WHAT CAN NEUROSCIENCE LEARN FROM CONTEMPLATIVE PRACTICES?

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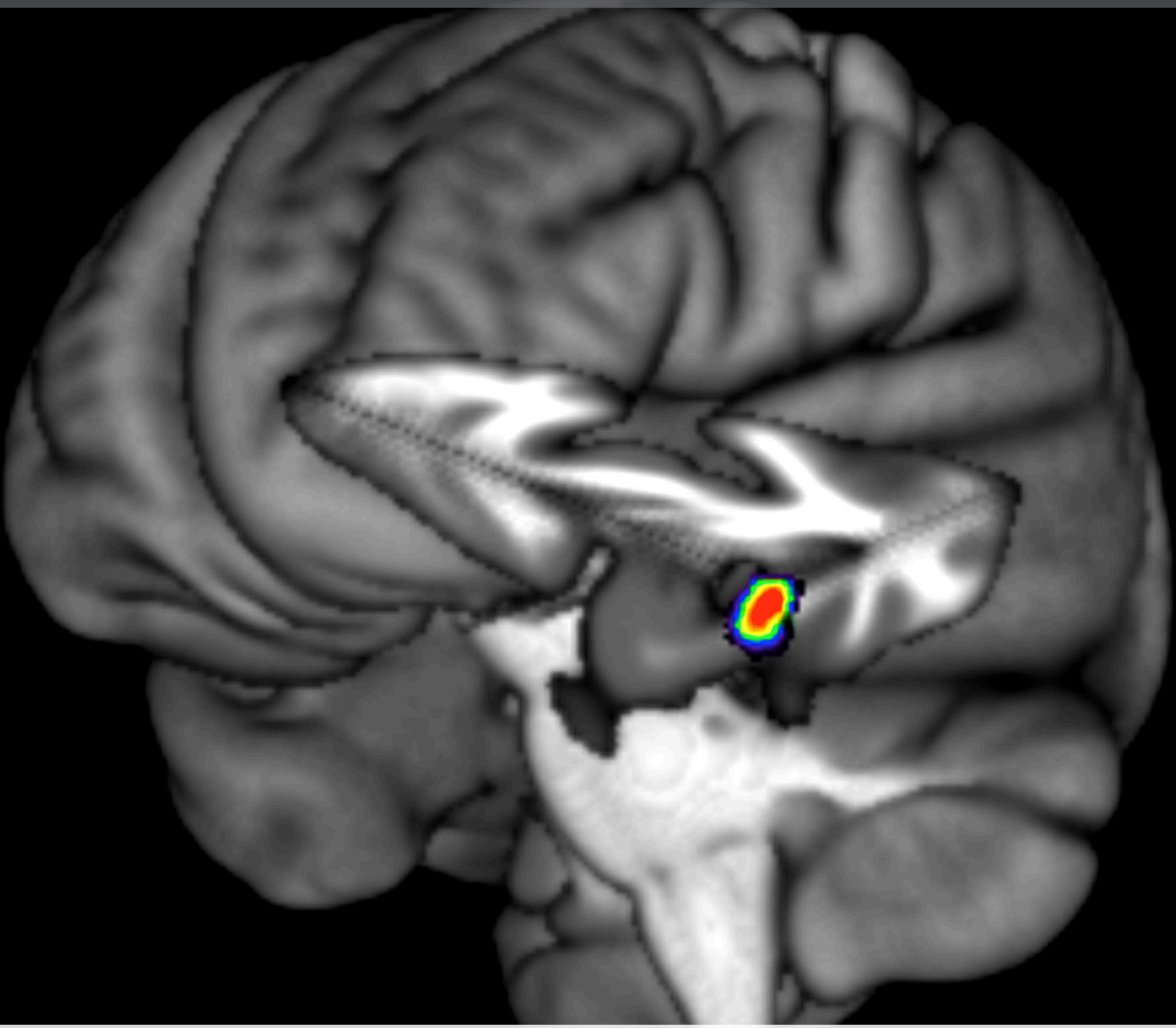

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WHAT CAN NEUROSCIENCE LEARN FROM CONTEMPLATIVE PRACTICES?

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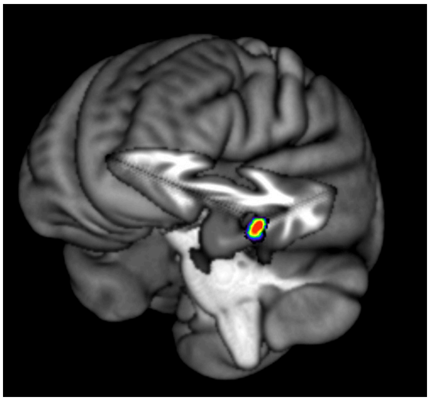

Figure taken from: Luders, E., Kurth, F., Toga, A.W., Narr, K. L. and Gaser, C. (2013). Meditation effects within the hippocampal complex revealed by voxel-based morphometric and cytoarchitectonic probabilistic mapping. Front. Psychol., doi: 10.3389/fpsyg.2013.00398

A recent wave of brain research has advanced our understanding of the neural mechanisms of conscious states, contents and functions. A host of questions remain to be explored, as shown by lively debates between models of higher vs. lower-order aspects of consciousness, as well as global vs. local models. (Baars 2007; Block, 2009; Dennett and Cohen, 2011; Lau and Rosenthal, 2011).

Over some twenty-five centuries the contemplative traditions have also developed explicit descriptions and taxonomies of the mind, to interpret experiences that are often reported in contemplative practices (Radhakrishnan & Moore, 1967; Rinbochay & Naper, 1981). These traditional descriptions sometimes converge on current scientific debates, such as the question of conceptual vs. non-conceptual consciousness; reflexivity or "self-knowing" associated with consciousness; the sense of self and consciousness; and aspects of consciousness that are said to continue during sleep. These real or claimed aspects of consciousness have not been fully integrated into scientific models so far.

This Research Topic in Consciousness Research aims to provide a forum for theoretical proposals, new empirical findings, integrative literature reviews, and methodological improvements inspired by meditation-based models. We include a broad array of topics, including but not limited to: replicable findings from a variety of systematic mental practices; changes in brain functioning and organization that can be attributed to such practices; their effects on adaptation and neural plasticity; measurable effects on perception, cognition, affect and self-referential processes.

We include contributions that address the question of causal attribution. Many published studies are correlational in nature, because of the inherent difficulty of conducting longitudinal experiments based on a major lifestyle decision, such as the decision to commit to a mental practice over a period of years. We also feature clinical and case studies, integrative syntheses and significant opinion articles.

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EDITORIAL
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Editorial: What can Neuroscience Learn from Contemplative Practices?

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Keywords: meditation, mindfulness, neural correlates of consciousness, structural plasticity, functional plasticity, contemplative practice, cultural issues

Contemplative practices like meditation and mindfulness have recently gained increased acceptance in science and clinical practice, although a number of issues related to their phenomenology and to experimental designs still remain (Dahl et al., 2015).

SIGNS OF PROGRESS

Significant progress has been made in the area of the neuroimaging of meditation and mindfulness, leading to increased understanding of the neural mechanisms underlying different techniques and stages of meditation (Lutz et al., 2008; Travis and Shear, 2010; Vago and Silbersweig, 2012; Craigmyle, 2013; Josipovic, 2014; Tang et al., 2015a). Results point to increased flexibility and efficiency of the brain's networks, and to enhanced functional and structural integration among their nodes (Braboszcz et al., 2013; Luders et al., 2013; Tang et al., 2015a).

The effects of meditation and mindfulness on physiological measures have been researched extensively. Although some of these findings have been challenged over the years, others, such as cortisol level decrease, enhanced immune response, decreased chronic pain, etc. have held. Recent findings of epigenetic changes due to relaxation response (Bhasin et al., 2013), focused attention meditation (Jacobs et al., 2013), and mindfulness (Carlson et al., 2014), may have significant clinical implications. Changes in structural plasticity in the brain due to both long-term (Luders et al., 2013; Kurth et al., 2015) and short term meditation training (Hölzel et al., 2011; Tang et al., 2012), provide further, though indirect, evidence of epigenetic effects.

Increasingly, studies point to beneficial effects of meditation and mindfulness on cognition, affect, and social behavior, though the findings can be contradictory at times and the effect sizes small (Braboszcz et al., 2013; Leonard et al., 2013; Ben-Soussan et al., 2014; for review see Dahl et al., 2015; Tang et al., 2015a). The effects on attentional networks have been seen most clearly in long-term practitioners, or after longer (3 month) retreats, with possible differential effects on alerting, orienting and executive attention networks at different stages of practice (Chiesa et al., 2011). Effects on the working memory, conflict monitoring and response inhibition, and the increased activation of related prefrontal areas, have been proposed as the top-down mechanism mediating the effects of mindfulness on emotion regulation (Vago and Silbersweig, 2012; Tang et al., 2015b). The overall pattern that emerges is one of initial reliance on the effortful top-down control that gradually shifts, with an acquisition of expertise, to a more effortless implicit bottom-up regulation. Understanding how different meditation techniques affect the sense of self, whether deconstructing or reconstructing it, may prove to be the key in understanding the more lasting effects of meditation (Austin, 2013; Tang and Tang, 2013; Dahl et al., 2015).

The validity of introspection has been a perennial issues for contemplative traditions. Though experienced meditation practitioners may be more accurate in reporting their experiences than average subjects (Lutz et al., 2007), the choice of contents reported, and the manner of reporting them, are often influenced by the language and beliefs of the tradition subjects belong to. Thus training research subjects in the art of phenomenological epoche may be necessary.

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Meditation and mindfulness practices can also generate intense and unusual experiences and altered states of consciousness, such as states of reduced phenomenal content, or absorptions (Lutz et al., 2007). These are akin to states of deep relaxation, or even deep sleep, but without actually sleeping. They can have other unusual features, such as alterations in the sense of time and space (Berkovich-Ohana et al., 2013), or spontaneous perceptions of light patterns (Lindahl et al., 2014). An intuitive, but arguable, idea is that most of these states should lead to global decreases in cortical activity (Hinterberger et al., 2014; Berkovich-Ohana et al., 2015), or at least to decreases in the areas related to spontaneous thinking (Brewer et al., 2011). Perhaps even more interesting are the states of reduced phenomenal content accompanied by increased awareness. The subjects report experiencing their consciousness as being relatively "pure," an awareness without a content. These may emerge at first as brief interruptions in one's usual stream of consciousness during meditation (Baars, 2013), then get progressively more stabilized and longer lasting, until eventually one can find the "pure" nondual awareness present as a background context of all one's experiences, including dreaming and deep sleep (Travis et al., 2002; Ferrarelli et al., 2013; Josipovic, 2014; Thompson, 2014). Baars (2013) discusses some possible ways of approaching the research of these states. Expanding the neuroscience view of consciousness to include certain perspectives found in contemplative traditions may help to resolve some of the current impasses in debates about the neural correlates of consciousness (Block, 2007; Cohen and Dennett, 2011; Lau and Rosenthal, 2011; Baars et al., 2013).

ONGOING CHALLENGES

One of the most challenging issues for meditation studies is the lack of accurate indices of subjects' experience during meditation, independent from subjects' reports. Several neurophysiological measures have been proposed over the years, however, it is not likely that any single measure can adequately capture the complexity of meditation experience (Davis and Vago, 2014). An interesting recent development are the attempts to obtain experience sampling data and provide neurofeedback via wearable devices and cell phones, as an adjunct to meditation training. As Brandmeyer and Delorme (2013) point out such attempts still await further scientific developments in sensor technology.

