during the Control and Meditation conditions.

3. Results

3.1. Self-report questionnaire data

In the fMRI experiment, the mean score in regard to the degree to which participants thought having succeeded was 3.6 (s.e.m. = 0.6) for the Meditation condition and 4.1 (s.e.m. = 0.9) for the Control condition. In the EEG experiment, the mean score was 3.8 (s.e.m. = 0.7) for the Meditation condition and 3.4 (s.e.m. = 0.7) for the Control condition. In the qualitative interviews, participants reported having felt an intense alteration of the state of consciousness as well as peace and bliss (a few participants shedded tears) during the Meditation condition (for both experiments). Participants also reported that they effectively experienced a feeling of connection with the "being of light" during the two experiments. Several participants reported having thought about their NDE during the meditative condition. As for the Control condition,

Table 1
Stereotaxic coordinates are derived from the human atlas of Talairach and Tournoux[40] and refer to medial–lateral position (x) relative to midline (positive = right), anterior–posterior position (y) relative to the anterior commissure (positive = anterior), and superior–inferior position (z) relative to the commissural line (positive = superior). Designation of Brodmann areas (BA) for cortical areas are also based on this atlas.

Brain regions	BA	Talairach coordinates			z value	Number of voxels
		x	y	z		
FMRI Meditation vs. Control						
L SOG	19	−36	−88	13	4.19	17
L ATP	38	−44	10	−23	4.08	43
R LOFC	47	36	27	−6	3.96	11
R SPL	7	17	−51	58	3.87	18
L PHG	36	−35	−22	−16	3.84	26
R Brainstem		2	−26	−12	3.45	80
L Substantia nigra		−7	−19	−11	3.27	11
L ITG	37	−57	−57	−7	3.06	10
R MPFC	10	8	54	10	3.03	40
L AI	13	−35	11	−4	3.02	21

AI: anterior insula; ATP: anterior temporal pole; SOG: superior occipital gyrus; ITG: inferior temporal gyrus; LOFC: lateral orbitofrontal cortex; MPFC: medial prefrontal cortex; PHG: parahippocampal gyrus; SPL: superior parietal lobule; L, left; R, right.

all participants reported to have been able to mentally visualize the light emitted by a lamp.

3.2. FMRI data

3.2.1. Meditation condition vs. Control condition

For the *a priori* search ($P < 0.05$ corrected), significant BOLD signal increases were found, in the right hemisphere (RH), in the brainstem, lateral orbitofrontal cortex (LOFC) (Brodmann area [BA] 47), medial prefrontal cortex (MPFC, BA 10) and superior parietal lobule (SPL, BA 7). In the left hemisphere (LH), significant BOLD signal increases were detected in the superior occipital gyrus (SOG, BA 19), anterior temporal pole (ATP, BA 38), inferior temporal gyrus (ITG, BA 37) and anterior insula (AI, BA 13). For the whole-brain *post hoc* analysis ($P < 0.005$), significant loci of activation were noted in the left parahippocampal gyrus (PHG, BA 36) and left substantia nigra (Table 1, Fig. 1).

3.2.2. Control condition vs. Meditation condition

The Control vs. Meditation contrast did not reveal any significant BOLD signal change.

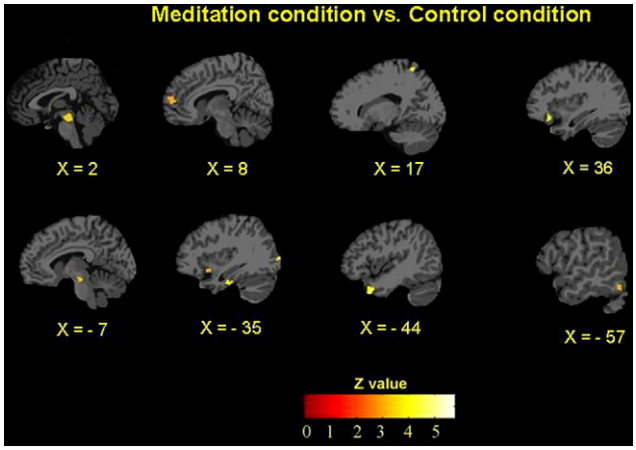

Fig. 1. FMRI activation maps for the Meditation condition vs. Control condition contrast. Images are sagittal sections for the data averaged across participants. Significant loci of activation were noted in the right brainstem, right MPFC, right SPL, right LOFC, left substantia nigra, left AI, left PHG, left SOG, left ATP and left ITG.

