



Contents lists available at ScienceDirect

Consciousness and Cognition

journal homepage: www.elsevier.com/locate/concog

Mapping complex mind states: EEG neural substrates of meditative unified compassionate awareness



Poppy L.A. Schoenberg^{a,d,*}, Andrea Ruf^a, John Churchill^c, Daniel P. Brown^b,
Judson A. Brewer^a

^a University of Massachusetts Medical School, Center for Mindfulness, Department of Medicine, Division of Preventive and Behavioral Medicine, Shrewsbury, MA, USA

^b Harvard Medical School, Beth Israel-Deaconess Medical Center, Department of Psychiatry, Boston, MA, USA

^c William James College, Department of Clinical Psychology, Newton, MA, USA

^d Vanderbilt University Medical Center, Osher Center for Integrative Medicine, Nashville, TN, USA

A B S T R A C T

Specific mental training cultivates diminished self-reference, encompassing non-duality, emptiness, awakened-awareness, and compassionate experiences. We aimed to elucidate the neural substrates of four distinct, interdependent *Essence-of-Mind* states: (1) timelessness, (2) non-preference, non-duality, non-conceptualization, (3) the view of luminosity and limitlessness, (4) unified compassionate experience of oneness (stable awakened-awareness). EEG data were collected from 30 advanced meditators concomitant to eyes-open/eyes-closed resting baseline, followed by 60-min of instructed practice. Alpha, beta, and gamma, frequency-spatial EEG-dimensions were analyzed. The results revealed that compared to baseline, current density across frequencies significantly decreased upon meditation onset in self-referential, and executive-control regions. During meditation, gamma-band current density significantly increased from state-1 compared to state-4, within the ACC, precuneus, and superior parietal lobule, whereas beta-band activity increased within the insula. These findings suggest a dissociation between brain regions regulating self-referential vs. executive-control processing, during non-dual, compassionate states, characterized by brilliantly awake awareness, free from conceptual thought and “doing”.

1. Introduction

The terrain of the mind is central to our everyday experience, or subjective ‘reality’. Refining one’s relationship to and understanding of the mind therefore appears highly apt, not only as a method to attain ‘wisdom’ (experiential knowledge and awareness), albeit to also maintain mental stability, clarity, and wellbeing. For example, mental training developed through meditative practices has been shown to enact beneficial effects upon attention regulation (see review by Cahn & Polich, 2006; Carmody, 2009), emotion regulation (Farb, Anderson, & Segal, 2012; Lutz, Dunne, & Davidson, 2007; Lutz, Slagter, Dunne, & Davidson, 2008), self-awareness (Farb et al., 2007), neuroplasticity (see reviews, Fox et al., 2014; Treadway & Lazar, 2010), and therapeutic pathways for an array of clinical populations (see reviews, Eisendrath, 2016; Rubia, 2009; Simkin & Black, 2014; Vollestad, Nielsen, & Nielsen, 2012).

Various contemplative traditions assert that refinement of the understanding (insight) of mind (one’s mental states) can be ascertained via specific mental training, including two closely related Indo-Tibetan essence-of-mind tradition lineages: Mahamudra

* Corresponding author at: Vanderbilt University Medical Center, Osher Center for Integrative Medicine, 3401 West End Ave., Suite 380, Nashville, TN 37203, USA.
E-mail address: poppy.schoenberg@vanderbilt.edu (P.L.A. Schoenberg).

<https://doi.org/10.1016/j.concog.2017.11.003>

Received 15 June 2017; Received in revised form 9 November 2017; Accepted 11 November 2017

Available online 21 November 2017

1053-8100/ © 2017 Elsevier Inc. All rights reserved.

and rDzogs-Chen [Great Contemplation]. The etymological Sanskrit root of the word “Mahamudra” means the “great seal”, reflecting the foundational premise of the technique that all that exists in the conditioned world is united by the same “seal” – namely, that of ‘ultimate reality’. rDzogs-Chen [Great Contemplation] meditation refers to the set of practices that introduce and stabilize awakening and bring it to “pinnacle” experience (or completion). Within this framework, ‘ultimate reality’ is essentially characterized by the constructs of ‘emptiness’, ‘non-duality’, ‘spaciousness’, and ‘vividness’; such that the intrinsic insubstantiality (emptiness) of all (internal and external) phenomena is part of a unified (non-dual), vast (spacious) field that constitutes a brilliantly vibrant dynamically ever-changing (vivid) objective reality. Importantly, non-duality refers to the absence of separation between oneself and the rest of one’s world or subjective reality, and awakening refers to the absence of localization of individual consciousness so as to operate from an experiential mode of “being” the unbounded wholeness (of objective reality). Ergo, to practice essence meditation (Mahamudra and/or rDzogs-Chen) is to refine the mental capacities to their full clarity vis-à-vis emptiness, non-duality, spaciousness, and vividness, not in a uni-leveled intellectual sense, but from a direct experiential awareness that is completely free of ‘conditioned’ mechanisms and responses of self and other.

A principal drive of integrative contemplative neuroscience is to illuminate the neurobiological substrates associated with such states of mind. Theoretically, meditation comprises a myriad of complex attention and emotion regulation pathways. As such, in order to optimally investigate meditative practices, the extant research purview has primarily subsumed mental training into two broad domains: concentration (focused, fixed-point attention), and insight development (open-monitoring, non-preferential awareness) (Lutz et al., 2008). The former, focused attention, has been associated with dissociable cortical systems pertaining to selective and sustained attention, in addition to the interplay with conflict monitoring processes associated with attention switching and saliency (Lutz et al., 2008; Manna et al., 2010). The latter, open-monitoring, appears to bridge with cortical systems associated with awareness and vigilance regulation (Lutz et al., 2008; Schoenberg et al., 2014). The essence-of-mind Indo-Tibetan meditative techniques switch between both focused attention and open-monitoring. Consequently, one aim of the present study was to examine the neurophysiological substrates of these dynamics in alignment with structured guided practice (Bru rGyal Ba, 2016). This allowed for a robust methodological approach, whereby the examination of neurophysiological changes could be mapped to specific internal processes that practitioners were engaging with at certain epochs within the practice, consistently across all participants.

Extant studies mapping brain morphology differences associated with meditation practice purport the clustering of specific regions associated with such mental training (Fox et al., 2014). These include; (a) regions associated with visceral interoceptive awareness, such as the insular cortex – one of the most well-replicated findings in meditation fMRI research (Farb, Segal, & Anderson, 2013; Farb et al., 2007; Fox et al., 2014; Gard et al., 2012; Manna et al., 2010; Monti et al., 2012; Wang et al., 2011; Zeidan et al., 2011); (b) areas related to introspection and metacognition, such as the prefrontal cortex/PFC, specifically the rostrolateral PFC/BA 10 (Fox et al., 2014; Lazar et al., 2005; Manna et al., 2010; Vestergaard-Poulsen et al., 2009); (c) areas associated with somatosensory processing (i.e. pain, proprioception, tactile information), such as the somatomotor cortices (Fox et al., 2014; Kang et al., 2013; Lazar et al., 2005; Luders et al., 2012); (d) self-referential processing regions implicated with ‘default-mode’ function, such as the precuneus/BA 7 (Baerentsen et al., 2010; Fox et al., 2014; Garrison, Zeffiro, Scheinost, Constable, & Brewer, 2015; Ives-Deliperi, Solms, & Meintjes, 2011; Manna et al., 2010); and the executive hub of the brain, the Anterior Cingulate Cortex/ACC, predominantly involved in self-regulation – another well replicated finding within the meditation morphometric research base (Dickenson, Berkman, Arch, & Lieberman, 2012; Hölzel et al., 2007; Manna et al., 2010; Orme-Johnson, Schneider, Son, Nidich, & Cho, 2006; Xue, Tang, & Posner, 2011; Zeidan et al., 2011; Fox et al., 2014). Moreover, Posterior Cingulate Cortex/PCC deactivation has been found in experienced meditators during various techniques within various types of practice (Brewer et al., 2011; Garrison et al., 2015). The PCC comprises a main hub of the Default Mode Network (DMN), in conjunction with the medial PFC as the other central node, wherein PCC deactivation has been found at both trait and state levels, interpreted as a neural mechanism in the reduction of self-referential processing in meditators (Brewer et al., 2011). Decreased connectivity between the PCC and medial PFC/ACC regions have been related to increased mindfulness (Doll, Hölzel, Boucard, Wohlschläger, & Sorg, 2015; Hasenkamp & Barsalou, 2012). Relatedly, EEG functional connectivity experiments have reported DMN decoupling during mindfulness and subsequent diminished self-referential processing (Berkovich-Ohana, Glicksohn, & Goldstein, 2011).

Here we present the first neurophysiological quantification of discrete mental states during forms of Indo-Tibetan essence-of-mind practice using electroencephalography (EEG). The paramount ‘outcome’ of essence practice is to engage deeply in an experience of shared humanity and non-self-referential (non-dual) unification, from a perspective of non-localized brilliantly awake, compassionate selflessness, described as ‘awakened awareness’. Previous EEG studies examining power and synchrony measures suggest that EEG bands in the higher frequency range (beta, gamma) are specifically associated with experiences of selflessness (Dor-Ziderman, Berkovich-Ohana, Glicksohn, & Goldstein, 2013; Lehmann et al., 2001), non-judgmental awareness (Cahn, Delorme, & Polich, 2010), self- ‘disintegrative’ equanimous states (Schoenberg & Barendregt, 2016), and loving-kindness compassionate practice (Lutz, Greischar, Rawlings, Ricard, & Davidson, 2004). A large portion of the EEG research base into mental training has also supported alpha band involvement, including increased alpha coherence and synchrony (Hebert, Lehmann, Tan, Travis, & Arenander, 2005; Murata et al., 2004; Travis et al., 2010), and alpha modulation connected to somatosensory attention and mindfulness (Kerr, Sacchet, Lazar, Moore, & Jones, 2013; Kerr et al., 2011), in addition to alpha power reduction during perceptions of inner light during Zen meditation (Lo, Huang, & Chang, 2003). In sum, such evidence provided the rationale to focus upon the alpha, beta, and gamma, frequency ranges within the present study.