Several persistent methodological issues have plagued meditation research studies since the early days (Nash and Newberg, 2013; Dahl et al., 2015; Tang et al., 2015a). Reliance on self-report measures with inadequate controls for placebo effect and demand characteristic can make the results questionable. Obtaining neuroimaging and other physiological measures that parametrically co-vary with self-report measures can remedy this and facilitate assessing the meaning of results. However, more direct systematic replications of results are needed. Replication attempts can be compromised when subjects or researchers in the original and replication studies belong to schools of contemplative practice that define the same meditation differently. Largely due to funding limitations, most meditation studies are still of a pilot kind, with a small number of self-selected subjects, utilizing within-subject or cross-sectional designs, and often with inadequate control groups for the placebo effect. Large scale, randomized, longitudinal studies with active control groups can overcome some of these shortcomings (Tang et al., 2015a).

DIFFICULTY IN RELATING TO TRADITIONAL VIEWS

The extraordinary multiplicity of meditation techniques and seemingly contradictory effects they produce pose a significant challenge for researchers. While the current research-oriented taxonomies have addressed this problem through categorizing meditation techniques into two or three major styles (Lutz et al., 2008; Josipovic, 2010; Travis and Shear, 2010), further optimizing is needed for such taxonomies to be more accurate and comprehensive (Nash and Newberg, 2013; Newberg, 2014; Dahl et al., 2015).

Contrary to popular "one-size-fits-all" approaches and advertisements, different meditations can have differential effects depending on one's psychological and physical makeup, and on the stage of one's practice. Adverse effects of meditation and mindfulness, which are often discounted in traditional contexts, can be significant and are only recently being studied in a systematic way (Garland et al., 2015).

Taking meditation out of its cultural, religious, and philosophical contexts may miss the influences that these contexts can have on the observed results. Future research will need to include spiritual and religious motivations, ethical concerns, as well as interpersonal and cultural contexts (Nash and Newberg, 2013; Dahl et al., 2015). The views on the overall goal of contemplative practice can be diametrically opposed both between different traditions and within the sects of the same tradition, and can significantly influence how individuals practice, which experiences they cultivate, and which ones get selected for research (Davis and Vago, 2014).

Science alone, in its present form, may not be able to answer ontological and metaphysical questions about the nature of consciousness that are the focus of contemplative traditions (Delorme et al., 2013). New scientific methods, and a more integrated approach that combines humanities and sciences, may be necessary to encompass the vastness of human experience that meditations can lead to.

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ORIGINAL RESEARCH ARTICLE
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Meditation effects within the hippocampal complex revealed by voxel-based morphometry and cytoarchitectonic probabilistic mapping

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Scientific studies addressing anatomical variations in meditators' brains have emerged rapidly over the last few years, where significant links are most frequently reported with respect to gray matter (GM). To advance prior work, this study examined GM characteristics in a large sample of 100 subjects (50 meditators, 50 controls), where meditators have been practicing close to 20 years, on average. A standard, whole-brain voxel-based morphometry approach was applied and revealed significant meditation effects in the vicinity of the hippocampus, showing more GM in meditators than in controls as well as positive correlations with the number of years practiced. However, the hippocampal complex is regionally segregated by architecture, connectivity, and functional relevance. Thus, to establish differential effects within the hippocampal formation (cornu ammonis, fascia dentata, entorhinal cortex, subiculum) as well as the hippocampal-amygdaloid transition area, we utilized refined cytoarchitectonic probabilistic maps of (peri-) hippocampal subsections. Significant meditation effects were observed within the subiculum specifically. Since the subiculum is known to play a key role in stress regulation and meditation is an established form of stress reduction, these GM findings may reflect neuronal preservation in long-term meditators—perhaps due to an attenuated release of stress hormones and decreased neurotoxicity.

Keywords: cytoarchitectonics, hippocampus, mapping, meditation, mindfulness, MRI, subiculum, VBM

INTRODUCTION

The scientific literature recording anatomical variations in meditators' brains has grown rapidly in recent years (Lazar et al., 2005; Pagnoni and Cekic, 2007; Holzel et al., 2008, 2010; Luders et al., 2009b, 2011, 2012a,b,c; Vestergaard-Poulsen et al., 2009; Grant et al., 2010; Tang et al., 2010, 2012; Murakami et al., 2012; Kang et al., 2013; Leung et al., 2013). Meditation effects, either established as differences between mindfulness practitioners and controls (using cross-sectional designs), as correlates between anatomical measures and the amount of practice, or as actual brain changes due to mindfulness practices (using longitudinal designs), have been observed for numerous cerebral measures. Findings with respect to the attributes of gray matter (GM), however, are amongst the most widely reproduced (Lazar et al., 2005; Pagnoni and Cekic, 2007; Holzel et al., 2008, 2010; Luders et al., 2009b; Vestergaard-Poulsen et al., 2009; Grant et al., 2010; Murakami et al., 2012; Kang et al., 2013; Leung et al., 2013). Moreover, numerous studies have revealed meditation effects in the vicinity of the hippocampus, such as more hippocampal and parahippocampal GM, larger hippocampal dimensions—both globally (total hippocampal volume) and locally (radial hippocampal distances)—as well as enhanced fiber integrity in white matter pathways connecting with the hippocampus (Holzel et al., 2008; Luders et al., 2009b, 2011, 2012c; Murakami et al., 2012; Leung et al., 2013). Altogether, this suggests GM to be a sensitive anatomical marker for determining links between mindfulness practices and brain anatomy, with the hippocampal complex implicated as a structure of particular interest.

To further explore GM characteristics in the framework of meditation, we analyzed a large sample of 100 subjects (i.e., 50 long-term meditation practitioners and 50 control subjects, closely matched for sex, age and handedness). We first applied a standard, whole-brain voxel-based morphometry (VBM) approach and, in accordance with prior studies, revealed significant meditation effects in the vicinity of the hippocampus. According to the matched filter theorem, VBM is most sensitive to effects in the size of the selected smoothing kernel. However, additional effects, ranging above and below that particular spatial scale, may be missed. Similarly, effects that largely deviate from the shape of the applied filter (e.g., occurring in non-spherical structures) may not be captured. Thus, since the hippocampal formation represents a complex of anatomic divisions varying in size and shape, we utilized a second volumetric approach refined by cytoarchitectonic probabilistic mapping to establish differential effects within (peri-) hippocampal subregions.

MATERIALS AND METHODS

SUBJECTS

The study included 50 meditation practitioners (28 men, 22 women) and 50 control subjects (28 men, 22 women). Their ages ranged from 24 to 77 years, where groups were closely matched for age [mean ± *SD*: 51.4 ± 12.8 years (meditators) vs. 50.4 ± 11.8 years (controls)]. While scans for the controls were obtained from the International Consortium for Brain Mapping (ICBM) database of normal adults (http://www.loni.ucla.edu/ICBM/Databases/), meditators were newly recruited from various meditation venues in the greater Los Angeles area. Years of meditation experience ranged between 4 and 46 years (mean ± *SD*: 19.8 ± 11.4 years). A detailed overview with respect to each subject's individual practice has been provided elsewhere (Luders et al., 2012a). The majority of subjects (89%) indicated that they were right-handed; six meditation practitioners and five control subjects were left-handed. All subjects gave their informed consent in accordance with the policies and procedures of UCLA's Institutional Review Board.

IMAGE ACQUISITION AND PREPROCESSING

All subjects (i.e., meditators and controls) were scanned at the same site, using the same scanner and image acquisition protocol. Specifically, magnetic resonance images were acquired on a 1.5 T Siemens Sonata scanner (Erlangen, Germany) using an 8-channel head coil and a T1-weighted MPRAGE sequence (1900 ms TR, 4.38 ms TE, 15° flip angle, 160 contiguous sagittal slices, 256 × 256 mm FOV, 1 × 1 × 1 mm voxel). Data was analyzed using SPM8 software (http://www.fil.ion.ucl.ac.uk/spm) and the VBM8 toolbox (http://dbm.neuro.uni-jena.de/vbm.html). Using the same generative model, images were corrected for magnetic field inhomogeneities and tissue-classified into GM, white matter and cerebrospinal fluid. The tissue segmentation procedure was further refined by accounting for partial volume effects (Tohka et al., 2004) and by applying adaptive maximum *a posteriori* estimations (Rajapakse et al., 1997) and non-local means denoising (Manjon et al., 2010). The resulting GM partition was then spatially normalized to the DARTEL template (provided by the VBM8 toolbox) using linear (12-parameter affine) transformation and high-dimensional warping (Ashburner, 2007). This set of warped GM segments in scaled space provided the basis for the standard VBM approach. In addition, we generated GM segments in native space constituting the input for the probabilistic approach.

VOXEL-WISE GM (VBM APPROACH): WHOLE BRAIN

As described previously (Luders et al., 2009a), the warped GM segments in scaled space were divided by the non-linear components (but not the linear components) derived from the normalization matrix. This modulation step serves to preserve actual GM values locally, while still accounting for the individual differences in brain size (via proportional scaling). The modulated GM volumes in scaled space were smoothed with a Gaussian kernel of 6 mm full-width-at-half-maximum (FWHM). Using these smoothed scaled GM segments, statistical analyses (described below) were conducted at each voxel across the entire brain.

VOLUMETRIC GM (PROBABILISTIC APPROACH): HIPPOCAMPAL COMPLEX

This refined approach utilized the three-dimensional (3D) probabilistic labels of the following (peri-) hippocampal subsections: (I) cornu ammonis (CA), (II) fascia dentata (FD), (III) entorhinal cortex (EC), (IV) subiculum (SUB), and (V) hippocampal-amygdaloid transition area (HATA). These 3D labels constitute cytoarchitectonic probabilistic maps, available as part of the Anatomy Toolbox (Eickhoff et al., 2005), that were originally created using cell-body stained histological sections of 10 *post mortem* brains, as detailed elsewhere (Amunts et al., 2005). Briefly, the cytoarchitectonically-defined structures were digitized, warped into MNI single-subject space and converted into 3D probability maps. Thus, each voxel within a 3D probability map contains a count of how many brains (out of ten) had that voxel labeled as the respective hippocampal subregion, therefore coding inter-individual cytoarchitectonic variability in MNI space.

In the current study, these 3D cytoarchitectonic probabilistic maps were first converted from MNI space into each subject's native space. Then, the individual GM segments in native space were multiplied voxel-wise with the 3D probabilistic labels of the five hippocampal substructures, bilaterally. Since the labels encode voxel-wise probabilities ranging between 0 and 100% (rather than a binary value indicating if a voxel is part of the label or not), multiplying them with the GM segments generates probability-weighted voxel-wise GM volumes within each (peri-) hippocampal subregion. The voxel-wise values were added yielding one single GM value per subregion per subject. Using the region-specific probability-weighted volumetric GM (in mm^3), statistical analyses were conducted as detailed below.

STATISTICAL ANALYSES

VBM approach

Voxel-wise GM differences between meditators and controls were examined, while co-varying for gender and age, via the general linear model in SPM8. In order to avoid possible edge effects, all GM voxels with values of less than 0.1 were excluded (absolute threshold masking). Threshold-free cluster enhancement (Smith and Nichols, 2009) was used to detect significant clusters at $p \leq 0.05$, corrected for the entire search volume by controlling the False Discovery Rate (Benjamini and Hochberg, 1995). In addition, within the sample of meditators, partial correlation analyses were performed to explore associations between voxel-wise GM and the number of meditation years, while removing the effects of gender and age.

Probabilistic approach

Volumetric GM differences between meditators and controls were examined using the general linear model in SPSS20 in a multivariate analysis of co-variance (MANCOVA), with the subregions as dependent measures and gender, age and brain size (approximated by the linear scaling factor derived from the normalization matrix)[1] as covariates. The significant main effect was followed by *post hoc* comparisons to examine group differences for each subregion separately, where $p \leq 0.05$ was determined as the threshold for statistical significance. In addition, within the sample of meditators, partial correlation analyses were performed to explore associations between region-specific volumetric GM and the number of meditation years, while removing the effects of gender, age and brain size.

[1]While total intracranial volume (TIV) might be a more commonly used measure, co-varying for the linear scaling factor makes the outcomes resulting from the two approaches more comparable. Nevertheless, we also repeated the volumetric GM analysis co-varying for TIV (rather than for the linear scaling factor). However, since both values are highly correlated ($r = 0.91$, $p \leq 0.001$), the outcomes are very similar (see Results).