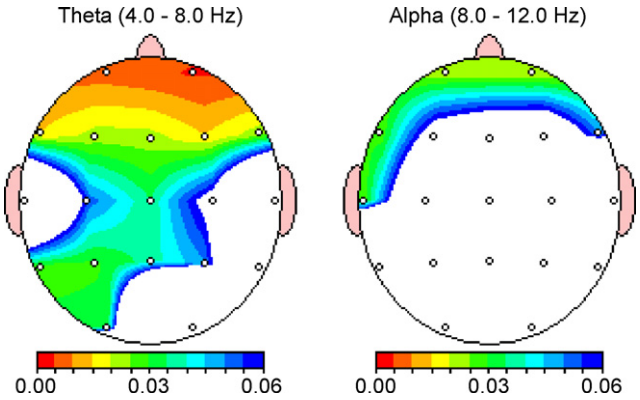

Fig. 2. EEG absolute power for the Meditation condition vs. Control condition contrast.

3.3. EEG data

3.3.1. Meditation condition vs. Control condition

Electrode sites showed greater theta power at FP1 ($P < 0.01$), F7 ($P < 0.05$), F3 ($P < 0.05$), T5 ($P < 0.05$), P3 ($P < 0.05$), O1 ($P < 0.05$), FP2 ($P < 0.01$), F4 ($P < 0.05$), F8 ($P < 0.05$), P4 ($P < 0.05$), Fz ($P < 0.05$), Cz ($P < 0.05$) and Pz ($P < 0.05$). Higher alpha power was detected at FP1 ($P < 0.05$), F7 ($P < 0.05$), T3 ($P < 0.05$) and FP2 ($P < 0.05$). In addition, electrode sites showed greater gamma power at FP2 ($P < 0.05$), F7 ($P < 0.05$), T4 ($P < 0.01$) and T5 ($P < 0.05$) (Fig. 2).

3.3.2. Control condition vs. Meditation condition

No significant EEG activity was measured for the Control vs. Meditation contrast.

4. Discussion

The meditative state was accompanied by significant hemodynamic and neuroelectric changes in various brain regions, including the temporal lobe. Religious/spiritual/mystical experiences (RSMEs) can occasionally be triggered by stimulation of this cerebral structure.[17] Based on this finding, it has been proposed that RSMEs are evoked by transient, electrical microseizures within this portion of the brain.[18] In line with this perspective, there is some clinical evidence indicating that RSMEs sometimes take place during ictal, peri-ictal, and post-ictal seizures associated with temporal lobe epilepsy (TLE).[19] Recently, we suggested that the right middle temporal lobe may be related with the impression of contacting a spiritual realm.[14] It is possible that the BOLD activation noted here in the left ITG (BA 37) during the Meditative condition was associated with the feeling of connection with the "being of light". This hypothesis implies that the various subdivisions of the temporal lobe can be functionally linked to RSMEs.

There is evidence that the extra-striate visual cortex is involved in visual mental imagery.[20] Neuroimaging and neuropsychological studies indicate that the SPL also plays a pivotal role in visual imagery.[21] Given this, it is arguable that the loci of activation found here in the left SOG (BA 19) and right SPL (BA 7) were connected to the mental visualization of the "being of light" during the Meditation condition. In keeping with this, activation of the right SPL has been measured during a form of meditation involving visual imagery.[22] Since the Control condition consisted in the mental visualization of a light emitted by a lamp, it is likely that the emotional charge of the visual mental images in the Meditation condition led to a more intense activation of the visual system relative to the Control condition.