Furthermore, the EEG signal represents direct neural activity that, alongside developments in existing signal processing techniques, can be decomposed into time, frequency, and spatial dimensions. Our empirical approach targeted time-frequency-spatial information within the EEG signal via the application of a functional brain imaging method called Low Resolution Brain Electromagnetic Tomography Analysis (LORETA) (Pascual-Marqui, Esslen, Kochi, & Lehmann, 2002), to discrete frequency

bandwidths (aforementioned alpha, beta, gamma), allowing for the elucidation of meditation-related EEG current density changes within distinct brain regions at discrete time windows. In light of previous findings, our analytical approach focused upon discrete experiential states practiced during Indo-Tibetan essence-of-mind meditation, such as emptiness, non-duality, and awakened awareness, by measuring modulations in current density magnitude within neural regions involved in self-regulation (ACC, and DMN regions), introspection (DMN regions, specifically PFC), metacognition (PFC), and interoceptive awareness (parietal streams). Based on the extant evidence, we utilized PCC activity as a control condition, hypothesizing that reduced PCC current density would be observed during meditative state(s) compared to baseline. Moreover, we predicted that across meditative states (from the first to the last state), current density would increase in regions of the executive function network, and specifically fronto-parietal circuitry, based on evidence that a fronto-parietal control system comprising an array of flexible hubs regulates distributed processing systems modulated by task demands (Cole, Repovš, & Anticevic, 2014; Cole et al., 2013). A central limitation regarding research on the neuroscience of meditation has been the restriction to studying meditation methods, like focused attention and open-monitoring, rather than outcomes. As such, a driving contribution of this study focuses on the neuroscience of awakening, specifically with regard to discovering the neuro-circuitry associated with ‘awakened awareness’, compared with (what is termed in the essence traditions) ‘ordinary awareness’.

2. Methods

2.1. Sample

Thirty advanced meditators practicing the Indo-Tibetan essence of mind meditations participated. Due to a technical issue with the EEG signal, the dataset of one meditator was not usable, thus, is not included in the statistical analyses. Demographics of the final statistical sample were $N = 29$, \bar{X} age = 53.7 yrs. ($\sigma = 11.7$); 14 female/15 male. In contrast to using number of hours or years of practice, meditation capacity and advancement was rated by two independent teachers of the method (including the teacher who provided the meditation guidance within the experiment), via a 0–10 scaling system. Those meditators who received an *a priori* determined score of > 6 for each meditation state by both teachers, were invited to participate (mean [S.D.] global score: 8.09 [0.69]). The primary eligibility requirement was that each subject could set up the practice and shift from ordinary mind to awakened awareness, albeit was not always in awakened awareness. People with any previous or current formally diagnosed psychiatric disorders, any previous or current substance abuse and/or addiction, were excluded. Participants were reimbursed \$30 for their time, and in some cases, financial assistance for travel to and from the laboratory was offered when required (i.e. out-of-state participants). This study was ethically approved by the UMASS Medical School IRB.

2.2. The pointing out way in the Indo-Tibetan essence-of-mind traditions

The essence meditation path instructions for pointing out the experience of an awakened mind are passed directly from teacher to student via highly detailed and specific teacher-led guidance, wherein the aim is to address any obstacles or challenges within individual meditation practice alongside an understanding of universality and immediacy within the practice; thus, the ‘pointing out way’ method (Brown, 2006; Bru rGyal Ba, 2016). Technically, the method involves the alternation of eye-open and eyes-closed during meditative practice. Experientially, the ultimate “aim” of the essence of mind technique is to experience a brilliantly awake, limitless, non-localized unified (non-dualistic) state of awakened awareness and compassion. This is “achieved” by progressing through four discrete yet interdependent experiential states as follows; (1) *Ocean and Waves*: experiencing timelessness, (2) *Automatic Emptiness and its refinement as the “Natural State”*: automatically experiencing the emptiness of all phenomena, in a state beyond all conceptualization and “doing” leading to a natural state of non-duality and non-preference, (3) *Lion’s Gaze*: utilization of the boundless visual field so to appreciate the natural luminosity and limitlessness of all experience, and (4) *Stabilized Awakening*: operating out of ‘being’ the unbounded wholeness of limitless, non-localized, brilliantly clear awakened awareness, culminating in a unified compassionately-based state of oneness. A brief overview of the different states are as follows:

2.2.1. Ocean & waves (state 1)

First, the practitioner refines one’s awareness so as to operate from a perspective of awareness beyond time and spatialization wherein phenomena of consciousness are experienced as an undulating timeless, ocean-like awareness within which events come and go like waves arising and passing in an ocean. Events are thus viewed from the vantage point of a changeless, vast awareness. Awareness of the field ‘opens up’. Once this high resolution perception is stable the practitioner recalibrates once again to a coarse-grain perception.

2.2.2. Automatic emptiness to natural state (state 2)

Second, the practitioner refines one’s relationship to the emptiness of all phenomena, wherein experience of the constructs of non-doing and non-conceptualization remain the central quality of the meditation. Any residual tendencies to “do” anything or to conceptualize about state or outcome are immediately expressed as ‘empty’ in such a way that neither doing anything nor conceptualizing can obscure the direct manifestation of awakened awareness. At this point, subject/object duality also disappears, and the realization of emptiness is spontaneous and automatic.

2.2.3. *Lion's Gaze (state 3)*

Third, the aim is now to set up the optimal 'view' (termed 'Lion's Gaze; or like a child viewing a temple taking in everything all at once and nothing in particular) for stabilized awakened awareness (state 4). In this state utilization of the entire, limitless visual field ensues so to envelop and transmute one's awareness into the totality of the global field. This may be recognized via two pathways; (a) via focusing on the non-localization of the limitless infinity of the field, and (b) via identifying the lucidity or brightness of the field of awareness. Both pathways culminate in an appreciation of the ultimate luminosity and limitlessness of experience.

2.2.4. *Stabilized awakening (state 4)*

At the stage of stabilized awakening (state 4), any residue of self-reference and localization dissipates, wherein the self-referential and localization of individual consciousness fully shifts to the limitlessness of lucid awakened awareness. This is considered a shift from 'ordinary mind' to 'awakened mind', within which this unbounded wholeness, unification, interconnection, and its expression as compassion pervades consciousness. The focus of the field spans out, from focusing primarily upon the visual field, towards all possible streams of perception, wherein phenomena are lively, vibrant, and indeterminate. Here, the practitioner works to stabilize the clarity (awakened) of awareness, to experience the shift from ordinary to awakened mind more frequently, for longer duration, and more immediately.

2.3. *Experimental procedure*

Meditators with scores of > 6 via teacher advancement ratings, and who agreed to participate, then followed an informed consent procedure. Prior to coming into the EEG laboratory for the recording, participants were sent guidance recordings of the discrete states on compact disk (CDs). They were instructed to practice with the CDs at home preceding the research session so to be fully familiar with the pacing and instruction of the meditation procedure once in the laboratory. As a check on the integrity of meditation practice, they were further asked to provide the experimenter with a written description ("in their own words") of their subjective personal experience of the discrete states. As an aid, the following prompts regarding what domains to describe were offered; (a) the nature of their awareness, (b) the field of experience, and (c) any phenomena that arose within the field of experience. The descriptions were to primarily ensure meditators had experienced the discrete states, and had stabilized during the meditation session within the laboratory setting. Feedback descriptions from meditators confirmed the general uniformity of their experiences.

Experimental EEG recording sessions were conducted at the UMASS Medical School, Center for Mindfulness. Meditators could assume whichever posture most suited them for the duration of the experimental session (some choosing to sit on a meditation cushion, others on a padded arm-chair). All instructions were shown to participants visually on a flat-panel 22" monitor within the recording room, and verified verbally by the experimenter. Sessions began with a standard 6-min recording of 3-min eyes open (EO) followed by 3-min eyes closed (EC) baseline. This was followed by the 1-h meditation session, comprising four blocks (one per state) of 5-min audio guided meditation followed by 10-min of silence in which participants self-stabilized meditation within that state. Progress through the four discrete states involved periods of eyes-closed and eyes-open instruction-guided meditation, thus ensuring empirical homogeneity. Meditators were given a response box which they could hold or place near them, however suited them. They were instructed to press the button whenever they "trusted" and simply "knew" that they had stabilized within the state during the 5-min audio guidance. Part of the teacher rating procedure during recruitment was to ensure invited participants would be able to stabilize within the 5-min guidance epoch of a given state. Participants were also instructed only to do this if it would not interfere with their meditation. If a meditator did not use the button response-box during the 5-min guidance epochs, the experimenter clarified retrospectively whether they had stabilized for every state at the end of the 1-h sitting practice. To note, all meditators reported stabilizing effectively during their meditation. Afterwards the experimenter asked the practitioners to rate their depth and stability of the 1-h meditation via a 0–10 scale, in addition to prompting practitioners to report their specific meditation experience within the laboratory, so to ensure experimental fidelity.

2.3.1. *Signal recording and processing*

EEG data were acquired using ActiView 7.1 software linked to a BioSemi Active Two high-density 128-channel active electrode system (www.biosemi.com). The Common Mode Sense (CMS) active electrode and Driven Right Leg (DRL) passive electrode grounding feedback loop set-up, referenced to the average of all electrodes (average REF) was used. Vertical and horizontal ocular activity was calculated by bipolar derivations of electrooculogram (EOG) signals recorded above and below the right eye (vEOG), and 1 cm to the outer canthi of each eye (hEOG). Impedance was maintained $< 30 \text{ K}\Omega$. Electrical signal was continuously sampled at a digitization rate of 2048 Hz, and online band-pass filtered between 0.16–100 Hz.