RESULTS

VBM ANALYSIS

As shown in **Figure 1**, the voxel-wise analysis revealed one cluster situated in the vicinity of the left hippocampus with significantly more GM in meditators than in controls. The significance maximum was located at x; y; $z = -18$; -37; -11. When extracting the GM values at the aforementioned peak voxel for each meditator and relating them to the individual number of meditation years, there was a significant positive partial correlation ($r = 0.34$; $p = 0.015$) suggesting that there is an increase of GM with increasing meditation experience.

PROBABILISTIC ANALYSIS

Descriptively, volumetric GM was larger on average in meditators than in controls (**Table 1**). The multivariate model, including

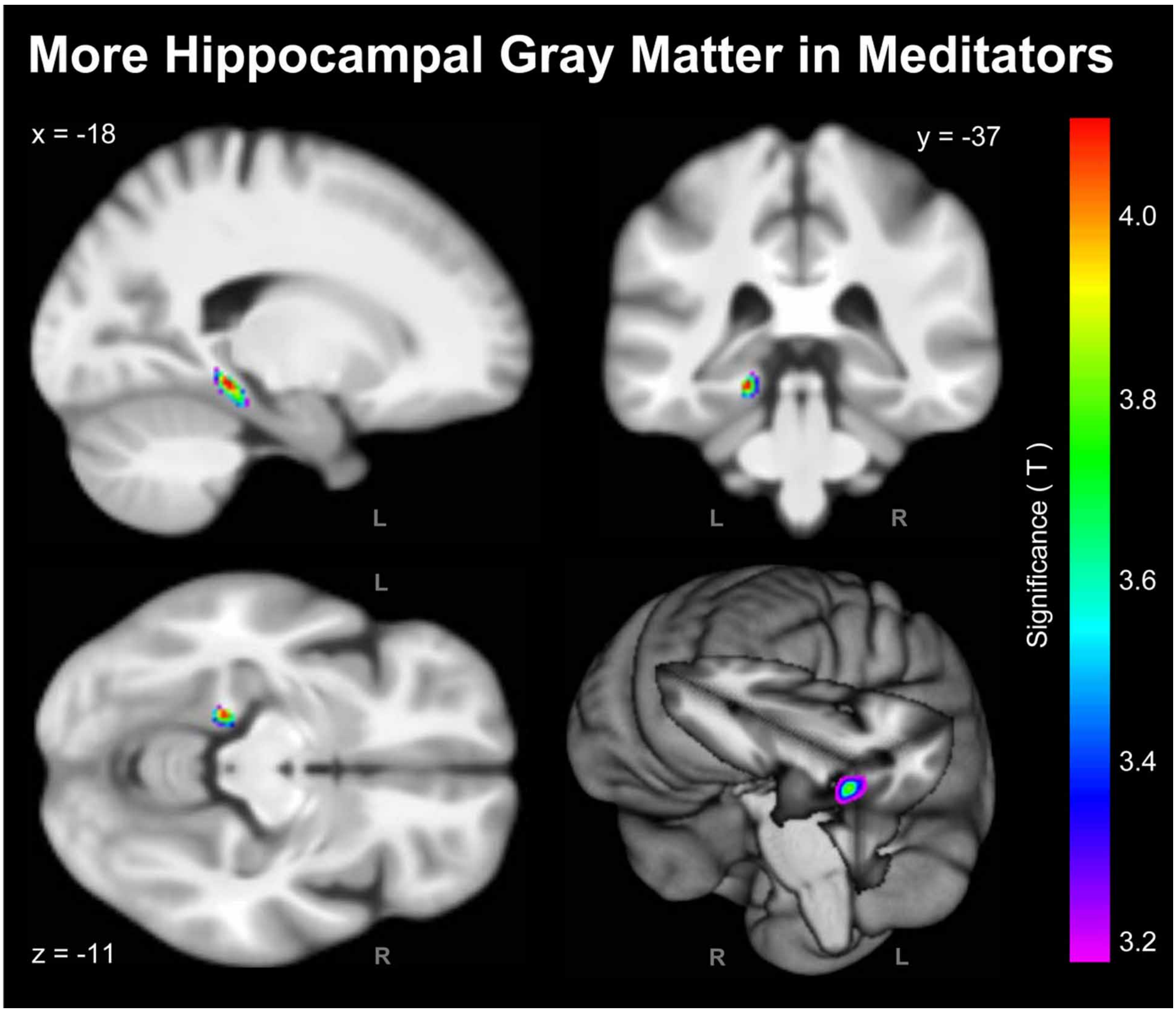

FIGURE 1 | Significant Group Differences. Shown are the outcomes of the voxel-wise analysis (VBM approach) indicating more hippocampal GM in meditators compared to controls (L, left hemisphere; R, right hemisphere). For the purpose of illustrating the significance gradient, the color bar encodes the *T*-value at $p \leq 0.001$, uncorrected. The difference cluster was confirmed when applying corrections for multiple comparisons at $q = 0.05$. Displayed are section views (sagittal, coronal, axial) and the rendered view of the mean brain created from the whole study population ($n = 100$). The *x*-, *y*-, *z*-coordinates in MNI space indicate the significance maximum.

Table 1 | Volumetric GM estimates (in mm^3).

Subregion	Group	Mean	Standard deviation	Significance (*p*)
LEFT HEMISPHERE				
CA	MED	4494.95	281.06	0.798
	CTL	4487.48	304.45	
EC	MED	3913.80	324.90	0.817
	CTL	3898.00	352.78	
FD	MED	2320.16	146.09	0.610
	CTL	2309.36	161.30	
HATA	MED	272.38	24.70	0.071
	CTL	264.53	25.02	
SUB	MED	3080.62	179.04	0.045*
	CTL	3009.22	218.55	
RIGHT HEMISPHERE				
CA	MED	4633.59	268.21	0.281
	CTL	4576.92	370.70	
EC	MED	4272.15	307.80	0.211
	CTL	4193.26	350.94	
FD	MED	2321.77	136.09	0.213
	CTL	2289.41	181.99	
HATA	MED	229.65	19.07	0.287
	CTL	225.98	21.13	
SUB	MED	3279.81	174.46	0.031*
	CTL	3199.38	247.18	

CA, cornu ammonis; EC, entorhinal cortex; FD, fascia dentata; HATA, hippocampal-amygdaloid transition area; SUB, subiculum; MED, meditators; CTL, controls. The asterisks mark the significant group differences ($p \leq 0.05$).

all 10 subregions, yielded a significant main effect of group ($F = 2.067$; $p = 0.036$). Subsequent *post hoc* comparisons of each subregion revealed significantly higher values in meditators within the left subiculum ($F = 4.126$; $p = 0.045$) and right subiculum ($F = 4.786$; $p = 0.031$). In addition, there was a trend for significance for the left hippocampal-amygdaloid transition area ($F = 3.333$; $p = 0.071$). Descriptively, for all subregions, partial correlations between the number of meditation years and volumetric GM were positive. However, effects were relatively small and only the left subiculum reached statistical significance ($r = 0.327$; $p = 0.025$). In addition, there was a trend for significance for the left entorhinal cortex ($r = 0.271$; $p = 0.066$)[2].

DISCUSSION

To our knowledge, this is the first study combining a whole-brain, voxel-based approach with probability-weighted cytoarchitectonic information to assess links between meditation and local GM. With 100 subjects (50 meditators, 50 controls), where meditators have been practicing close to 20 years on average, our sample constitutes one of the largest, more experienced meditation cohorts studied to date. Our study revealed robust meditation effects, with more GM in meditators than in controls within the hippocampal complex as well as positive associations between (peri-) hippocampal GM and number of practice years.

Several studies have demonstrated the hippocampus to be anatomically altered in meditation practitioners, with more hippocampal or parahippocampal GM (Holzel et al., 2008; Leung et al., 2013), larger hippocampal volumes globally (Luders et al., 2009b, 2012c), larger hippocampal radial distances locally (Luders et al., 2012c), as well as enhanced fiber integrity in white matter pathways connecting with the hippocampus (Luders et al., 2011). Moreover, positive correlations have been reported between parahippocampal GM and a specific facet of mindfulness (Murakami et al., 2012). In addition, functional experiments, either using positron emission tomography (PET) or functional magnetic resonance imaging (fMRI), seem to implicate the hippocampus and/or the parahippocampal gyrus as significantly involved in meditation processes (Lou et al., 1999, 2005; Lazar et al., 2000; Holzel et al., 2007; Engstrom et al., 2010; Kalyani et al., 2011). The observed voxel-wise findings in the vicinity of the hippocampus are in close agreement with these previously reported findings. The hippocampal complex, however, is not a single, homogeneous structure but comprises of cytoarchitecturally distinct subdivisions. Thus, in contrast to previous analyses where the hippocampus was mostly considered as a single unit (either already defined *a priori* or detected as different *a posteriori*), we set out to discriminate between the different subregions of the hippocampal complex. While the borders of (peri-) hippocampal subsections rarely match macro-anatomical landmarks, microscopic labeling enables a more precise localization of these boundaries (Amunts et al., 2005). We therefore analyzed local GM within 3D (peri-) hippocampal labels that were carefully determined using microscopic information obtained via silver staining for cell bodies (Amunts et al., 2005). This unique approach revealed significant meditation effects within the left and right hippocampal subiculum.

The hippocampus is a key structure for memory processes, both in terms of memory encoding and retrieval, and the subiculum seems to occupy a central position within this memory system (Naber et al., 2000). Our current findings might thus account for positive effects of meditation on memory performance, such as an enhanced capacity of working memory as well as increased specificity of autobiographical memory (Williams et al., 2000; Heeren et al., 2009; Kozhevnikov et al., 2009; Chiesa et al., 2011). With particular respect to the subiculum, a specific association with episodic recollection has been reported (Viskontas et al., 2009), suggesting that the subiculum plays a significant role for "re-experiencing an event as part of one's personal past." Regular meditating, especially meditation over many years, involves engaging in an established routine. It not only leads to a variety of mind-altering / new states, but it also involves re-experiencing states, such as the shift that occurs from normal consciousness to meditation (Travis and Wallace, 1999). Our current findings of GM alterations within the subiculum might thus be associated with this kind of recollective experience during

[2] When co-varying for TIV (rather than for the linear scaling factor), the main effect was significant with $F = 2.013$ ($p = 0.041$). The *post hoc* comparisons revealed $F = 4.010$ ($p = 0.048$) for the left subiculum, $F = 4.804$ ($p = 0.031$) for the right subiculum, and $F = 3.468$ ($p = 0.066$) for the left hippocampal-amygdaloid transition area. The partial correlations were $r = 0.314$ ($p = 0.032$) for the left subiculum and $r = 0.257$ ($p = 0.082$) for the left entorhinal cortex.

meditation. Alternatively, or as a complementary association, more (peri-) hippocampal GM might also account for meditators' abilities to habitually engage in mindful behavior by regulating their responses in a context-sensitive fashion. The key role of the subiculum within the behavioral inhibition system has been extensively reviewed (McNaughton, 2006). One of its functions is to compare and integrate incoming goal-related information and to produce output when conflict between incompatible goals is detected. Thus, more GM within the subiculum might be the neuronal foundation that allows meditators to mindfully choose from an array of behavioral options leading to well-adjusted responses not only to everyday occurrences, but also major life events. This ability is often referred to as non-reactivity.