Regarding the emotional dimension of the experiences reported by the participants in the Meditative condition, we posit that the

loci of activation measured in the brainstem, substantia nigra, AI, ATP, LOFC and MPFC were related to distinct aspects of emotion processing. There is some empirical support to the view that certain brainstem nuclei map the organism's internal state during emotion.[23] Therefore, it is tenable that the activation in the right brainstem was linked to the somatovisceral changes associated with the feelings of peace and bliss. As for the AI (BA 13), this region contains a topographical representation of inputs from visceral and sensory areas and is proposed to integrate representations of external sensory experience and internal somatic state. Activation of the AI has been found in previous neuroimaging studies of emotion and appears to support a representation of somatic and visceral responses accessible to consciousness.[24] It is plausible that the left AI noted here was connected with the representation of the somatovisceral reactions related to the feelings of the participants. Of note, we found activation in this region in Carmelite nuns during a mystical state.[14] With respect to the substantia nigra, this cerebral structure constitutes a major component of the mammalian brain's "reward system".[25] It appears credible that the activation in the left substantia nigra reflected the rewarding nature of the emotional experiences felt during the meditative state.

The ATP (BA 38) is a paralimbic region that receives inputs from unimodal and heteromodal sensory regions, as well as limbic inputs. The function of this cortical region is not yet well known. Activation of the ATP has been reported during various types of emotional responses. The ATP appears to bind highly processed perceptual inputs to visceral emotional responses.[26] In this study, the left ATP activation was perhaps related with the binding of mental visual images to the visceral responses associated with the positive feelings. In regard to the LOFC (BA 47), there is some evidence that this prefrontal area, which receives sensory as well as limbic inputs, is implicated in the combination of viscerosensory information with affective signals.[27] The right LOFC activation noted here was possibly correlated to the integration of visceral changes with the peaceful and blissful feelings experienced by the participants. In addition, we propose that the right MPFC activation (BA 10) was linked with conscious awareness of those feelings. This hypothesis is based on the results of functional neuroimaging studies suggesting that the MPFC is involved in the metacognitive representation of one's own emotional state.[28]

Interestingly, an activation of the left PHG (BA 36) was found in the Meditation condition. This cortical region has been shown to play an important role in memory retrieval.[29] Several participants reported having thought about their NDE during the meditative condition. Consequently it is possible that the PHG activation accompanied the retrieval of memories linked to the NDEs of the participants.

Increases in alpha power have been measured when meditators are evaluated during meditating compared with various control conditions.[30,31] It has been suggested[32] that enhanced alpha synchronization over frontal regions reflects 'switching off' mechanisms of external attention. We submit that the higher alpha power detected over frontal and left temporal regions during the Meditation condition is an index of reduced cortical arousal associated with a relaxation response.

Previous work[33,34] has revealed that the gamma frequency band represents an important feature of EEG activity during meditation. It has been advanced that the gamma frequency band plays a central role in brain mechanisms underlying conscious experience[35] and states of consciousness.[33] Given the various lines of evidence suggesting an involvement of the temporal lobe in RSMEs,[17–19] it is conceivable that the increased gamma activity over the temporal region was related with the spiritual aspect of the meditative state. In line with this, we recently found in Carmelite nuns that enhanced gamma-band activity in the temporal lobe was associated with the subjective impression of union with God.[15] In other respects, a number of studies emphasize the role of evoked gamma band activity for attentional processing.[36,37] It is tenable that the gamma activity found here over frontal areas reflected focused attention for the contents of the mental experience (e.g., visual mental images, emotional feelings) during the Meditation condition.

Theta power increases during meditation have been reported in several studies.[22,30] It has been previously demonstrated that emotionally positive "blissful" experience during Sahaja Yoga meditation is accompanied by increased frontal theta activity.[30] It is thus credible that enhanced theta power over frontal regions was related with the feelings of peace and bliss. As for the increased theta power over the parietal regions, we propose that it was associated with visual mental images during the meditative state, based on the evidence suggesting an implication of parietal theta activity in visual mental imagery.[38] It is likely that the occipital theta activity was also linked with visual imagery. Last, since theta band activity in the temporal lobe appears to play a role in declarative memory retrieval,[39] the increased theta power over the left temporal region was perhaps connected with the retrieval of memories associated with the NDEs of the participants.

5. Conclusions

The results indicate that the meditative state in NDErs was associated with prominent hemodynamic and neuroelectric changes in brain regions known to be implicated in either positive emotions, visual mental imagery, attention or spiritual experiences. Interestingly, these changes exhibit a notable similarity with those found in Carmelite nuns during another form of spiritual meditation.[14,15]

Conflict of interest

The contributing authors declare no conflict of interest.

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