EEG data analysis was conducted using Brain Vision Analyzer 2.0.2. Data were filtered between 0.05 and 66 Hz (12-dB/octave slope), via zero-phase shift band-pass (IIR Butterworth) and 60 Hz notch filters. Ocular artefacts were corrected via standard regression methods (Gratton, Coles, & Donchin, 1983). Data were then Butterworth filtered into the following frequency bandwidths: alpha (8–12 Hz), beta (13–30 Hz), gamma-1 (30–45 Hz), gamma-2 (45–60 Hz).

Data were initially segmented depending on dataset type/condition: (1) into 2.5-min (150,000 ms) epochs for EO vs. EC with the baseline data (tapered 15,000 ms each end of the 3-min EO/EC epoch), and (2) into 10-min (600,000 ms) time-windows per meditation state; *Ocean & Waves* (S1), *Automatic Emptiness to Natural State* (S2), *Lion's Gaze* (S3), and *Stabilized Awakening* (S4), for the meditation data. For (2) (meditation state analysis), the 5-min guidance audio recording time-windows preceding each meditation state, were not included in the signal analysis. Following condition segmentation, data were further segmented into 2-s epochs (75 bins for baseline data, and 300 bins per meditation state, approx.). Artefact rejection removed electromyographic activity and/or

amplifier saturation and drifting, based on voltages lower than 0.01 μV , and those exceeding $\pm 50 \mu\text{V}$. The signal was carefully scanned where these parameters may have not have identified all artefact, and any remaining artefact was subsequently manually removed. Averages per condition (i.e. EO/EC, and S1-S2-S3-S4) were finally calculated for subsequent source localization analysis.

2.3.2. Low resolution brain electromagnetic tomography analysis (LORETA)

Source localization was implemented using the original LORETA (Pascual-Marqui, Michel, & Lehmann, 1994), a well-established method (Pascual-Marqui et al., 2002) which estimates the three-dimensional intracerebral current density distribution within the source space. LORETA spatial resolution is approximately 7 mm within the millisecond time domain. Theoretically, direct neural activity is inferred from electrical potentials at electrode sites on the scalp surface, wherein LORETA estimates the source location and dynamics of the underlying neural generators. This technique solves the inverse problem (Grech et al., 2008) via computing the instantaneous, three-dimensional, discrete linear solution consisting of the smoothest of all possible neural current density distributions within the source space (Pascual-Marqui et al., 1994). The magnitude of the current density vector ($\mu\text{A}/\text{mm}^2$) was extracted, representing the mean of all current density vectors within a specified region of interest (ROI) for a single time point. The in-built transform within Brain Vision Analyzer 2.0.2 utilises a three-shell spherical head model registered to the standardized stereotactic space available as digitized MRI data from the Brain Imaging Centre (Montreal Neurological Institute, MN1305).

Whole brain LORETA (including the full 47 Brodmann Area/BA coordinates) was performed. Analyses were then examined by lobe, to ascertain whether any significant changes in whole brain analyses represented global current density change, or were specific to particular lobar. Separately, we further examined specific *a priori* defined ROIs as follows: (i) DMN (defined by Buckner, Andrews-Hanna, & Schacter, 2008) [BAs: 7, 10, 23, 25, 31, 32]; (ii) mvPFC [BAs: 10, 25, 32]; (iii) precuneus [BA 7]; (iv) PCC [BAs: 23, 31 and by LORETA estimated gyri]; (v) Anterior Cingulate Cortex/ACC [BAs: 24, 32, 33]; (vi) ventral ACC/vACC [BA 32]; (vii) vACC [BA 33]; dorsal ACC/dACC [BA 24]; (viii) Insula [LORETA estimated gyri]; and (ix) Inferior + Superior Parietal Lobules [LORETA estimated regions]. To ensure the systematization of any observed findings, this analysis break-down approach was based upon the premise that any changes in specific ROIs would be in alignment with lobar changes. This would also be a method to ensure strength of energy change within specific ROIs, since if a change in lobar was observed but none in the associated ROI of that lobar region, then one could infer dissipated global change rather than acute energy dispersion.

2.3.3. Statistical analyses

Current density vector magnitude values were not normally distributed. Albeit, normalization was not carried out since important information within the data may be lost. Rather, non-parametric Friedman tests were utilized to compare any changes in mean current density vector magnitude values across the four states (S1, S2, S3, S4). Where Friedman Q (or χ^2) was significant, post hoc Wilcoxon Signed-Ranks tests further examined the direction and relationship within the findings. Effect sizes for the Wilcoxon Signed-Ranks tests were calculated as $r = z/\sqrt{N}$, where N is the total number of observations on which the Wilcoxon z-score is determined. Effect size r scores are reported, where 0.1 = small, 0.3 = medium, and 0.5 = large, effect sizes (Fritz, Morris, & Richler, 2012). Based on the statistical tests conducted and number of multiple tests applied, the Bonferroni technique was utilized to correct for multiple comparisons.

3. Results

3.1. Baseline to meditation state #1 (S1) comparison

Analyses showed that upon entering into the first meditative state, there was a marked drop in current density magnitude when compared to the baseline control condition, across examined α , β , and γ bandwidths. The significant reduction in current density across the examined frequency bands and ROIs remained at meditation State 4 (S4) compared to baseline measures. For readability,

Table 1
Friedman test results: Baseline to Meditation State 1 (S1) comparisons in current density vector ($\mu\text{A}/\text{mm}^2$) change.

ROI	Alpha (8–12 Hz)		Beta (13–30 Hz)		Gamma-1 (30–45 Hz)		Gamma-2 (45–60 Hz)	
	Friedman Q (χ^2)	p value	Friedman Q (χ^2)	p value	Friedman Q (χ^2)	p value	Friedman Q (χ^2)	p value
DMN (BA: 7, 10, 23, 25, 31, 32)	38.104	< .0001	33.257	< .0001	27.379	< .0001	29.221	< .0001
mvPFC	43.931	< .0001						
ACC (BA: 24, 32, 33)	41.061	< .0001	38.386	< .0001	32.678	< .0001	32.887	< .0001
dACC (BA 24)	40.828	< .0001	38.104	< .0001	35.034	< .0001	35.704	< .0001
vACC (BA 32)	38.104	< .0001	37.724	< .0001	29.862	< .0001	29.263	< .0001
vACC (BA 33)	41.061	< .0001	38.138	< .0001	32.483	< .0001	33.469	< .0001
Insula	43.770	< .0001	32.678	< .0001	28.281	< .0001	28.207	< .0001
Precuneus	39.565	< .0001	38.138	< .0001	30.070	< .0001	28.500	< .0001
PCC	40.621	< .0001	35.579	< .0001	35.860	< .0001	35.704	< .0001
Superior parietal lobule	43.931	< .0001	35.579	< .0001	33.754	< .0001	34.316	< .0001
Inferior parietal lobule	37.724	< .0001	38.386	< .0001	27.793	< .0001	29.965	< .0001

To note: meditation state #4 current density remained significantly attenuated compared to baseline measures across examined frequency bands and ROIs.

Table 2
Current density vector ($\mu\text{A}/\text{mm}^2$) values ($\times 10^{-4}$) for baseline control and meditation states.

ROI	Alpha (8–12 Hz)				Beta (13–30 Hz)				Gamma-1 (30–45 Hz)				Gamma-2 (45–60 Hz)			
	S1		S4		S1		S4		S1		S4		S1		S4	
	BL1	EO	BL1	EO	BL1	EO	BL1	EO	BL1	EO	BL1	EO	BL1	EO	BL1	EO
<i>DMN (BA: 7, 10, 23, 25, 31, 32)</i>	1.01 (0.5)	1.02 (0.5)	0.54 (0.2)	0.57 (0.3)	1.18 (0.5)	1.15 (0.5)	0.66 (0.3)	0.77 (0.6)	0.88 (0.4)	0.82 (0.4)	0.48 (0.3)	0.60 (0.5)	0.74 (0.4)	0.68 (0.3)	0.39 (0.2)	0.51 (0.4)
<i>mPPC</i>	0.84 (0.4)	0.82 (0.5)	0.45 (0.2)	0.49 (0.3)	0.99 (0.5)	0.96 (0.5)	0.56 (0.3)	0.64 (0.5)	0.77 (0.4)	0.72 (0.3)	0.41 (0.2)	0.50 (0.5)	0.67 (0.3)	0.62 (0.3)	0.34 (0.2)	0.42 (0.4)
<i>ACC (BA: 24, 32, 33)</i>	2.43 (1.1)	2.46 (1.1)	1.28 (0.5)	1.31 (0.6)	2.79 (1.2)	2.74 (1.2)	1.54 (0.8)	1.74 (1.1)	2.05 (0.9)	1.91 (0.8)	1.10 (0.6)	1.32 (0.9)	1.72 (0.8)	1.59 (0.8)	0.89 (0.5)	1.09 (0.8)
<i>dACC (BA 24)</i>	3.36 (1.5)	3.40 (1.5)	1.77 (0.7)	1.80 (0.8)	3.84 (1.7)	3.78 (1.6)	2.13 (1.0)	2.38 (1.4)	2.82 (1.2)	2.65 (1.1)	1.51 (0.8)	1.80 (1.3)	2.38 (1.1)	2.20 (1.0)	1.22 (0.7)	1.49 (1.1)
<i>vACC (BA 32)</i>	1.61 (0.8)	1.63 (0.8)	0.85 (0.4)	0.89 (0.4)	1.88 (0.9)	1.82 (0.8)	1.04 (0.6)	1.22 (0.8)	1.40 (0.7)	1.39 (0.6)	0.76 (0.5)	0.94 (0.8)	1.18 (0.6)	1.08 (0.6)	0.62 (0.4)	0.79 (0.6)
<i>vACC (BA 33)</i>	2.20 (1.0)	2.24 (1.0)	1.15 (0.5)	1.18 (0.5)	2.51 (1.1)	2.48 (1.1)	1.38 (0.7)	1.56 (1.0)	1.84 (0.8)	1.73 (0.8)	0.98 (0.5)	1.18 (0.8)	1.54 (0.7)	1.43 (0.7)	0.79 (0.4)	0.97 (0.7)
<i>Insula</i>	1.31 (0.6)	1.36 (0.6)	0.69 (0.3)	0.77 (0.5)	1.55 (0.7)	1.53 (0.7)	0.86 (0.5)	1.05 (1.0)	1.17 (0.6)	1.09 (0.5)	0.64 (0.4)	0.84 (0.9)	1.00 (0.5)	0.91 (0.4)	0.53 (0.4)	0.71 (0.8)
<i>Precuneus</i>	1.28 (0.6)	1.32 (0.6)	0.67 (0.3)	0.70 (0.3)	1.46 (0.7)	1.45 (0.7)	0.80 (0.4)	0.94 (0.7)	1.06 (0.5)	1.00 (0.5)	0.58 (0.3)	0.72 (0.6)	0.89 (0.4)	0.82 (0.4)	0.47 (0.3)	0.60 (0.5)
<i>PCC</i>	1.18 (0.6)	1.16 (0.6)	0.64 (0.3)	0.69 (0.4)	1.40 (0.7)	1.34 (0.6)	0.79 (0.4)	0.90 (0.7)	1.08 (0.5)	1.01 (0.5)	0.59 (0.3)	0.71 (0.7)	0.95 (0.5)	0.86 (0.4)	0.48 (0.3)	0.60 (0.6)
<i>Superior parietal lobule</i>	0.82 (0.4)	0.85 (0.4)	0.44 (0.2)	0.47 (0.3)	0.93 (0.4)	0.94 (0.4)	0.52 (0.3)	0.61 (0.6)	0.68 (0.3)	0.66 (0.3)	0.38 (0.2)	0.48 (0.5)	0.58 (0.2)	0.55 (0.2)	0.31 (0.2)	0.40 (0.5)
<i>Inferior parietal lobule</i>	2.23 (1.0)	2.22 (1.0)	1.18 (0.6)	1.22 (0.6)	2.54 (1.2)	2.44 (1.1)	1.44 (0.8)	1.65 (1.2)	1.87 (0.9)	1.72 (0.8)	1.04 (0.7)	1.28 (1.1)	1.57 (0.7)	1.44 (0.7)	0.85 (0.6)	1.07 (0.9)