Due to the cross-sectional design of our study, it is impossible to determine if the observed GM alterations are a prerequisite for meditation practices or an actual consequence of meditating. More specifically, it is possible that more GM in the hippocampal subiculum constitutes an innate brain characteristic that attracts an individual toward meditation. Likewise, a specific neuronal build-up may facilitate reaching desired states during meditation and/or experiencing positive effects following meditation, and may thus help maintaining a regular and long-term practice via intrinsic positive reinforcement. On the other hand, engaging in meditation is an active mental process that, depending on the technique, incorporates efforts to exercise awareness, attention, concentration, focus, etc. Thus, if occurring regularly, such intense mental processes may directly affect local GM volume by initiating microscopic events, such as dendritic branching, synaptogenesis or even adult neurogenesis as occurs in the dentate (Eriksson et al., 1998; Gage, 2002; Elder et al., 2006). Although the precise underlying mechanisms for GM changes in healthy volunteers are still poorly understood, similar training-induced increases of hippocampal GM, albeit unrelated to meditation, have been reported during periods of extensive learning and exercise (Draganski et al., 2006; Pereira et al., 2007; Boyke et al., 2008). Alternatively, or as a complementary mechanism to the aforementioned direct training effects, meditation might also have indirect preservative and/or restorative effects by positively affecting stress regulation. It is well-known, for example, that mindfulness-based techniques are highly effective in stress reduction, both in terms of subjectively perceived stress as well as objectively measured biomarkers of stress (Holzel et al., 2010; Jung et al., 2010, 2012; Mohan et al., 2011; Baer, 2003; Ciesla et al., 2012; Jensen et al., 2012; Marchand, 2012; Fan et al., 2013). The hippocampus and especially the subiculum play a major role in stress regulation by inhibiting the hypothalamo-pituitary-adrenocortical (HPA) axis. Specifically, the output neurons of the hippocampal subiculum (i.e., where main effects occurred in the present study) are heavily involved in attenuating the release of stress-induced glucocorticoids (Herman and Mueller, 2006). Prolonged glucocorticoid elevations, in turn, have been demonstrated to increase hippocampal vulnerability to neurotoxicity (Conrad et al., 2007), which may manifest as loss of (peri-) hippocampal neurons or disturbances in hippocampal neurogenesis. Consequently, if actively meditating is accompanied by stress reduction (and thus by an attenuated release of stress hormones and decreased neurotoxicity), meditation practitioners might have more GM in the vicinity of the hippocampus due to neuron preservation and/or neurogenesis. In strong support of this theory, a recent longitudinal VBM study, designed to identify brain regions that changed in association with participation in an 8-week mindfulness-based stress reduction (MBSR) intervention, revealed significant GM increases within the left hippocampus (Holzel et al., 2011).

FUTURE RESEARCH

The current findings may suggest that actively meditating induces changes of (peri-) hippocampal GM (either directly or indirectly). However, as our study is cross-sectional in nature, any conclusions with respect to a causal role of meditation remain speculative. Further research incorporating longitudinal designs is clearly needed. Moreover, future studies may also obtain measures of cortisol (a biological marker for stress). This will serve to elucidate the underlying mechanisms for the observed effects by comparing cortisol levels between expert meditators, novice meditators, and non-meditators, by examining possible changes in cortisol levels due to intense periods of meditation, and by relating cortisol levels to structural brain imaging measures. Last but note least, future studies collecting subject-specific information with respect certain lifestyle choices—including diet, recreational drugs, and physical exercise—may further advance this field of research by taking into account additional features (i.e., aside from the actual practice of meditation) discriminating between meditators and non-meditators.

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Mindfulness training improves attentional task performance in incarcerated youth: a group randomized controlled intervention trial

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We investigated the impact of cognitive behavioral therapy and mindfulness training (CBT/MT) on attentional task performance in incarcerated adolescents. Attention is a cognitive system necessary for managing cognitive demands and regulating emotions. Yet persistent and intensive demands, such as those experienced during high-stress intervals like incarceration and the events leading to incarceration, may deplete attention resulting in cognitive failures, emotional disturbances, and impulsive behavior. We hypothesized that CBT/MT may mitigate these deleterious effects of high stress and protect against degradation in attention over the high-stress interval of incarceration. Using a quasi-experimental, group randomized controlled trial design, we randomly assigned dormitories of incarcerated youth, ages 16–18, to a CBT/MT intervention (youth $n = 147$) or an active control intervention (youth $n = 117$). Both arms received approximately 750 min of intervention in a small-group setting over a 3–5 week period. Youth in the CBT/MT arm also logged the amount of out-of-session time spent practicing MT exercises. The Attention Network Test was used to index attentional task performance at baseline and 4 months post-baseline. Overall, task performance degraded over time in all participants. The magnitude of performance degradation was significantly less in the CBT/MT vs. control arm. Further, within the CBT/MT arm, performance degraded over time in those with no outside-of-class practice time, but remained stable over time in those who practiced mindfulness exercises outside of the session meetings. Thus, these findings suggest that sufficient CBT/MT practice may protect against functional attentional impairments associated with high-stress intervals.

Keywords: adolescent development, incarcerated adolescents, detained adolescents, stress, attention, mindfulness meditation

INTRODUCTION

On any given day, over 100,000 youth are detained in prisons, jails, and juvenile detention centers across the United States (OJJDP, 2009). The overwhelming majority of these youth have experienced significant early psychosocial adversity which often has deleterious effects on brain development, particularly in areas of cognitive control responsible for regulating emotions (Abram et al., 2004; van Goozen et al., 2007; Ganzel et al., in press). Deficits in cognitive control processes, including attention, working memory, and regulation of emotion, are associated with behavioral disorders that are prevalent among youth offenders and contribute to the development and persistence of antisocial behavior (Teplin et al., 2002; Cauffman et al., 2005; Blair and Razza, 2007). In addition, early adversity, particularly childhood maltreatment and hostile behavior in primary caregivers, is associated with hypervigilance to hostile cues and a bias toward interpreting malevolent intent in ambiguous or neutral social situations (Dodge, 2006). Emotionally charged risk-taking situations may exacerbate these biases, particularly for youth who have challenges with cognitive control. These prevalent social and emotional characteristics in detained youth are met with a culture of bullying and violence by peers and staff in correctional facilities [Connell and Farrington, 1996; Ashkar and Kenny, 2008; New York State Juvenile Justice Advisory Group (NYSJJAG), 2010]; loneliness, boredom, and reduced autonomy (Lyon et al., 2000); and a lack of social and educational services (Ashkar and Kenny, 2008). As correctional facilities are often located far from youths' homes, detainees typically have reduced contact with family and friends (NYSJJAG, 2010). Thus, there is a need for treatment and support strategies for detained youth to improve cognitive and emotional control in the stressful detainment environment. In addition, training methods that allow youth to actively engage in exercises on their own to improve cognitive control may be ideal in conjunction with structured intervention activities or psychotherapy to help youth cultivate resilience by building their capacity for cognitive control while detained and after release.

Cognitive behavioral therapy (CBT) has garnered the greatest empirical support as a treatment modality for youth involved in the criminal justice system, although the effects of these interventions tend to be small to moderate in magnitude (Lipsey and Wilson, 1998; McCart et al., 2006; Lipsey, 2009). In the present study, we investigate if mindfulness training (MT) increases the potency of a CBT intervention that is directly targeted to youthful offenders. MT has been previously found to have salutary effects on cognitive and emotional functioning among community and clinical samples of adults and youth (Shapiro et al., 2006; Biegel et al., 2009; Segal et al., 2012) as well as high stress adult cohorts such as pre-deployment military service members (Jha et al., 2010), although its effects on detained youth has not yet been explored. Mindfulness can be described as a particular way of paying attention, on purpose, and in the present moment (Kabat-Zinn, 1990) and is often characterized as comprising two components: self-regulation of attention and non-judgmental awareness (Bishop et al., 2004). One foundational mindfulness exercise, referred to as mindfulness of breathing, involves directing attention to localized sensations related to breathing; when attention wanders, it is to be gently shifted back to the breath. Paired with instructions to focus attention, participants are guided to remain receptive and to monitor the occurrence of wandering thoughts, feelings, and sensations during the exercise by acknowledging their presence without judgment or elaboration. MT has been embedded in interventions that focus on stress reduction, such as Mindfulness-Based Stress Reduction (MBSR; Kabat-Zinn, 1990), and those that utilize cognitive behavioral treatment strategies, such as Mindfulness-Based Cognitive Therapy (MBCT; Segal et al., 2002). In MBCT, consistent training in shifting attention away from ruminative thoughts and back to the breath is postulated to break the self-perpetuating cycle of negative thinking and the downward spiral of negative mood (Segal et al., 2002). Mindfulness-based interventions have been found to improve attention regulation and adaptive coping in community samples of adults (Shapiro et al., 2006; Jha et al., 2007; Tang et al., 2007; van den Hurk et al., 2010) and, more recently, a growing body of research has examined the effects of interventions that incorporate MT for youth who have challenges regulating their emotions and behavior (Semple et al., 2005; Bögels et al., 2008; Biegel et al., 2009; Haydicky et al., 2012).

Attention is a key aspect of cognitive functioning and underlies behavior regulation (Posner and Petersen, 1990). For detained youth, improving attentional control would be highly beneficial; it is a means of increasing awareness of thoughts, feelings, and situations that may lead to offending behavior and directing attention toward interpreting environmental cues more accurately or more consistent with pro-social norms. Attention is a cognitive system that is supported by three discrete subsystems: alerting, orienting, and conflict monitoring (Posner and Petersen, 1990). The alerting network is hypothesized to acquire and maintain an alert state of preparedness and is fully mature by the age of 4 years (Rueda et al., 2004). The orienting network selects information that is most relevant for the current task and may be fully developed by age 9 or 10 (Huang-Pollock et al., 2007). The conflict monitoring network resolves the conflict between goals and performance and prioritizes among competing stimuli (Fan et al., 2002). In typically developing youth, it does not reach full maturity until early adulthood (Rueda et al., 2005; Diamond, 2006). Mindfulness training has been found to improve performance in orienting and conflict monitoring in adults (Brefczynski-Lewis et al., 2007; Chan and Woollacott, 2007; Jha et al., 2007; Slagter et al., 2007; Tang et al., 2007; Heeren et al., 2009) and in adolescents (Baijal et al., 2011). While short periods of MT have been found to improve attention regulation and cognitive control among novice practitioners (Tang et al., 2007; Jha et al., 2010), several studies with adults have observed a dose-response relationship with more practice leading to greater improvement in these domains (Carmody and Baer, 2008; Jha et al., 2010). For example, Jha et al. (2010) examined the protective effect of MT on adults' cognitive functioning during a period of stress. Pre-deployment U.S. Marine reservists participated in either an 8-week MT course or were placed in a no-intervention control group. Performance on a working memory task degraded over time in both groups. However, Marines who reported a spending more time engaging in mindfulness exercises demonstrated greater working memory capacity (WMC, akin to greater cognitive control) relative to those who did not practice or practiced very little.

Cognitive control mechanisms involving engagement of attention and working memory have been proposed to be critical for successful emotion regulation (Gross, 1998, 2002), which includes a sequence of automatic and controlled mental processes that occur prior to the height of emotional, physiological, and behavioral responses in high-emotion situations. In line with the centrality of attentional control in emotion regulation, Jha et al. (2010) found that greater improvements in WMC with MT led to greater reduction in negative mood. Thus, the promise of MT emerging from a growing literature in adults (see Lutz et al., 2009) is that it is a form of mental exercise that improves attention and working memory, which may in turn bolster regulation of cognitive and emotional processes. Yet, it is an open question of whether MT might similarly benefit attentional control in highly stressed youth.

In the current study, we examine whether a group-based, multisession cognitive behavioral therapy and MT (CBT/MT) resulted in improved attentional capabilities among adolescents incarcerated in a high-stress, high-security correctional facility in comparison to an active control intervention. Four main questions were examined: (1) Does performance degrade over time among detained youth, as might be expected given the stressful context? (2) If so, does CBT/MT protect against performance degradation? (3) If MT is helpful, is participation in intervention sessions alone sufficient or are there added benefits to engaging in MT practice outside of sessions? (4) Does being released from incarceration impact the magnitude of potential benefits in attentional performance that may come from CBT/MT?