Bold font indicates statistically significant increase from meditation S1 to S4 within specified frequency and ROI.

the results from the Friedman test comparisons between baseline and State 1 (S1) meditation, are displayed in [Table 1](#). Current density values for the EO and EC baseline epochs (along with S1 and S4) are displayed in [Table 2](#).

3.2. Brain activity changes during discrete meditative states (S1 to S4)

3.2.1. Whole brain (WB) analyses

Friedman tests showed significantly increased current density magnitude within β ($\chi^2(3) = 12.464, p = .006$), $\gamma-1$ ($\chi^2(3) = 18.354, p = < .0001$), and $\gamma-2$ ($\chi^2(3) = 19.120, p = < .0001$) frequency bands between meditation states. Wilcoxon tests showed a significant increase in β -band current density from S1 to S4 ($z = -3.255, p = .001, r = 0.4$). A significant increase in $\gamma-1$ band current density was also evident from S1 to S4 ($z = -3.349, p = .001, r = 0.4$). For $\gamma-2$ band, current density significantly increased from S1 to S4 ($z = -3.259, p = .001, r = 0.4$).

3.2.2. Lobar analyses

To further disentangle whether the whole brain analyses reflected a global increase in current density vector magnitude across the brain, or whether this reflected a more specific neural pattern related to particular regions, analyses by lobe were conducted.

3.2.3. Frontal & occipital

No significant changes in current density across states were evident within the frontal or occipital lobes.

3.2.4. SubLobar

Increased current density vector magnitude across states was exclusive to the β -band ($\chi^2(3) = 11.366, p = .010$). Wilcoxon tests revealed this increase was significant from S1 to S4 ($z = -2.542, p = .011, r = 0.3$).

3.2.5. Limbic

Friedman tests revealed a significant change within the limbic region ($\chi^2(3) = 12.498, p = .006$) exclusively for the $\gamma-2$ band. Wilcoxon tests revealed this increase in current density significantly increased from S1 to S4 ($z = -2.747, p = .006, r = 0.4$).

3.2.6. Temporal

Within the temporal lobe, Friedman tests showed significant changes in β -band ($\chi^2(3) = 17.493, p = .001$), $\gamma-1$ ($\chi^2(3) = 14.018, p = .003$), and $\gamma-2$ ($\chi^2(3) = 14.540, p = .002$) band current density across states within the temporal lobe. Wilcoxon tests revealed a significant increase within the β -band from S1 to S4 ($z = -3.190, p = .001, r = 0.4$), and from S3 to S4 ($z = -2.537, p = .011, r = 0.3$). For the $\gamma-1$ band, current density significantly increased from S1 to S4 ($z = -3.178, p = .001, r = 0.4$), and from S3 to S4 ($z = -2.531, p = .011, r = 0.3$). For $\gamma-2$ band, significantly increased current density vector magnitude was observed from S1 to S4 ($z = -3.201, p = .001, r = 0.4$).

3.2.7. Parietal

Current density vector magnitude increased within the parietal lobe exclusively for the $\gamma-2$ band ($\chi^2(3) = 12.083, p = .007$). Wilcoxon tests showed this increase was significant from S1 to S4 ($z = -2.963, p = .003, r = 0.4$).

3.3. Specific ROIs

In alignment with our hypotheses, specific ROIs pertaining to the default mode and self-referential processing were subsequently explored further. Current density values for S1 and S4 are displayed in [Table 2](#).

3.3.1. Medial ventral pre frontal cortex (mvPFC) and post cingulate cortex (PCC)

There were no significant changes between meditative states in current density magnitude related to mvPFC or PCC (and to note, not for the PCC by LORETA-estimated gyri location or Brodmann Area/BA coordinates).

3.3.2. Anterior cingulate cortex

When subdividing the ACC into ventral (vACC) and dorsal (dACC) pathways, current density vector magnitude markedly increased from S1 to S4. When analyzing global ACC (MNI BAs: 24, 32, 33), a marked increase in current density within the $\gamma-2$ band ($\chi^2(3) = 10.951, p = .012$) was found. Wilcoxon tests revealed this change was significant from S1 to S4 ($z = -2.617, p = .009, r = 0.3$). (see [Fig. 1](#)). When stratifying the ACC dorsally, a Friedman test showed a significant change within the $\gamma-2$ band ($\chi^2(3) = 8.146, p = .043$), wherein Wilcoxon tests indicated a significant increase from S1 to S4 ($z = -2.450, p = .014, r = 0.3$). When stratifying the ACC ventrally, a change in current density vector magnitude was apparent for $\gamma-1$ ($\chi^2(3) = 7.792, p = .051$), and $\gamma-2$ ($\chi^2(3) = 9.839, p = .020$) bands within the vACC (BA 32). Wilcoxon tests further revealed a significant increase in current density from S1 to S4, for $\gamma-1$ ($z = -2.574, p = .010, r = 0.3$), and $\gamma-2$ ($z = -2.700, p = .007, r = 0.4$), bands respectively. For the vACC (BA 33), increased current density magnitude was observed in the $\gamma-2$ band only ($\chi^2(3) = 11.108, p = .011$), again, a Wilcoxon test showed a marked increase from S1 to S4 ($z = -2.650, p = .008, r = 0.4$).

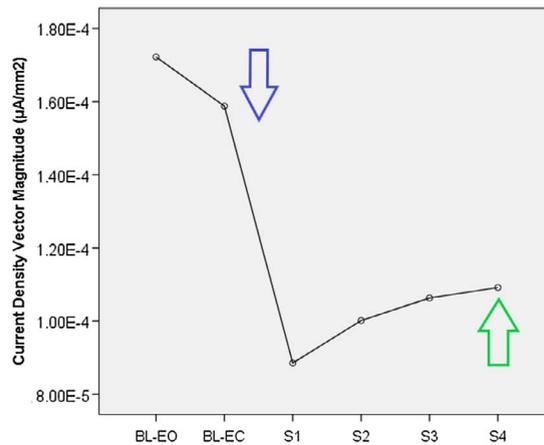


Fig. 1. Change in Gamma-2 (45–60 Hz) Current Density from baseline to across states within the Anterior Cingulate Cortex (ACC) [BA: 24, 32, 33]. Key: BL-EO = baseline eyes-open/BL-EC = baseline eyes-closed/S1-2-3-4 = State 1-2-3-4. **Blue ↓**: shift towards “effortless” state from baseline to meditation onset – requiring the “settling” into initial meditation essentially characterized by timelessness (*state 1*: ocean & waves). Neurophysiologically, we see this in the overall reduction in brain energy (gauged in terms of current density vector) across frequencies and ROIs. **Green ↑**: within meditation, which has now shifted one’s global experience out of the “effortful-effortless axis”, there is progressive increase in brain energy (current density vector magnitude) as the attainment of each state engages more complex executive functioning and active alertness (i.e. the brilliantly awake state of unified compassion, within *state 4*). However, such (‘extraordinary’) states of “awakening” are not intentionally cognitively driven *per se*, rather highly effortless (and devoid of self-referential processing) to the practitioner at this stage, thus global brain energy remains lower than baseline (considered as ‘ordinary state’).

3.3.3. Insula

Increased current density magnitude was observed for the β -band only within the Insula ($\chi^2(3) = 9.823, p = .020$). Wilcoxon tests revealed a significant incremental increase from S1 to S4 ($z = -2.439, p = .015, r = 0.3$).

3.3.4. Precuneus

A marked increase in current density magnitude was observed within the precuneus, specific to the γ -1 ($\chi^2(3) = 9.256, p = .026$), and γ -2 ($\chi^2(3) = 11.605, p = .009$) bands. Within both bands, this increase in current density magnitude across states was significant when comparing S1 to S4 for γ -1 ($z = -2.520, p = .012, r = 0.3$), and γ -2 ($z = -2.737, p = .006, r = 0.4$) bands, respectively.

3.3.5. Superior & inferior parietal lobules

Stratifying the parietal lobe into inferior and superior regions showed a diverging pattern. Namely, within the Superior Parietal lobe alterations in current density magnitude were observed within the β ($\chi^2(3) = 9.665, p = .022$), γ -1 ($\chi^2(3) = 7.802, p = .050$), and γ -2 ($\chi^2(3) = 8.816, p = .032$), bands. Wilcoxon tests revealed no significant differences between states for the β and γ -1 bands. For γ -2 band, a Wilcoxon test showed a marked increase in current density was evident from S1 to S4 ($z = -2.441, p = .01, r = 0.3$). Examining the Inferior Parietal lobe, increased current density pertained to the γ -1 band only ($\chi^2(3) = 8.811, p = .032$). However, following Bonferroni correction post hoc tests revealed only S1 to S4 incremental change showed a very near (0.01 from significance), albeit non-significant, increase.

4. Discussion

To our knowledge, this is the first empirical investigation into the spatial neurophysiological substrates associated with discrete advanced meditative states of the Indo-Tibetan essence-of-mind techniques. Specifically, it outlines the neurobiological quantification of mental states characterized by experiences of non-self-referentiality described as non-duality (and non-localization), and ‘awakened’ awareness, attained during specialized mental training.

Essentially, the findings revealed two main patterns. First, upon entering a meditative state, current density markedly attenuated in comparison to a baseline control condition and was observed in all frequencies and ROIs (alpha, beta, gamma). Second, while DMN activity in the mvPFC and PCC did not significantly increase across meditative states, a convergence towards enhanced beta and gamma-band current density magnitude was observed, linearly increasing from the meditation entry-point (state 1) to a stabilized awakened awareness (state 4). Topographically, increased cortical activity within the gamma band spanned the ACC, precuneus, and parietal lobules as well as the insular cortex within the beta-band. This separation of DMN and executive function systems provides evidence for an active, yet non-self-referential pattern during meditation. Contrary to predictions, no significant findings were evident within the frontal lobe, contradicting our assumption that the mechanisms of advanced meditation would involve the downregulation of frontal cortical processing systems implicated in task processing and self-regulation, i.e. the frontoparietal control network (Cole et al., 2013).

4.1. Tonic changes in brain state: attenuated current density compared to baseline

Globally, current density magnitude reduced across frequencies upon commencement of meditation when compared to baseline measures. This is in line with a previous study reporting reduced EEG spectral power across bandwidths (Hinterberger, Schmidt, Kamei, & Walach, 2014), in relation to “thoughtless emptiness”. In this case, the authors defined “emptiness” as encompassing focused attention and open monitoring towards the experience of a pure state of mindful presence.

The present study also investigated mind states of “emptiness”, albeit pertaining to the earlier stages of the 4-state cycle progression. In the Hinterberger et al. (2014) study, meditators essentially remained in a (tonic) brain state of emptiness practice. Here, we hypothesize that the meditation states developed further. That is, within meditation, global experience and associated brain energy, shifted out of the “effortful-effortless axis”. Accordingly, changes in baseline to meditative state represents the shift from ‘ordinary’ mind (baseline state) to an altered state of ‘extraordinary’ mind. Essentially, meditators dropped out of an “effortful-effortless” dimension, so as to enter the discrete states of the essence-of-mind tradition. For the specific state-progression we examined here, meditation must be continuously effortless. For instance, if meditators do not reach effortlessness initially, then the main ‘point of exercise’ within their meditation will be to ‘enter’ this initial state. This is often a ‘technical issue’ for novel meditators, in addition to mistaking a state of physical relaxation as effortlessness of mind. This provided the rationale to rigorously screen meditators with regard to their ‘capacity’ to speedily enter and stabilize within each meditative state prior to invitation to participate in the study.

In this vein, baseline state is not comparable to meditative state in terms of interpreting the subsequent progressive increase in brain energy, whereby the attainment of each meditative state engaged higher complexity in terms of executive functioning and active alertness (i.e., the brilliantly awake state of unified compassion, within *state 4*). However, such (‘extraordinary’) states of “awakening” are not intentionally cognitively driven *per se*, rather highly effortless (and devoid of self-referential processing) to the practitioner at this stage, thus global brain energy remains lower than baseline (considered as ‘ordinary state’). The following sections focus upon disentangling this process, and refer to the meditators once they had crossed over into “extraordinary mind”, a phenomenologically non-comparable state from baseline.

4.2. State brain changes following tonic re-calibration during meditation

4.2.1. Gamma frequency and executive functioning

Modulation within the anterior cingulate (ACC) executive hub was observed in the gamma band range. This finding also concurs with other meditation research showing significant gamma-related change in long-term practitioners engaging in compassion practice (Lutz et al., 2004). Altered ACC activity has been replicated across morphometric studies examining differing meditative techniques (Dickenson et al., 2012; Hölzel et al., 2007; Manna et al., 2010; Orme-Johnson et al., 2006; Xue et al., 2011; Zeidan et al., 2011; Fox et al., 2014). The ACC represents a core brain structure in terms of centralized executive functioning, with disparate anatomical distinctions pertaining to the dorsal pathway associated with cognitive processing, contrary to the ventral pathway connected with emotion regulation and adaptive response (Bush, Luu, & Posner, 2000). An overarching theory proposes the key interplay of the ACC in “self-regulatory” processes, broadly defined (Posner, Rothbart, Sheese, & Tang, 2007).

As studies accrue, it appears that ACC involvement can be subsumed into three main domains of functional significance (Gasquoine, 2013); (1) *executive functioning*, as demonstrated by Go/No-Go (Schulz, Bedard, Czarnecki, & Fan, 2011), Stroop (Mansouri, Tanaka, & Buckley, 2009), working memory (Critchley et al., 2003; Weissman, Gopalakrishnan, Hazlett, & Woldorff, 2005), and theory of mind (Kobayashi, Glover, & Temple, 2008) tasks, in addition to encoding reward prediction and prediction error (Vassena, Krebs, Silveti, Fias, & Verguts, 2014); (2) *homeostatic physical states*, such as hunger, thirst, awareness of breath, and body temperature (Gasquoine, 2013); and (3) *the encoding of the valence of stimuli in all sensory modalities*, including experimentally induced pain (Tracey & Mantyh, 2007; von Leupoldt et al., 2009), social inclusion/exclusion (Eisenberger, Lieberman, & Williams, 2003), viewing sexually explicit stimuli (Karama et al., 2002), and unconscious processing (Carlson et al., 2012).

Relating back to the results here, our results showed global ACC modulation, in addition to significant changes related to both dorsal and ventral streams of the executive network. These findings suggest enhanced executive control extending to challenging cognitive, emotional, and physical processing demands, largely observed during periods of sustained attention. Furthermore, enhanced current density within the ACC, dACC, and vACC, was exclusive to the gamma-band frequency range, whereby modulation of gamma activity has been associated with increasing complexity of experimental tasks, task difficulty, and mental effort (Fitzgibbon, Pope, Mackenzie, Clark, & Willoughby, 2004; Mulert et al., 2007; Posada, Hugues, Franck, Vianin, & Kilner, 2003; Simos, Papanikolaou, Sakkalis, & Micheloyannis, 2002).

4.2.2. Gamma frequency and parietal pathways

The parietal cortex is largely considered to be functionally generalized, and an intrinsic ‘association cortex’ involved in complex multimodal functioning. The integration of spatial information regulates via the dorsal stream, compared to perceptual recognition via the ventral stream (Culham & Kanwisher, 2001). For example, the inferior parietal lobule has connections to proprioceptive processing, such as the switching from first to third person perspectives (Ruby & Decety, 2004), detached modes of self-referential experience via induced out-of-body experiences/OBEs (Blanke, Ortigue, Landis, & Seeck, 2002), and the construct of ‘stepping outside’ the sense of corporeal ‘self’ during mindfulness practice (Farb et al., 2007). Despite the absence of highly replicated support for parietal lobe involvement within the morphometric meditation literature (Fox et al., 2014), the utilization of multimodal perceptual processing of the ‘total field’ of awareness undertaken by our Mahamudra essence of mind meditator sample extends high

relevance for parietal cortex involvement. A recent proposition by Vago and Zeidan (2016), asserts that the fronto-parietal control network (FPCN) facilitates insightful meta-awareness during both focused attention and open-monitoring meditative practices, via its role as an associative network that integrates information across other contextually relevant networks in moment-to-moment awareness of the arising and ceasing of meditative phenomena. Furthermore, the authors premise the importance of parietal pathways that function in unison with frontostriatal circuitry during the processing of pertinent stimulus-response associations (e.g. the focus of attention upon distractors and subsequent response of reorienting attention to the meditative focus) in the absence of attentional ‘effort’ (Vago & Zeidan, 2016).

The latter offers one interpretational perspective for the parietal activity findings here, in that, both inferior/superior lobules, and more specifically the precuneus and PCC, all significantly attenuated upon commencement of meditation practice. This would be in line with previous research showing PCC deactivation as a marker of diminished self-referential processing during meditation (Brewer et al., 2011; Garrison et al., 2015), as well as a gauge of “undistracted awareness” and effortless intention during such practice (Garrison et al., 2013). Interestingly, whereas PCC activity did not significantly change across the one-hour meditation session, the parietal lobules and precuneus yielded significant incremental current density increases, exclusive to the gamma band, from state-to-state across the discrete states.

One interpretation of these results is that whilst integrative regions of the parietal cortex (particularly the superior parietal lobule which also specifically encompasses the precuneus) involved in multimodal perceptual and self-detached processing remained ‘on-line’ (and even increased) in cortical terms, the PCC ‘efforting’ axis remained ‘offline’. Interestingly, the precuneus presents a discrete pattern of connectivity with the DMN, suggesting it not only represents a specialized hub within the network but also more broadly via distinct engagement associated with multimodal processing states (Utevsky, Smith, & Huettel, 2014), distinct from the role of the PCC. This emphasizes the specificity of the findings observed here. Within the context of the essence meditation traditions, we could surmise that such neural activity reflects a neurophysiological shift from the phenomenological dimension of “doing” to that of non-localized perspective-taking (i.e. modulated via specialized parietal integrative processing regions).