METHODS

PARTICIPANTS

We recruited 267 incarcerated male youth (age $M = 17.4$ years; $SD = 0.71$, range 16–18) from two buildings within a large urban correctional complex that houses mainly adults. Within each building, youth dormitories were assigned at random to receive either a CBT/MT intervention or an active control intervention. Only a subset of participants completed both pre- and post-training assessments ($n = 201$) due to the following reasons. As per the study protocol, participants ($n = 24$) who were transferred or released after the T1 assessment but before intervention activities began were not contacted for follow-up assessment. Participants ($n = 28$) who were later transferred to a facility where study activities were prohibited by correction officials could not be contacted for a follow-up assessment. In addition, 4 participants refused to complete the T2 assessment, 9 computer files were corrupted, and 1 participant was deported out of the country. Finally, an additional 10 participants were missing release dates, thus, a subset ($n = 191$) were included in the analyses. Between Time 1 (T1; pre-intervention) and Time 2 (T2; 4 months post-baseline) testing sessions, 123 participants were not released and 68 participants were released. The mean length of stay was 106 days (Median = 73 days, IQR = 111).

The majority of the participants (98%) were Black or Latino, reflecting the racial/ethnic composition of all youth in the facility. Self-report of offending behavior indicated that 74% of participants reported ever engaging in non-violent offenses (e.g., theft, selling drugs) and over half (54%) of participants reported engaging in violent offenses (e.g., murder, assault). Official reports of offending behavior were not available from the correctional facility for the majority of youth.

POWER SOURCE INTERVENTION

Power Source (PS) is a group-based cognitive-behavioral/mindfulness meditation intervention for youth involved in the criminal justice system (Casarjian and Casarjian, 2003). The intervention's overarching theoretical frame, the process model of emotional regulation (Gross, 1998), identifies five points at which emotions can be regulated in the emotion-generative process. These points include situation selection, situation modification, attention deployment and appraisal, cognitive change, and response modulation. PS specifically targets all five points by blending the social-cognitive change components of CBT with the attentional and response modification elements of mindfulness meditation. In PS, youth are trained to select peers and situations that decrease the likelihood of offending behavior and build skills to modify situations that might precipitate risk-taking behavior. Attentional training involves learning to appraise high-risk situations, identify environmental, social, emotional, and physiological triggers for risk-taking behaviors, and direct attention toward elements of situations that are incongruent with offending behavior. In addition, youth are trained to reappraise the meaning of situations to alter the emotional impact. Cognitive change is achieved in part via mindfulness, which is a key technique in this emotion regulation process as it trains youth to control their focus of attention toward more neutral stimuli and helps youth reappraise the meaning of a situation in a way that alters its emotional impact. Moreover, MT assists in modulating physiological responses to emotionally charged situations and choosing behavioral responses that are more socially appropriate and adaptive. Importantly, CBT and mindfulness have been described as complementary and synergistic processes where training in mindfulness may foster openness to different perspectives and set the stage for the adoption of CBT skills (Teasdale et al., 2003).

Both formal meditation practice and cognitive behavioral exercises were included in the PS group intervention. The intervention is manual-based and includes videos for demonstrating specific skills including directed meditations. Meditation exercises include sitting meditation, body scans, and walking meditations. After each meeting, youth are given reading assignments from a companion book that reiterates concepts from the intervention in the form of role model stories. Participants are also strongly encouraged to meditate outside of the group sessions and record the amount of time spent in meditation practice outside of sessions.

Youth in the control group received an evidence-based cognitive-perception intervention focusing on attitudes and beliefs about substance use and violence which was modified to exclude any skills or concepts that were under investigation in the PS intervention. Thus, the intervention controlled for time, attention, and the effects of common therapeutic factors, such as therapeutic alliance, empathic counselors, and group cohesion (Safer and Hugo, 2006; Del Boca and Darkes, 2007).

The CBT/MT and control groups met separately for approximately 750 min over the course of 3 to 5 weeks, depending on the safety and security demands of the housing areas. Each session lasted approximately 75 min and each group typically contained between 8 and 12 participants. The groups were led by two trained clinicians who received weekly clinical supervision on implementation and fidelity to the respective manuals. Youth received $5.00 in their commissary account for each group session attended. Make-up sessions were offered individually or in small groups for youth who missed sessions due to court appearances or confinement out of the dormitory for disciplinary purposes. The CBT/MT clinicians had training in mindfulness meditation and their own meditation practices. Clinicians completed quality assurance forms after every session and received weekly supervision that included a review of audiotapes of sessions. Approximately 10% of session recordings were subject to quality assurance ratings for fidelity to both the control and PS intervention and fidelity was high across both conditions.

PROCEDURES

Between August 2009 and April 2011, we recruited 267 incarcerated male youth from a large, urban correctional complex populated primarily by adult prisoners. Two buildings in the complex that contained dormitories for youth, ages 16–18, were used for the current study. The first building (2 dormitories) housed sentenced youth who were serving short-term sentences (up to 12 months) while the second building (5 dormitories) housed youth who were awaiting trial or sentencing. Within each building youth dormitories were assigned at random to receive either the Power Source cognitive behavior/mindfulness training (CBT/MT) intervention (youth $n = 147$ in 4 dormitories) or an active control intervention (youth $n = 117$ in 3 dormitories). The four CBT/MT dormitories contained 20, 24, 33, and 70 participants, respectively. The three active control intervention dormitories contained 17, 26, and 74 participants, respectively.

Recruitment procedures

Youth were approached by research staff in the common room of each dormitory for participation in the study. Youth who had at least six weeks remaining on their sentence or estimated length of stay and could complete an interview in English were invited to participate. Youth who were 18 years old, or considered emancipated if 16 or 17, signed informed consent. Youth less than 18 years of age signed informed assent, and parental consent was obtained for participation. All procedures were approved by the New York University Institutional Review Board and the New York City Department of Corrections.

Assessments

At T1, as part of a longer computer-based interview using audio-computer assisted self-interview format (A-CASI), participants reported demographic and background including age, race/ethnicity, and offense history. The Self Report of Offending (SRO; Huizinga et al., 1991) was used to measure offending history. Youth reported (yes/no) if they engaged one or more of 10 illegal/antisocial behaviors over their lifetime which included violent (e.g., assault, homicide) and non-violent crimes (theft, selling illegal drugs). T2 interviews occurred approximately 21 weeks (range 11–79 weeks) after the T1 interview. At T2, participants in the PS intervention used a 5-point Likert scale ("never" to "several times a day") to report the amount of time they typically meditated outside of the intervention sessions. Participants received $25.00 in their commissary accounts (or in cash if released at T2) for participation in each interview.

STIMULI AND DESIGN

Participants completed the computerized Attention Network Test (ANT; Fan et al., 2002) at T1 and T2 which tests the efficiency of the attentional networks. In the ANT, participants are instructed to focus on a fixation cross in the center of the computer screen. At the start of each trial, a warning cue (asterisks) provides spatial and temporal information about the upcoming target. Participants are instructed to press the right or left arrow key when the target appears as quickly and as accurately as possible. There are four cue conditions. In the no-cue condition, the fixation cross remains on the screen, and the target can appear either above or below the cross; in the double-cue condition, cues appear above and below the fixation cross, and the target can appear either above or below the cross. In the center-cue condition, the fixation cross is replaced with a cue, and the target can appear either above or below the cross. In the spatial cue condition, one cue appears at the location of the target; the spatial cue was 100% predictive of the target position and was equally likely to occur above or below the fixation point. Targets were groups of five arrows pointing in the same direction (congruent), the central arrow pointing in the opposite direction (incongruent), or the solitary central arrow (neutral). The participant's task was to indicate the direction of the central arrow by responding with a left- or right-click on a mouse using the left or right index finger. After an initial practice session, all participants performed a total of 312 experimental trials which lasted approximately 8 min.

RESULTS

All analyses were performed on response times (RT) for correct trials and accuracy (% correct) scores. In addition to overall task performance, the efficiency of each attentional network (alerting, orienting, and conflict monitoring) was examined separately via paired RT subtractions across subsets of conditions. These analyses considered only trials on which the target was flanked by arrows, excluding the neutral target condition. Alerting was indexed by the difference between RTs on double-cue trials and no-cue trials (collapsed across target congruency condition). Orienting was indexed by the difference between RTs on spatial-cue trials and center-cue trials (collapsed across target congruency). Conflict monitoring was indexed by the difference between RTs on congruent target trials and those on incongruent target trials (collapsed across cue-type). The results of these paired subtractions will be referred to as subsystem scores. This method of analysis has been used extensively with the ANT and has been reported in detail elsewhere (e.g., Fan et al., 2002; Jha et al., 2007). We also investigated response variability by calculating the ICV (intra-individual coefficient of variation) which has been shown to decrease after intensive mediation training (Lutz et al., 2009). This coefficient provides a measure of response time dispersion relative to the mean (e.g., Reed et al., 2002; Volkow et al., 2002; Stuss et al., 2003; Bellgrove et al., 2004; Kelley, 2007). It is computed by dividing the standard deviation of response time by the mean response time for each participant. Many recent reports suggest that such response variability changes may reflect distinct processes from overall performance changes. They may be more aligned with a subjective sense of concentration vs. changes in effort, motivation, or mastery over performance (see Zanesco et al., 2013).

There were four stages of analysis. For the first stage, T1 data were examined (1) to confirm basic task effects and compare effects to prior ANT findings in this age-range (see Baijal et al., 2011) and (2) to determine whether there were baseline group differences (CBT/MT vs. control). For the second stage, analyses of variance (ANOVAs) were completed on subsystem scores and overall performance (% correct, RT) as a function of Time and Group (CBT/MT vs. control). For the third stage, the CBT/MT group was divided into those who reported practicing MT outside of intervention sessions and those who did not practice outside of intervention sessions, and ANOVAs were performed to determine if the Control, No-Practice, and Practice groups differed from each other at T2. In the last stage, we examined differences based on possible effects of environmental conditions.

STAGE 1: BASIC EFFECTS AT T1 (PRE-INTERVENTION)

Overall task accuracy was high (93%, SD = 11).

Subsystem performance by group

Independent t-tests were conducted to examine if there were group differences (CBT/MT vs. Control) at T1 on each system score (Alerting, Orienting, Conflict Monitoring).

Alerting

The contrast between the CBT/MT group and the control group revealed no significant difference between groups in either RT

[$t_{(197.58)} = -0.57$, $p = 0.57$] or % correct [$t_{(199)} = -0.19$, $p = 0.85$] scores. See **Figure 1**.

Orienting

There was a marginally significant difference between CBT/MT and control groups in RT difference [$t_{(199)} = 1.68$, $p = 0.09$, Cohen's $d = 0.24$] and no significant differences in % correct difference scores [$t_{(199)} = -1.06$, $p = 0.29$]. See **Figure 2**.

Conflict monitoring

The CBT/MT group and the control group did not differ in either RT difference [$t_{(165.09)} = -1.65$, $p = 0.10$] or % correct difference [$t_{(196.34)} = 1.32$, $p = 0.19$] scores. See **Figure 3**.

Overall task performance

In addition to the system scores, experimental group and release status differences were examined via bivariate analyses. Treatment and control groups did not differ in overall % correct [$F_{(1,\ 199)} = 0.81$, $p = 0.37$] or RT [$F_{(1,\ 199)} = 2.26$, $p = 0.13$].

Thus, the magnitude of the basic effects observed for all three system scores and overall performance are in line with previous results in this age-range (Baijal et al., 2011). In addition, there do not appear to be any group-wise differences in intervention arm scores prior to the onset of the intervention.

STAGE 2: INTERVENTION-RELATED CHANGES OVER TIME

Subsystem performance by group

A series of repeated measures ANOVAs were conducted to examine the effects of intervention arm (CBT/MT vs. Control) and time (T1 vs. T2) on each system score (Alerting, Orienting, Conflict Monitoring).

Alerting

For Alerting, analyses of RT and % correct revealed no main effect of time [$F_{(1,\ 199)} = 2.71$, $p = 0.10$; $F_{(1,\ 199)} = 0.06$, $p = 0.80$], no main effect of group [$F_{(1,\ 199)} = 0.003$, $p = 0.96$; $F_{(1,\ 199)} = 0.11$, $p = 0.75$], and no interaction of time by group [$F_{(1,\ 199)} = 0.41$, $p = 0.52$; $F_{(1,\ 199)} = 0.01$, $p = 0.92$].

Orienting

For Orienting, analyses of RT and % correct revealed a main effect of time for RT only [$F_{(1,\ 199)} = 7.22$, $p = 0.01$, partial $\eta^2 = 0.04$; $F_{(1,\ 199)} = 0.36$, $p = 0.55$], no main effect of group [$F_{(1,\ 199)} = 0.46$, $p = 0.50$; $F_{(1,\ 199)} = 0.78$, $p = 0.38$], and no interactions of time and group [$F_{(1,\ 199)} = 1.18$, $p = 0.28$; $F_{(1,\ 199)} = 0.10$, $p = 0.75$].

Conflict monitoring

Finally, for RT and % correct analyses of Conflict Monitoring, there was a main effect of time for RT only [$F_{(1,\ 199)} = 12.73$, $p < 0.01$, partial $\eta^2 = 0.06$; $F_{(1,\ 199)} = 0.66$, $p = 0.42$], a main effect of group for RT only [$F_{(1,\ 199)} = 3.97$, $p = 0.05$, partial $\eta^2 = 0.02$; $F_{(1,\ 199)} = 1.11$, $p = 0.29$], and no interaction of time and group [$F_{(1,\ 199)} = 0.01$, $p = 0.93$; $F_{(1,\ 199)} = 0.63$, $p = 0.43$]. At post-intervention testing, there were no differences between the CBT/MT and Control groups on any of the attentional subsystem scores.

Overall performance by group

To determine if overall % correct and RT were influenced by training group over time, repeated measures ANOVAs were conducted. Examination of % correct scores revealed a significant main effect of time [$F_{(1,\ 199)} = 39.16$, $p < 0.01$, partial $\eta^2 = 0.16$], no main effect of group [$F_{(1,\ 199)} = 0.92$, $p < 0.34$], and a significant interaction of group by time [$F_{(1,\ 199)} = 11.60$, $p < 0.01$, partial $\eta^2 = 0.06$]. At T2, overall % correct was lower for both groups but higher for the CBT/MT than control group [$t_{(156.07)} = -2.04$, $p = 0.04$, Cohen's $d = 0.30$]. Analyses of RT revealed a significant main effect of time [$F_{(1,\ 199)} = 11.08$, $p < 0.01$, partial $\eta^2 = 0.05$] but no effect of group [$F_{(1,\ 199)} = 1.54$, $p = 0.22$] and no interaction of group by time [$F_{(1,\ 199)} = 0.55$, $p = 0.46$]. See **Figure 4**.

Response variability by group

To examine response variability, we conducted a repeated measures ANOVA with factors of time and intervention group. Results revealed a main effect of time [$F_{(1,\ 199)} = 56.75$, $p < 0.01$, partial $\eta^2 = 0.22$], no main effect of group [$F_{(1,199)} = 2.75$, $p = 0.10$], and an interaction of time and group [$F_{(1,\ 199)} = 5.75$, $p = 0.02$, partial $\eta^2 = 0.03$]. At T2, ICV was lower (responses were more stable) in the CBT/MT group compared to the control group, [$t_{(199)} = 2.42$, $p = 0.02$, Cohen's $d = 0.34$]. See **Table 1** for descriptives of overall % correct, overall RT, and ICV.

STAGE 3: THE INFLUENCE OF OUT-OF-SESSION PRACTICE ON T2 PERFORMANCE

To examine the effect of those who engaged in out-of-session MT practice and those who did not, we looked at participants in the

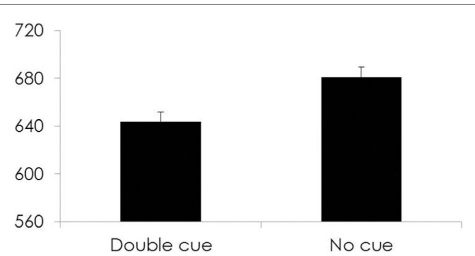

FIGURE 1 | For all participants, Time 1 Response times (ms) on the y-axis and cue type for each condition of the Alerting subsystem on the x-axis.

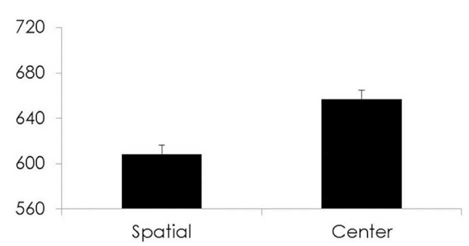

FIGURE 2 | For all participants, Time 1 Response times (ms) on the y-axis and cue type for each condition of the Orienting subsystem on the x-axis.

control arm ($n = 87$), those in the CBT/MT arm who practiced MT ($n = 89$), and those in the CBT/MT arm who did not practice ($n = 25$) in relation to changes in overall performance (% correct, RT, and ICV) given the intervention-related changes over time in these variables. Before exploring the differences between these groups at follow-up, we first checked for differences at baseline. A univariate ANOVA with baseline data from the three groups revealed significant differences in practice groups for % correct [$F_{(2,\ 198)} = 2.89, p = 0.06$, partial $\eta^2 = 0.03$] and RT [$F_{(2,\ 198)} = 3.46$, $p = 0.03$, partial $\eta^2 = 0.03$] such that the CBT/MT participants who did not practice had the lowest accuracy and the fastest RT (88%, 614 ms) when compared to the participants in the control group (94%, 632 ms) and the CBT/MT participants who practiced (94%, 666 ms).

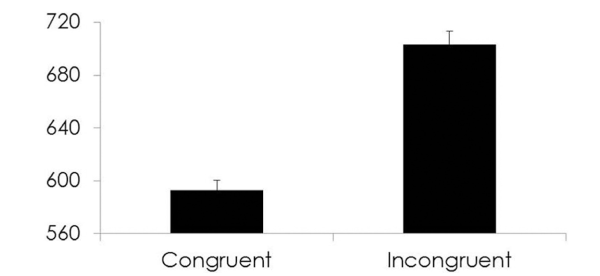

FIGURE 3 | For all participants, Time 1 Response times (ms) on the y-axis and cue type for each condition of the Conflict Monitoring subsystem on the x-axis.

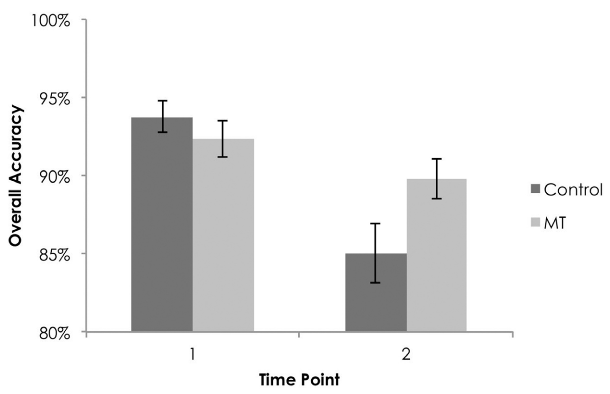

FIGURE 4 | Overall accuracy (% correct) on the y-axis and time on the x-axis as a function of training group.

Because of these baseline differences between the practice groups, two One-Way ANCOVAs were conducted with T1 overall % correct and T1 RT as covariates. There was a main effect of practice group for % correct [$F_{(2,\ 197)} = 6.59$, $p < 0.01$, partial $\eta^2 = 0.06$], such that those who practiced had better accuracy (92%) at T2 than those who did not practice (83%, effect size = 0.70) and controls (85%, effect size = 0.53). No significant effects of group were observed for RT [$F_{(2,\ 197)} = 0.09$, $p = 0.92$]. See **Figure 5**.

We also examined the effects of out-of-session practice over time on the ICV coefficient. These analyses showed a main effect of time with higher variability at T2 [$F_{(1,\ 198)} = 37.84$, $p < 0.01$, partial $\eta^2 = 0.16$], no main effect of practice [$F_{(2,\ 198)} = 2.26$, $p = 0.11$], and an interaction of time and group [$F_{(2,\ 198)} = 3.21$, $p = 0.04$, partial $\eta^2 = 0.03$]. *Post-hoc* tests (LSD) showed significant differences between control participants and participants who practiced ($p = 0.05$) with lower variability in those who practiced (0.29, effect size = 0.32) than in controls (0.33, effect size = 0.44) at T2. See **Figure 6**.

STAGE 4: EFFECTS OF ENVIRONMENTAL CONDITIONS

Release status

Release information was available for only a subset of participants ($n = 191$). Before examining the possible effect of release on participants, we first compared the groups (released and detained) at baseline. Independent t-tests revealed no group differences on system scores or overall performance variables at T1, $p > 0.05$. Next, we confirmed the basic intervention-related pattern in this subset of individuals.

An ANOVA for % correct with time (T1 vs. T2) and intervention arm (CBT/MT vs. control) revealed a main effect of time [$F_{(1,\ 189)} = 35.98, p < 0.01$, partial $\eta^2 = 0.16$], no main effect of group [$F_{(1,\ 189)} = 1.49, p = 0.22$], and an interaction of time and group [$F_{(1,\ 189)} = 10.53$, $p < 0.01$, partial $\eta^2 = 0.05$]. For RT, there was a main effect of time [$F_{(1,\ 189)} = 9.82, p < 0.01$, partial $\eta^2 = 0.05$], no main effect of group [$F_{(1,\ 189)} = 2.00$, $p = 0.16$], and no interaction of time and group [$F_{(1,\ 189)} = 0.51, p = 0.48$]. These results directly parallel the intervention patterns found in the group as a whole.

To determine if the release of participants from incarceration during the study period interacted with the intervention arm, an ANOVA was conducted with factors of time (T1 vs. T2), intervention arm (CBT/MT vs. control), and release group (not-released vs. released). For % correct, there was a significant effect

Table 1 | Intervention-related changes over time.

	Control		CBT/MT		Mixed ANOVA Interaction
	T1 *M*(*SE*)	T1 *M*(*SE*)	T1 *M*(*SE*)	T1 *M*(*SE*)	*p*-value
Overall ACC	93.77% (0.01)	85.07% (0.02)	92.34% (0.01)	89.77% (0.01)	0.001
Overall RT	632.02 (11.45)	663.30 (12.99)	655.08 (10.17)	675.00 (10.60)	0.46
ICV	0.26 (0.01)	0.33 (0.01)	0.26 (0.01)	0.30 (0.01)	0.02

At T2, the CBT/MT group had higher accuracy and more stability in response time (ICV) than the control group.

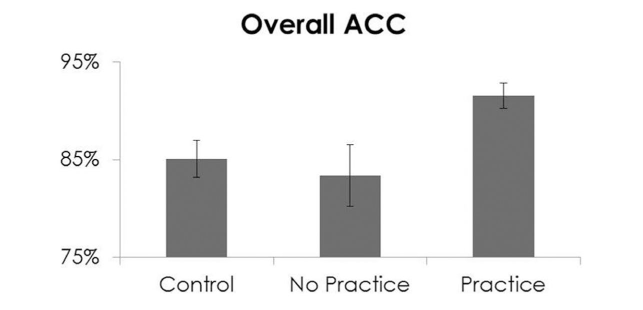

FIGURE 5 | Overall accuracy (% correct) on the y-axis and group (Controls, No Practice, and Practice) on the x-axis at Time 2 only.