4.2.3. Beta frequency and the insular cortex

A significant increase in current density within the insula exclusive to the beta-band was found. Morphometric differences within the insular cortex between meditators versus non-meditators is a well replicated finding (Farb et al., 2007, 2013; Fox et al., 2014; Gard et al., 2012; Manna et al., 2010; Monti et al., 2012; Wang et al., 2011; Zeidan et al., 2011). The principal inference drawn from such evidence is that meditators are intentionally training interoceptive awareness, particularly techniques that utilize the body as the meditation phenomena of focus wherein the insula has been consistently associated with visceral awareness (Critchley, Wiens, Rotshtein, Öhman, & Dolan, 2004), emotional self-awareness (Craig, 2011), and connections with metacognitive awareness (Fleming & Dolan, 2012). For example, neuroimaging investigations into ‘expert’ meditators proficient in both focused concentration and open-monitoring practices (Theravada), show the conscious engagement of processing related to sensory, cognitive, and affective domains (metacognitive awareness) via enhanced self-regulation of insular areas (among others) (Manna et al., 2010).

The insula also appears to enact in cohesion with an array of disparate neural architecture towards specialized processing. For example, in collaboration with the ACC, the insula has been shown to be the integral hub of the cortical saliency network. This integrative arrangement purportedly represents an intrinsic connectivity network that unites neural systems during conflict monitoring, interoceptive autonomic functioning, and reward processing (Seeley et al., 2007). Within this functional network model, the insula represents a heterogeneous structure serving poly-mechanistic purposes; (i) primarily in bottom-up saliency detection, (ii) cooperating with wide ranging networks involved in attention and working memory resources, following the detection of salient stimuli, (iii) modulation of autonomic reactivity to salient stimuli via the interaction of anterior and posterior striations of the insular cortex, and (iv) alongside integration with the ACC to administer rapid motor system activity (Menon & Uddin, 2010). As such, the insula integrates information regarding the saliency of incoming signals (whether internally or externally driven) alongside their effects on bodily state, serving to meditate germane autonomic response towards optimal emotion regulation (Terasawa, Fukushima, & Umeda, 2013).

Connecting the relevance of the functional role of the insula in line with meditative states, more broadly, it has been associated with self-processing in terms of current-state-related physiological/emotional awareness and consciousness (Craig, 2009; Craig, 2011; Lamm & Singer, 2010), and attribution of self-agency (see review, Sperduti, Delaveau, Fossati, & Nadel, 2011). It has also been implicated in prosocial states requiring shared representations of self and others (i.e., non-dual unification), including empathy (Singer, Critchley, & Preuschoff, 2009), and compassion (Lutz et al., 2004), associated with unified non-dual experiences (diminished self-referential, and converging enhanced self-other shared representations) during the ‘awakened’ meditative state of the essence-of-mind tradition. Furthermore, the implication of the insula, as part of the ACC-insula saliency network, provides an interesting hypothesis regarding what is referred to as ‘having no reference point’ (non-preference) or ‘equanimity’, in the Indo-Tibetan essence-of-mind traditions. Equanimity can be defined as a state of neutrality towards all stimuli, whether they be heavily ‘colored’ by positive or negative valence (Desbordes et al., 2015), thus culminating in the intentional attitude of acceptance toward every sort of experience (pleasant/unpleasant, past/present/future) (Hadash, Segev, Tanay, Goldstein, & Bernstein, 2016). Equanimity is a fundamental pre-requisite for deeply compassionate states of unification (H.H. Dalai Lama Gyatso, 2005; Shonin, Van Gordon, & Griffiths, 2014), and is the essential quality of the experience of awakened awareness (state 4) of essence of mind practices. Interestingly, a previous study into highly diminished self-referential (self-disintegrative) states via concentrative open-monitoring (Vipassana) also found changes in beta-frequency (in line with the insula beta changes here) and diminished reactivity, and interpreted such findings as a possible neural marker of equanimity (Schoenberg & Barendregt, 2016).

4.3. Limitations

A technical limitation is that the original LORETA utilized here achieves low localization error, but not zero, unlike standardized or exact LORETA. As such, future replications of these findings with the differing LORETA methods may be advantageous with regard to increasing the rigor of such research examining the discrete states observed here. Albeit an aside, at present, all LORETA techniques (original, sLORETA, eLORETA) are vulnerable to head-modelling errors (Grech et al., 2008). As such electroencephalographic LORETA represents an estimation of the neuronal origins of brain activity.

Additionally, modulation within gamma-frequency may be associated with muscular artefact under certain circumstances. Indeed, upon entering meditation, gamma band decreased, although, current density decreased across all bandwidths examined (i.e. alpha, beta, and gamma 1 + 2), and to statistically significant levels for beta and gamma. Second, the subsequently observed increases in current density across meditative states were region specific, rather than global. More importantly, gamma current density did not significantly increase within frontal sites, wherein increased muscle tension is often reflected in these topographically placed electrodes. Methodologically, artefact was carefully monitored and removed during the signal processing stage (Section 3.3.1). Finally, our definition of gamma did not exceed 60 Hz (gamma-1 was defined as 30–45 Hz, and gamma-2 within 45–60 Hz), where referrals to gamma as reflective of muscle activity generally pertain to 60 Hz and over. These pertinent points together suggest that we may infer that the reported gamma-frequency findings reflect a *result proper*.

4.4. Summary

The present findings advocate various candidate neural markers for meditative states pertaining to internal modes of mind such as timelessness, emptiness, non-duality, non-localized consciousness, and stable awakened awareness (embodying compassionate unification) experiences recorded at discrete temporal epochs during Indo-Tibetan essence-of-mind practice. First, meditative state compared to baseline showed global attenuation in current density magnitude with regards to topography and frequency oscillation, representing the shift in state of mind during meditation to one of an effortless practice. As previously noted, ‘effortlessness’ of mind-related practice differs from ‘physical relaxation’. This subtle technical differentiation within such meditation practice is often the first hurdle for ‘novices’ to experientially comprehend and integrate. Returning to the findings here, following the initial shift into an effortless state (reflected by a significant drop in current density magnitude from baseline to meditation state-1), it could be argued that the further progression through the essence-of-mind states represents a complete shift out of the effortful-effortless axis altogether, rendering the analysis between baseline to meditation data non-comparable. Thus, the increase in current density magnitude as the meditation progressed reflects the modulation of brain activity within a substantially altered tonic brain state (essence-of-mind meditation).

Within this shifted tonic brain meditative state (S1 onwards), collectively, enhanced ACC and parietal cortex current density vector magnitudes in concert with increased activation within the insula, suggest the onset of executive brain networks involved in saliency, conflict monitoring, emotion control and shifts in perspective-taking. We may infer that such neural activity contributed to the cultivation and sustainment of intricate internal states encompassing experiences of non-duality, and having no reference point (thus non-preference). Furthermore, decreases in cortical networks involved with self-referential processing, such as the PCC, support the down-regulation of self-orientation, while the continued attenuation of these regions with a simultaneous increase in executive network activity between meditative states provides initial evidence of a dissociability of these networks within an active, ongoing movement towards non-dual states. Such complex functioning is consistent with selfless (and thus effortless), yet active meditation in line with the construct of non-localized awakened awareness and its expression as “unified compassion”.

Acknowledgements

This work was supported by the Fetzer Franklin Fund of the John E. Fetzer Memorial Trust. The authors give much appreciation and thanks to all the meditators who participated for their generosity of time and spirit. We are especially thankful to Paula Sacks for setting up recruitment channels; and to Sue Druker for processing ethical approval. Thank you to Dr. Rebecca Morrissey and Dr. Michelle Foote-Pearce for their helpful comments on the final manuscript.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.concog.2017.11.003>.

References

- Baerentsen, K. B., Stodkilde-Jorgensen, H., Sommerlund, B., Hartmann, T., Damsgaard-Madsen, J., Fosnaes, M., et al. (2010). An investigation of brain processes supporting meditation. *Cognitive Processing*, *11*, 57–84.
- Berkovich-Ohana, A., Glicksohn, J., & Goldstein, A. (2011). Mindfulness-induced changes in gamma band activity – Implications for the default mode network, self-reference and attention. *Clinical Neurophysiology*, *123*(4), 700–710.
- Blanke, O., Ortigue, S., Landis, T., & Seeck, M. (2002). Neuropsychology: Stimulating illusory own-body perceptions. *Nature*, *419*, 269–270.
- Brewer, J. A., Worhunsky, P. D., Gray, J. R., Tang, Y.-Y., Weber, J., & Kober, H. (2011). Meditation experience is associated with differences in default mode network activity and connectivity. *PNAS*, *108*(50), 20254–20259.

- Brown, D. P. (2006). *Pointing out the great way: The stages of meditation in the mahamudra tradition*. Somerville, MA: Wisdom Publications.
- Bru rGyal Ba (2016). Pith instruction for A Khrid rDzogs Chen [Great Completion Meditation]. Translated by Gurung, G.S., and Brown, D. Occidental CA: Bright Alliance Press.
- Buckner, R. L., Andrews-Hanna, J. R., & Schacter, D. L. (2008). The brain's default network: Anatomy, function, and relevance to disease. In A. Kingstone, & M. B. Miller (Eds.). *The year in cognitive neuroscience* (pp. 1–38). Malden, MA: Blackwell.
- Bush, G., Luu, P., & Posner, M. I. (2000). Cognitive and emotional influences in anterior cingulate cortex. *Trends in Cognitive Sciences*, 4, 215–222.
- Cahn, R. B., & Polich, J. (2006). Meditation states and traits: EEG, ERP, and neuroimaging studies. *Psychological Bulletin*, 132(2), 180–211.
- Cahn, R. B., Delorme, A., & Polich, J. (2010). Occipital gamma activation during Vipassana meditation. *Cognitive Processing*, 11(1), 39–56.
- Carlson, J. M., Beacher, F., Reinke, K. S., Habib, R., Harmon-Jones, E., Mujica-Parodi, L. R., et al. (2012). Nonconscious attention bias to threat is correlated with anterior cingulate cortex grey matter volume: A voxel-based morphometry result and replication. *Neuroimage*, 59, 1713–1718.
- Carmody, J. (2009). Evolving conceptions of mindfulness in clinical settings. *Journal of Cognitive Psychotherapy*, 23(3), 270–280.
- Cole, M. W., Repovš, G., & Anticevic, A. (2014). The frontoparietal control system: A central role in mental health. *The Neuroscientist*, 20(6), 652–664.
- Cole, M. W., Reynolds, J. R., Power, J. D., Repovš, G., Anticevic, A., & Braver, T. S. (2013). Multi-task connectivity reveals flexible hubs for adaptive task control. *Nature Neuroscience*, 16, 1348–1355.
- Craig, A. D. (2009). How do you feel – now? The anterior insula and human awareness. *Nature Reviews Neuroscience*, 10(1), 59–70.
- Craig, A. D. (2011). Significance of the insula for the evolution of human awareness of feelings from the body. *Annals of the New York Academy of Sciences*, 1225, 72–82.
- Critchley, H. D., Mathias, C. J., Josephs, O., O'Doherty, J., Zanini, S., Dewar, B. K., et al. (2003). Human cingulate cortex and autonomic control: Converging neuroimaging and clinical evidence. *Brain*, 126(10), 2139–2152.
- Critchley, H. D., Wiens, S., Rotshtein, P., Öhman, A., & Dolan, R. J. (2004). Neural systems supporting interoceptive awareness. *Nature Neuroscience*, 7, 189–195.
- Culham, J. C., & Kanwisher, N. G. (2001). Neuroimaging of cognitive functions in human parietal cortex. *Current Opinion in Neurobiology*, 11, 157–163.
- Desbordes, G., Gard, T., Hoge, E. A., Hölzel, B. K., Kerr, C., Lazar, S. W., et al. (2015). Moving beyond mindfulness: Defining equanimity as an outcome measure in meditation and contemplative research. *Mindfulness*, 6(2), 356–372.
- Dickenson, J., Berkman, E. T., Arch, J., & Lieberman, M. D. (2012). Neural correlates of focused attention during a brief mindfulness induction. *Social Cognitive & Affective Neuroscience*, 8(1), 40–47.
- Doll, A., Hölzel, B. K., Boucard, C. C., Wohlschläger, A. M., & Sorg, C. (2015). Mindfulness is associated with intrinsic functional connectivity between default mode and salience networks. *Frontiers in Human Neuroscience*, 9, 461.
- Dor-Ziderman, Y., Berkovich-Ohana, A., Glicksohn, J., & Goldstein, A. (2013). Mindfulness-induced selflessness: A MEG neurophenomenological study. *Frontiers in Human Neuroscience*, 7, 582.
- Eisenberger, N. I., Lieberman, M. D., & Williams, K. D. (2003). Does rejection hurt? An fMRI study of social exclusion. *Science*, 302, 290–292.
- Eisendrath, S. J. (2016). *Mindfulness-based cognitive therapy: Innovative applications*. Switzerland: Springer International Publishing.
- Farb, N. A. S., Anderson, A. K., & Segal, Z. V. (2012). The mindful brain and emotion regulation in mood disorders. *Canadian Journal of Psychiatry*, 57(2), 70–77.
- Farb, N. A. S., Segal, Z. V., & Anderson, A. (2013). Mindfulness meditation training alters cortical representations of interoceptive attention. *Social Cognitive and Affective Neuroscience*, 8(1), 15–26.
- Farb, N. A. S., Segal, Z. V., Mayberg, H., Bean, J., McKeon, D., Fatima, Z., et al. (2007). Attending to the present: Mindfulness meditation reveals distinct neural modes of self-reference. *Social Cognitive & Affective Neuroscience*, 2(4), 313–322.
- Fitzgibbon, S. P., Pope, K. J., Mackenzie, L., Clark, C. R., & Willoughby, J. O. (2004). Cognitive tasks augment gamma EEG power. *Clinical Neurophysiology*, 115(8), 1802–1809.
- Fleming, S. M., & Dolan, R. J. (2012). The neural basis of metacognitive ability. *Philosophical Transactions of The Royal Society B: Biological Science*, 367(1594), 1338–1349.
- Fox, K. C. R., Nijeboer, S., Dixon, M. L., Floman, J. L., Ellamil, M., Rumak, S. P., et al. (2014). Is meditation associated with altered brain structure? A systematic review and meta-analysis of morphometric neuroimaging in meditation practitioners. *Neuroscience and Biobehavioral Reviews*, 43, 48–73.
- Fritz, C. O., Morris, P. E., & Richler, J. J. (2012). Effect size estimates: Current use, calculations, and interpretation. *Journal of Experimental Psychology: General*, 141(1), 2–18.
- Gard, T., Hölzel, B. K., Sack, A. T., Hempel, H., Lazar, S. W., Vaitl, D., et al. (2012). Pain attenuation through mindfulness is associated with decreased cognitive control and increased sensory processing in the brain. *Cerebral Cortex*, 22(11), 2692–2702.
- Garrison, K. A., Santoyo, J. F., Davis, J. H., Thornhill, T. A., Kerr, C. E., & Brewer, J. A. (2013). Effortless awareness: Using real time neurofeedback to investigate correlates of posterior cingulate cortex activity in meditators' self-report. *Frontiers in Human Neuroscience*, 7, 440.
- Garrison, K. A., Zeffiro, T. A., Scheinost, D., Constable, T. R., & Brewer, J. A. (2015). Meditation leads to reduced default mode network activity beyond an active task. *Cognitive, Affective, & Behavioral Neuroscience*, 15(1), 712–720.
- Gasquoine, P. G. (2013). Localization of function in anterior cingulate cortex: From psychosurgery to functional neuroimaging. *Neuroscience and Biobehavioral Reviews*, 37, 340–348.
- Gratton, G., Coles, M. G. H., & Donchin, E. (1983). A new method for off-line removal of ocular artifact. *Electroencephalography and Clinical Neurophysiology*, 55(4), 468–484.
- Grech, R., Cassar, T., Muscat, J., Camilleri, K. P., Fabri, S. G., Zervakis, M., et al. (2008). Review on solving the inverse problem in EEG source analysis. *Journal of NeuroEngineering and Rehabilitation*, 5, 25.
- Gyatso, T. (H.H. Dalai Lama). (2005). *Essence of the Heart Sutra: The Dalai Lama's Heart of Wisdom Teachings*. Translated and edited by Geshe Thupten Jinpa. Boston, MA: Wisdom Publications.
- Hadash, Y., Segev, N., Tanay, G., Goldstein, P., & Bernstein, A. (2016). The decoupling model of equanimity: Theory, measurement, and test in a mindfulness intervention. *Mindfulness*, 7(5), 1214–1226.
- Hasenkamp, W., & Barsalou, L. W. (2012). Effects of meditation experience on functional connectivity of distributed brain networks. *Frontiers in Human Neuroscience*, 6, 38.
- Hebert, R., Lehmann, D., Tan, G., Travis, F., & Arenander, A. (2005). Enhanced EEG alpha time-domain phase synchrony during transcendental meditation: Implications for cortical integration theory. *Signal Processing*, 85(11), 2213–2232.
- Hinterberger, T., Schmidt, S. N. L., Kamei, T., & Walach, H. (2014). Decreased electrophysiological activity represents the conscious state of emptiness in meditation. *Frontiers in Consciousness Research*, 99(5), 1–14.
- Hölzel, B. K., Ott, U., Hempel, H., Hackl, A., Wolf, K., Stark, R., et al. (2007). Differential engagement of anterior cingulate and adjacent medial frontal cortex in adept meditators and non-meditators. *Neuroscience Letters*, 421, 16–21.
- Ives-Deliperi, V. L., Solms, M., & Meintjes, E. M. (2011). The neural substrates of mindfulness: An fMRI investigation. *Social Neuroscience*, 6(3), 231–242.
- Kang, D., Jo, H. J., Jung, W. H., Kim, S. H., Jung, Y., Choi, C., et al. (2013). The effect of meditation on brain structure: Cortical thickness mapping and diffusion tensor imaging. *Social, Cognitive, & Affective Neuroscience*, 8(1), 27–33.
- Karama, S., Lecours, A. R., Leroux, J.-M., Bourgoin, P., Beaudoin, G., Joubert, S., et al. (2002). Areas of brain activation in males and females during viewing of erotic film excerpts. *Human Brain Mapping*, 16, 1–13.
- Kerr, C. E., Jonse, S. R., Wan, Q., Pritchett, D. L., Wasserman, R. H., Wexler, A., et al. (2011). Effects of mindfulness meditation training on anticipatory alpha modulation in primary somatosensory cortex. *Brain Research Bulletin*, 85, 96–103.
- Kerr, C. E., Sacchet, M. D., Lazar, S. W., Moore, C. I., & Jones, S. R. (2013). Mindfulness starts with the body: Somatosensory attention and top-down modulation of cortical alpha rhythms in mindfulness meditation. *Frontiers in Human Neuroscience*, 7, 12.
- Kobayashi, C., Glover, G. H., & Temple, E. (2008). Switching language switches mind: Linguistic effects on developmental neural bases of 'theory of mind'. *Scan*, 3, 62–70.
- Lamm, C., & Singer, T. (2010). The role of anterior insular cortex in social emotions. *Brain Structure and Function*, 214(5), 579–591.