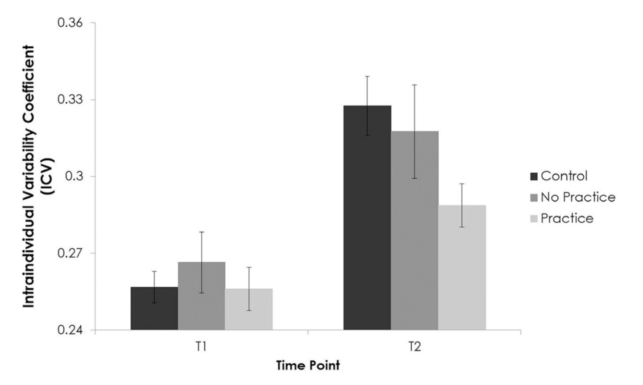

FIGURE 6 | Response variability on the y-axis and time on the y-axis as a function of group (Controls, No Practice, and Practice).

of time [$F_{(1,\ 187)} = 36.15$, $p < 0.01$, partial $\eta^2 = 0.06$], no effect of release group [$F_{(1,\ 187)} = 1.61$, $p = 0.21$], no effect of training group [$F_{(1,\ 187)} = 1.50$, $p = 0.22$], and no interaction of time, release group, and training group [$F_{(1,\ 187)} = 0.77$, $p = 0.38$]. For RT, there was a significant effect of time [$F_{(1,\ 187)} = 11.92$, $p < 0.01$], no main effect of either release status or training group [$F_{(1,\ 187)} = 1.12$, $p = 0.29$; $F_{(1,\ 187)} = 1.46$, $p = 0.23$], and no interaction of time, release group, and training group [$F_{(1,\ 187)} = 0.01$, $p = 0.94$].

Facility

Detained youth (those awaiting sentencing) and sentenced youth were held in two different buildings. To determine whether these two groups differed at baseline, we completed three univariate ANOVAs with overall % correct, overall RT, and ICV. There was no effect of facility on T1 overall % correct [$F_{(1,\ 199)} = 0.39$, $p = 0.53$] or T1 ICV [$F_{(1,\ 199)} = 0.02$, $p = 0.90$], but there was an effect of facility on T1 overall RT [$F_{(1,\ 199)} = 12.09$, $p < 0.01$, partial $\eta^2 = 0.06$]. Sentenced participants were faster than those who were detained. Thus, for those measures in which T1 differences were present, ANCOVAs were conducted instead of ANOVAs to account for these baseline group differences. For those measures on which no T1 differences as a function of facility were present, ANOVAs were conducted.

Next, to examine the impact of facility over time on the control and CBT/MT arms, we conducted 2-by-2 ANOVAs for % correct and ICV and a 2-by-2 ANCOVA (with T1 RT as a covariate) for RT with facility (detained and sentenced) and group (CBT/MT and Control). For overall % correct, there was a main effect of time [$F_{(1,\ 197)} = 25.47$, $p < 0.01$, partial $\eta^2 = 0.11$], no main effect of group [$F_{(1,\ 197)} = 0.96$, $p = 0.33$], a main effect of facility [$F_{(1,\ 197)} = 3.81$, $p = 0.05$, partial $\eta^2 = 0.02$], a significant interaction of time and group [$F_{(1,\ 197)} = 6.83$, $p = 0.01$, partial $\eta^2 = 0.03$], and no significant interaction of time, group, and facility [$F_{(1,\ 197)} = 1.92$, $p = 0.17$]. For ICV, there was a main effect of time [$F_{(1,\ 197)} = 40.41$, $p < 0.01$, partial $\eta^2 = 0.17$], no main effect of group [$F_{(1,\ 197)} = 2.38$, $p = 0.13$], a main effect of facility [$F_{(1,\ 197)} = 6.11$, $p = 0.01$, partial $\eta^2 = 0.03$], a significant interaction of time and group [$F_{(1,\ 197)} = 3.93$, $p = 0.05$, partial $\eta^2 = 0.02$], and no significant interaction of time, group, and facility [$F_{(1,\ 197)} = 0.02$, $p = 0.89$]. Finally, for overall RT, there was no main effect of facility [$F_{(1,\ 196)} = 2.25$, $p = 0.14$] and no main effect of group [$F_{(1,\ 196)} = 0.16$, $p = 0.69$]. These patterns, namely the time by group interactions, are consistent with the intervention-related changes over time and demonstrate that facility or adjudication statuses compound the effects of the CBT/MT.

To test for possible effects due to individual dormitories, we calculated intra-class correlation coefficients (ICC) for overall performance and ANT system scores at T1 to investigate the variability within dormitories vs. between dormitories using the following formula which accounts for variable cluster sizes (Shrout and Fleiss, 1979): $\frac{MS_{\text{between}} - MS_{\text{within}}}{MS_{\text{between}} + MS_{\text{within}}(m_o)}$ where $m_o = \left[\frac{1}{k-1}\right]\left[n - \frac{\sum m_i^2}{n}\right]$, k is the total number of clusters, and m_i is the number of participants in each cluster. Because dormitory and treatment condition effects cannot be disentangled after treatment began, we only consider dorm effects at T1, before treatment.

At T1, the ICCs for % correct, RT, and ICV were 0.00, 0.09, and −0.02, respectively. The ICCs for % correct for alerting, orienting, and conflict monitoring were −0.02, 0.02, and 0.00; for RT, the ICCs were −0.04, 0.02, and 0.03. Most of these ICCs are small in size (≤0.05), with one ICC approximating a medium size ICC (0.10), as reported by (Zyzanski et al., 2004).

DISCUSSION

The current study is the first to demonstrate efficacy of a CBT/MT intervention for attentional functioning in high-risk incarcerated youth. Observed effects based on four lines of investigation are discussed in turn. First, we found that the high-stress period of incarceration led to degradations in attentional task performance across both groups as shown by lower overall accuracy, slower RTs, and increased response-time variability. This poorer performance over time might be accounted for by consistent stress on cognitive control, which is necessary for complex problem solving, emotion regulation, and behavioral inhibition. Unfortunately, this degradation may have negative consequences for youth as the cognitive control resources that are necessary to promote corrective behavior as resources to engage in rational (vs. reactive) decision making are increasingly unavailable. As this depletion may result in a downward spiral for high-risk youth, it is important that we investigate viable intervention strategies for this group. Since earlier research demonstrated the beneficial effects of MT on cognitive task performance in adults (e.g., Jha et al., 2007; Lutz et al., 2008) and in high-stress cohorts (e.g., Jha et al., 2010), we assessed the effects of a CBT/MT intervention for detained youth. We correctly hypothesized that degradation in attentional task performance would be attenuated in the CBT/MT group. Specifically, overall accuracy and response time variability were better in the CBT/MT group compared to the control group. These findings indicate that a CBT/MT intervention can be effective in limiting degradation in attentional performance in incarcerated youth.

Our third area of focus is based on prior studies that observed a dose-response relationship between time spent engaging in mindfulness exercises outside of the formal class context and the magnitude of performance benefits in adults. As expected, we found that those in the CBT/MT group who practiced outside of class had higher accuracy and lower response variability (greater response time stability) at T2 than those who did not practice or did not receive training. Finally, some members of the CBT/MT and control groups were released during the period of the project, but there was no significant effect of release on the pattern of results described above.

This project investigated whether an intervention program designed to bolster core cognitive control and emotion-regulation resources in individuals experiencing a protracted period of high stress might curb the degree of degradation in cognitive control. Our findings support this; however, the mechanisms of action are yet unclear. It may have been that the CBT/MT group was more motivated to engage in the task, and this basic motivation (not MT-related improvements in present-moment focus) could have produced the group-wise effects. Motivation may differ in the groups due to the content differences between the CBT/MT and control intervention. The control intervention was a cognitive-perception intervention designed to raise awareness of expectancies related to violence and substance use. In contrast, the CBT/MT intervention included emotionally-laden exercises focused on exploring familial histories of maltreatment and offending, accepting responsibility for offending behavior, and taking the perspective of the victim in their offense. Exploring these painful topics with two trusting, empathic adults who were not correctional staff may have therapeutic value that increased motivation for the task. However, we did not find differences between the CBT/MT and the control group on other tasks requiring similar levels of motivation.

Alternatively, performance in the CBT/MT group may have differed from the control group because of training in different attention skills. The CBT/MT intervention taught attention-related metacognitive skills such as reappraisal and identification of triggers for offending behavior. Training of these metacognitive skills involved repeated discussion and practice of specific ways of attending to affective, cognitive, and behavioral stimuli that place youth at risk for offending behavior. Training in mindfulness meditation involved engaging youth in discussions about their practice immediately after each sitting meditation, thereby cultivating meta-awareness of their process of attending, including when their attention wanders and their capacity to repeatedly return attention back to the breath. The intervention clinicians were experienced meditation practitioners who provided tips for maintaining engagement in meditation both in intervention sessions and outside of class. Thus, MT may have set the stage for the adoption of attention-related metacognitive skills through CBT training. Further studies should fractionate the differing possible contributions of motivation, specific intervention-related elements, and psychosocial support as well as include a direct comparison of CBT alone to the combined CBT/MT intervention with this population.

A necessary practical constraint of the study is that the group randomization was carried out at the level of the dormitories. One concern is that individuals within the same cluster might be more similar to each other than to individuals from different clusters, which could undermine standard error of the ANOVAs. To investigate such cluster variability, intraclass correlations at T1 were conducted. ICCs for most of the variables of analysis were small, with one ICC approximating a medium size for Overall RT. However, there were no significant group effects or interaction between group and time for this variable. Moreover, a small ICC is reported for variables in which we report a significant effect. Thus, it is unlikely that the pattern of findings is a result of intraclass correlations at the level of the dormitory. Therefore, the findings from the current study are well-suited to provide estimates of effect sizes and T1 ICC estimates that are essential to planning a larger cluster-randomized study.

Although our results are in line with the view that MT may be protective, there is a lack of specificity in effects on the subsystems of attention. Prior studies suggest that MT improves selective attention more so than receptive attention in novice practitioners (see Jha et al., 2007). Yet, the orienting system scores, which index input-level selection mechanisms, and the conflict monitoring scores, which reflect response-related selection mechanisms, did not vary by group or by time. Instead the benefits of CBT/MT were observed only in response variability and overall accuracy. It is important to note that the lack of MT-related change in subsystem scores cannot be explained by task insensitivity. At T1 and T2, the overall effects for each subsystem were in line with previous studies (Baijal et al., 2011). Accuracy was higher and RTs were faster for the double cue vs. no cue trials (used to index the alerting system), for the spatial cue vs. center cue (orienting system), and for the congruent vs. incongruent trials (conflict monitoring system). One point to consider is the particular direction given during particular MT exercises. Because the practice instruction for the foundational exercise of mindfulness of breathing is to pay attention to the present moment, it may be that CBT/MT participants were better able to maintain present-moment awareness *for all trials* relative to controls, and this deliberate and voluntary general attention to the task may have resulted in better performance in that group. Thus, further research is required to better understand the mechanisms by which this program was beneficial.

Nonetheless, better performance in the training group suggests that offering this CBT/MT intervention to incarcerated youth may be beneficial, and the degree of benefit does not seem to differ based on release status over the course of the program. It is notable that the degradation in performance did not remit once youth were released, highlighting the long-lasting, harmful effects of incarceration on youth. If these results are due to improvements in present-moment focus tied to the MT practices that were engaged during the intervention, the benefits of training may go far beyond our laboratory measures of attentional task performance. Many studies have reported that greater attentional capacity and WMC are tied to improved rational decision making, better emotion-regulation, behavioral inhibition, reduced impulsivity, and better psychological health (see Schmeichel et al., 2008). Future studies will be required to determine if MT-related sensitivity in laboratory-based measures correspond to real-world indices of intervention effectiveness, such as rates of recidivism and long-term psychological health.

In sum, the current study suggests that a multi-session CBT/MT intervention exerted a protective effect on offending youths' functional attentional impairments during incarceration in a high-security urban jail. Though performance on an attention control task degraded over time among youth in both the CBT/MT and control groups, the magnitude of performance degradation was significantly less in the CBT/MT condition. Moreover, within the CBT/MT group, performance degraded over time in those with no outside-of-session practice time, but remained stable over time among youth who practiced mindfulness outside of intervention sessions. Although this was a quasi-experimental study, to our knowledge, this is the first active-controlled study of the effects of CBT/MT for youth involved in the criminal justice system and it adds to the small but expanding body of research on the protective aspects of contemplative practice for youth in highly stressful situations.