- Lazar, S. W., Kerr, C. E., Wasserman, R. H., Grey, J. R., Greve, D. N., Treadway, M. T., et al. (2005). Meditation experience is associated with increased cortical thickness. *NeuroReport*, *16*, 1893–1897.
- Lehmann, D., Faber, P. L., Achermann, P., Jeanmonod, D., Gianotti, L. R. R., & Pizzagalli, D. (2001). Brain sources of EEG gamma frequency during volitionally meditation-induced, altered states of consciousness, and experience of the self. *Psychiatry Research: Neuroimaging*, *108*(2), 111–121.
- Lo, P.-C., Huang, M.-L., & Chang, K.-M. (2003). EEG alpha blocking correlated with perception of inner light during Zen meditation. *The American Journal of Chinese Medicine*, *31*(4), 629–642.
- Luders, E., Kurth, F., Mayer, E. A., Toga, A. W., Narr, K. L., & Gaser, C. (2012). The unique human anatomy of meditation practitioners: Alterations in cortical gyrification. *Frontiers in Human Neuroscience*, *6*(34), 1–9.
- Lutz, A., Dunne, J. D., & Davidson, R. J. (2007). Meditation and the neuroscience of consciousness: An introduction. In P. Zelazo, M. Moscovitch, & E. Thompson (Eds.). *The Cambridge handbook of consciousness* (pp. 499–551). New York: Cambridge University Press.
- Lutz, A., Greischar, L. L., Rawlings, N. B., Ricard, M., & Davidson, R. J. (2004). Long-term meditators self-induce high-amplitude gamma synchrony during mental practice. *Proceedings of the National Academy of Sciences of the United States of America*, *101*(46), 16369–16373.
- Lutz, A., Slagter, H. A., Dunne, J. D., & Davidson, R. J. (2008). Attention regulation and monitoring in meditation. *Trends in Cognitive Sciences*, *12*(4), 163–169.
- Manna, A., Raffone, A., Perrucci, M. G., Nardo, D., Ferretti, A., Tartaro, A., et al. (2010). Neural correlates of focused attention and cognitive monitoring in meditation. *Brain Research Bulletin*, *82*, 46–56.
- Mansouri, F. A., Tanaka, K., & Buckley, M. J. (2009). Conflict-induced behavioral adjustment: A clue to the executive functions of the prefrontal cortex. *Nature Reviews Neuroscience*, *10*, 141–152.
- Menon, V., & Uddin, L. Q. (2010). Saliency, switching, attention, and control: A network model of insula function. *Brain, Structure, and Function*, *214*, 655–667.
- Monti, D. A., Kash, K. M., Kunkel, E. J. S., Brainard, G., Wintering, N., Moss, A. S., et al. (2012). Changes in cerebral blood flow and anxiety associated with an 8-week mindfulness programme in women with breast cancer. *Stress Health*, *28*, 397–407.
- Mulert, C., Leicht, G., Pogarell, O., Mergl, R., Karch, S., Juckel, G., et al. (2007). Auditory cortex and anterior cingulate cortex sources of the early evoked gamma-band response: Relationship to task difficulty and mental effort. *Neuropsychologia*, *45*(10), 2294–2306.
- Murata, T., Takahashi, T., Hamada, T., Omori, M., Kosaka, H., Yoshida, H., et al. (2004). Individual trait anxiety levels characterizing the properties of Zen meditation. *Neuropsychobiology*, *50*, 189–194.
- Orme-Johnson, D. W., Schneider, R. H., Son, Y. D., Nidich, S., & Cho, Z. (2006). Neuroimaging of meditation's effect on brain reactivity to pain. *NeuroReport*, *17*(12), 1359–1363.
- Pascual-Marqui, R. D., Esslen, M., Kochi, K., & Lehmann, D. (2002). Functional imaging with low-resolution brain electromagnetic tomography (LORETA): A review. *Methods and Findings in Experimental and Clinical Pharmacology*, *24*(Suppl D), 91–95.
- Pascual-Marqui, R. D., Michel, C. M., & Lehmann, D. (1994). Low resolution electromagnetic tomography: A new method for localizing electrical activity in the brain. *International Journal of Psychophysiology*, *18*(1), 49–65.
- Posada, A., Hugues, E., Franck, N., Vianin, P., & Kilner, J. (2003). Augmentation of induced visual gamma activity by increased task complexity. *European Journal of Neuroscience*, *18*(8), 2351–2356.
- Posner, M. I., Rothbart, M. K., Sheese, B. E., & Tang, Y. (2007). The anterior cingulate gyrus and the mechanism of self-regulation. *Cognitive, Affective, & Behavioral Neuroscience*, *7*(4), 391–393.
- Rubia, K. (2009). The neurobiology of meditation and its clinical effectiveness in psychiatric disorders. *Biological Psychology*, *82*(1), 1–11.
- Ruby, P., & Decety, J. (2004). How would you feel versus how do you think she would feel? A neuroimaging study of perspective-taking with social emotions. *Journal of Cognitive Neuroscience*, *16*(6), 988–999.
- Schoenberg, P. L. A., & Barendregt, H. P. (2016). Mindful disintegration and the decomposition of self in healthy populations: Conception and preliminary study. *Psychological Studies*, *61*(4), 307–320.
- Schoenberg, P. L. A., Hepark, S., Kan, C. C., Barendregt, H. P., Buitelaar, J. K., & Speckens, A. E. M. (2014). Effects of mindfulness-based cognitive therapy on neurophysiological correlates of performance monitoring in adult attention-deficit/hyperactivity disorder. *Clinical Neurophysiology*, *125*, 1407–1416.
- Schulz, K. P., Bedard, A. C. V., Czamecki, R., & Fan, J. (2011). Preparatory activity and connectivity in dorsal anterior cingulate cortex for cognitive control. *Neuroimage*, *57*, 242–250.
- Seeley, W. W., Menon, V., Schatzberg, A. F., Keller, J., Glover, G. H., Kenna, H., et al. (2007). Dissociable intrinsic connectivity networks for salience processing and executive control. *Journal of Neuroscience*, *27*(9), 2349–2356.
- Shonin, E., Van Gordon, W., & Griffiths, M. D. (2014). Loving-kindness and compassion meditation in psychotherapy. *Thresholds: Quarterly Journal of British Association for Counselling & Psychotherapy*. http://irep.ntu.ac.uk/id/eprint/26064/1/221466_2984.pdf.
- Simkin, D. R., & Black, N. B. (2014). Meditation and mindfulness in clinical practice. *Child & Adolescent Psychiatric Clinics*, *23*(3), 487–534.
- Simos, P. G., Papanikolaou, E., Sakkalis, E., & Micheloyannis, S. (2002). Modulation of gamma-band spectral power by cognitive task complexity. *Brain Topography*, *14*, 191.
- Singer, T., Critchley, H. D., & Preuschoff, K. (2009). A common role of insula in feelings, empathy and uncertainty. *Trends in Cognitive Science*, *13*(8), 334–340.
- Sperduti, M., Delaveau, P., Fossati, P., & Nadel, J. (2011). Different brain structures related to self- and external- agency attribution: A brief review and meta-analysis. *Brain Structure and Function*, *216*(2), 151–157.
- Terasawa, Y., Fukushima, H., & Umeda, S. (2013). How does interoceptive awareness interact with the subjective experience of emotion? An fMRI study. *Human Brain Mapping*, *34*(3), 598–612.
- Tracey, I., & Mantyh, P. W. (2007). The cerebral signature for pain perception and its modulation. *Neuron*, *55*, 377–391.
- Travis, T., Haaga, D. A., Hagelin, J., Tanner, M., Arenander, A., Nidich, S., et al. (2010). A self-referential default brain state: Patterns of coherence, power, and eLORETA sources during eyes-closed rest and Transcendental Meditation practice. *Cognitive Processing*, *11*(1), 21–30.
- Treadway, M. T., & Lazar, S. W. (2010). Meditation and neuroplasticity: Using mindfulness to change the brain. In R. A. Baer (Ed.). *Assessing mindfulness and acceptance processes in clients: Illuminating the theory & practice of changem*. Oakland, CA: New Harbinger Publications Inc.
- Utevsky, A. V., Smith, D. V., & Huettel, S. A. (2014). Precuneus is a functional core of the default-mode network. *The Journal of Neuroscience*, *34*(3), 932–940.
- Vago, D. R., & Zeidan, F. (2016). The brain on silent: Mind wandering, mindful awareness, and states of mental tranquility. *Annals of the New York Academy of Sciences*, *1373*, 96–113.
- Vassena, E., Krebs, R. M., Silvetti, M., Fias, W., & Verguts, T. (2014). Dissociating contributions of ACC and vmPFC in reward prediction, outcome, and choice. *Neuropsychologia*, *59*, 112–123.
- Vestergaard-Poulsen, P., van Beek, M., Skewes, J., Bjarkam, C. R., Stubberup, M., Bertelsen, J., et al. (2009). Long-term meditation is associated with increased grey matter density in the brain stem. *NeuroReport*, *20*, 170–174.
- Vollestad, J., Nielsen, M. B., & Nielsen, G. H. (2012). Mindfulness- and acceptance-based interventions for anxiety disorders: A systematic review and meta-analysis. *British Journal of Clinical Psychology*, *51*(3), 239–260.
- von Leupoldt, A., Sommer, T., Kegat, S., Baumann, H. J., Klose, H., Dahme, B., et al. (2009). Dyspnea and pain share emotion-related brain networks. *Neuroimage*, *48*, 200–206.
- Wang, D. J. J., Rao, H., Korczykowski, M., Wintering, N., Pluta, J., Khalsa, D. S., et al. (2011). Cerebral blood flow changes associated with different meditation practices and perceived depth of meditation. *Psychiatry Research: Neuroimaging*, *191*, 60–67.
- Weissman, D. H., Gopalakrishnan, A., Hazlett, C. J., & Woldorff, M. G. (2005). Dorsal anterior cingulate cortex resolves conflict from distracting stimuli by boosting attention toward relevant events. *Cerebral Cortex*, *15*, 229–237.
- Xue, S., Tang, Y.-Y., & Posner, M. I. (2011). Short-term meditation increases network efficiency of the anterior cingulate cortex. *NeuroReport*, *22*, 570–574.
- Zeidan, F., Martucci, K. T., Kraft, R. A., Gordon, N. S., McHaffie, J. G., & Coghill, R. C. (2011). Brain mechanisms supporting modulation of pain by mindfulness meditation. *Journal of Neuroscience*, *31*(14), 5540–5548.