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The beneficial effects of meditation: contribution of the anterior cingulate and locus coeruleus

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During functional magnetic resonance imaging studies of meditation the cortical salience detecting and executive networks become active during "awareness of mind wandering," "shifting," and "sustained attention." The anterior cingulate (AC) is activated during "awareness of mind wandering." The AC modulates both the peripheral sympathetic nervous system (SNS) and the central locus coeruleus (LC) norepinephrine systems, which form the principal neuromodulatory system, regulating in multiple ways both neuronal and non-neuronal cells to maximize adaptation in changing environments. The LC is the primary source of central norepinephrine (C-NE) and nearly the exclusive source of cortical norepinephrine. Normally activated by novel or salient stimuli, the AC initially inhibits the SNS reflexively, lowering peripheral norepinephrine and activates the LC, increasing C-NE. Moderate levels of C-NE enhance working memory through alpha 2 adrenergic receptors, while higher levels of C-NE, acting on alpha 1 and beta receptors, enhance other executive network functions such as the stopping of ongoing behavior, attentional set-shifting, and sustained attention. The actions of the AC on both the central and peripheral noradrenergic systems are implicated in the beneficial effects of meditation. This paper will explore some of the known functions and interrelationships of the AC, SNS, and LC with respect to their possible relevance to meditation.

Keywords: meditation, salience detecting, anterior cingulate, locus coeruleus, norepinephrine

INTRODUCTION

During a recent functional magnetic resonance imaging (fMRI) study of focused mindfulness meditation the cortical salience detecting and executive networks, were shown to become active during "awareness of mind wandering," "shifting," and "sustained attention," while the default mode network (DMN) was active during "mind wandering" (Hasenkamp et al., 2012). This paper will primarily address mindfulness meditation, but awareness of mind wandering, shifting, and sustained attention could be expected to be involved, at least initially, in all forms of meditation.

The salience detecting and executive networks include the anterior insula, anterior cingulate (AC), anterior inferior parietal, dorsolateral prefrontal cortex (DLPFC), and anterior medial prefrontal cortex (Sturm et al., 1999; Sridharan et al., 2008; Vincent et al., 2008). These areas are essentially the same as those of the highly interconnected frontoparietocingulate (FPC) system thought to represent the cortical component of the orienting system (Halgren et al., 1998) and to underlie intrinsic alertness (Sturm et al., 1999; Kiehl et al., 2001, 2005; Dien et al., 2003; Calhoun et al., 2006).

The AC is a major component of the medial prefrontal cortex (mPFC). In much of the relevant literature, the mPFC is roughly divided into two subregions, relative to the genu of the corpus callosum: the dorsal medial prefrontal cortex (dmPFC) and the ventral medial prefrontal cortex (vmPFC) (Kim et al., 2011a).

Broadly defined, the dmPFC includes areas of the salience detecting/executive FPC network including the dorsal AC [BA24 and BA32], the anterior medial frontal cortex [BA10], and the DLPFC [BA9/46]. The areas of the medial frontal gyrus encompassing the dorsal attention network (DAN), including the pre-supplementary motor area (pre-SMA) and frontal eye fields [BA8], and the supplementary motor area (SMA) [BA6] are also a part of the dmPFC. The vmPFC includes the subgenual AC area [BA25], the vmPFC [ventral portions of BA32 and BA10], and the medial orbitofrontal cortex [BA11 and BA12], areas associated with the DMN and the amygdala (AM).

The salience detecting/executive FPC network shifts between and relates to both the externally directed DAN, which receives the stimuli of the present moment from the external environment, and to the internally directed hippocampal–cortical memory system, a part of the DMN (Sridharan et al., 2008; Vincent et al., 2008).

The salience detecting anterior insula and AC of the FPC network also receive the interoceptive information from within the organism, which underlies the sense of oneself and of one's emotions (Craig, 2009). The interoceptive information is carried to the cortical anterior insula and AC, as well as to the somatosensory cortex, ventrolateral medulla (VLM), and the locus coeruleus (LC) (Craig, 1992) from the peripheral noradrenergic sympathetic nervous system (SNS) via its ascending lamina 1 spinothalamocortical tract (STT) (Craig, 2009).

In turn, the dorsal AC (Verberne, 1996; Verberne et al., 1997; Verberne and Owens, 1998; Viltart et al., 2003) and the insula (Hardy, 1994; Ter Horst et al., 1996) modulate activity in the SNS via the rostral VLM. Inhibition of the rostral VLM causes a reflex fall in SNS nerve activity, resulting in decreased peripheral norepinephrine (P-NE), and decreased blood pressure (Standish et al., 1995).

The more ventral, emotion associated, portions of the AC [BA 25 and BA32] also project to the parasympathetic vagal nuclei including the dorsal motor nucleus (DM), the nucleus of the solitary tract (NTS), and to both the periambiguus and core areas of the nucleus ambiguus (NA) (Hurley et al., 1991; Buchanan et al., 1994).

The NA contains primary source nuclei for the cardiopulmonary branch of the vagus and has myelinated axons thought to rapidly modulate the function of the heart and lungs (Standish et al., 1995). Some neurons in the NA simultaneously innervate both the adrenal gland and the stellate sympathetic ganglion (Jansen et al., 1995) through which it can rapidly modulate the SNS.

The NA is also closely linked to the rapid expression and regulation of emotional state (Porges, 1995; Tonhajzerova et al., 2013). A withdrawal of the cardiopulmonary vagal efferent outflow from the NA is seen during both acute and chronic stress, which, in healthy individuals, is accompanied by increased sympathetic tone (Porges, 1995), by increased levels of P-NE.

Rapid autonomic changes, including cardiovascular and respiratory changes, such as respiratory rate, respiratory sinus arrhythmia, and heart rate variability (Reyes Del Paso et al., 2013; Tonhajzerova et al., 2013), are thought to occur by way of the parasympathetic NA (Porges, 1995; Standish et al., 1995; Wong et al., 2007; Tonhajzerova et al., 2013), in conjunction with the rostral and caudal VLM (Standish et al., 1995).

Central and autonomic interactions altered by short-term meditation suggest control of parasympathetic activity by the AC [BA25 and BA32] (Tang et al., 2009). This control of parasympathetic activity and the resultant inhibition of the SNS during meditation may occur by way of the AC [BA 25 and BA 32] projections to the NA (Hurley et al., 1991; Buchanan et al., 1994). During meditation greater parasympathetic activity is observed in the lower heart rate and skin conductance, increased belly respiratory amplitude, decreased chest respiration rate and increased high-frequency heart rate variability (HF-HRV) (Tang et al., 2009).

The AC also directly modulates the central norepinephrine (C-NE) levels by increasing activity in the LC (Jodo et al., 1998; Rajkowski et al., 2000), the principal central noradrenergic nucleus.

The AC is normally activated by novel or significant stimuli (Aston-Jones and Cohen, 2005). In turn, the AC activates the LC (Jodo et al., 1998; Rajkowski et al., 2000) exerting a tonic influence (Jodo et al., 1998) on LC baseline firing, while LC burst firing to stimuli is thought to reflect AC decisions following the stimuli (Clayton et al., 2004; Nieuwenhuis et al., 2005a).

The LC projects throughout the brain, is the principal source of C-NE in the thalamus (McCormick et al., 1991; Robertson et al., 2013), and the only known source of C-NE in the hippocampus and cortex, with the exception of a recently described projection to the insular and orbital prefrontal cortex of C-NE (r4-derived) neurons from the subcoeruleus nuclei and from the caudal portions of the C2/A2 and C1/A1 sympathetic nuclei of the medulla thought to receive visceral sensory, interoceptive input from the peripheral nervous system (Robertson et al., 2013).

The LC acts both synaptically and by volume transmission (O'Donnell et al., 2012) on its target neurons in the brain and differentially effects the different types of neurons found within each section of the areas to which it projects (Chandler and Waterhouse, 2012). C-NE participates in the rapid modulation of cortical circuits and cellular energy metabolism, and on a slower time scale in neuroplasticity and inflammation (O'Donnell et al., 2012).

Silent only during rapid eye movement (REM) sleep (Hobson and Stickgold, 1994), increases in LC baseline firing progressively increases wakefulness, cortical arousal (Berridge et al., 2012a), the neuronal signal to noise ratio (Aston-Jones et al., 1999), and receptivity to the sensory signals of the present moment (Foote et al., 1991). Although the LC can be activated by stress (Aston-Jones and Cohen, 2005), this wakeful receptivity and cortical arousal are not the same as the SNS arousal under stress; there is an inverse relationship between cortical arousal and peripheral sympathetic arousal (Nagai et al., 2004a,b, 2009; Duschek et al., 2007, 2013).

The integrated P-NE and C-NE systems form the principal neuromodulatory system, a homeostatic system regulating in multiple ways the activity of both neuronal and non-neuronal (astrocytes and microglial) cells (O'Donnell et al., 2012) to adapt the state of both the body and the brain for optimal functioning in changing environments.

As a part of the salience detecting/executive FPC network, the AC is in a position to integrate the information (Wang et al., 2005; Vincent et al., 2008) concerning the state of the external, the internal (Vincent et al., 2008), and the interoceptive environments in the present moment. By rapidly modulating the activity levels of both the principal NE systems, the AC is in a position to adapt the state of the whole organism to optimize attention and behavior as changes are detected in any of these environments.

The LC is thought to optimize attention and behavior in changing environments (Aston-Jones and Cohen, 2005). Activation of the AC is accompanied by a widespread coactivation of other areas of the brain (Wang et al., 2005). A number of fMRI studies of the cortical orienting response of intrinsic alertness have indicated that activity in the salience detecting/executive FPC network is accompanied by an activation of the LC (Sturm et al., 1999; Kiehl et al., 2001, 2005; Dien et al., 2003; Calhoun et al., 2006). This activation of the LC is associated with the widespread coactivation of other areas until the event-encoding cycle ends (Halgren et al., 1998). As the cycle ends activity decreases in the initial areas associated with orienting, while effective connectivity between relevant cortical areas increases (Büchel et al., 1999; McIntosh et al., 1999).

All the areas of the brain activated by the intentional, impartial, sustained attention of meditation are of significant, interrelated importance, including the insula, the other cortical salience detecting network area (Craig, 2009; Menon and Uddin, 2010). One of the largest activations at the moment of awareness of mind wandering, however, is seen in the AC (Hasenkamp et al., 2012). In this paper we will briefly explore some of the known functions and interrelationships of the AC, the SNS, and the LC with respect to their possible relevance to the process of meditation. The LC core and the subcoerulear (Westlund and Coulter, 1980) or pericerulear (Shipley et al., 1996; Aston-Jones et al., 2004) areas will be, here, treated as one, except where specifically mentioned.

UNCONSCIOUS DETERMINANTS OF CONSCIOUS DECISIONS

Immediately prior to the conscious awareness of voluntary, self-determined conscious decisions there is a consistent decrease in heart rate (Tallon-Baudry, 2012). Studies of the unconscious determinants of voluntary conscious decisions (Soon et al., 2008; Bode et al., 2011; Fried et al., 2011; Kreiman, 2012) have shown that the anterior medial prefrontal cortex, also called the rostral AC [BA10] (Soon et al., 2008; Bode et al., 2011; Fried et al., 2011), the SMA, pre-SMA, and the dorsal AC are active prior to conscious awareness (Fried et al., 2011; Kreiman, 2012). The SMA, pre-SMA, and AC are known to inhibit the SNS via the rostral VLM (Viltart et al., 2003) causing a reflex fall in sympathetic nerve activity and blood pressure (Standish et al., 1995). The ventral AC (Hurley et al., 1991; Buchanan et al., 1994) and the pre-SMA (38 Buchanan et al., 1994) can also modulate the SNS through their projections to the parasympathetic vagal nuclei, while the anterior medial prefrontal cortex [BA10], along with ventral portions of BA 32, has been found to covary inversely with skin conductance (Critchley et al., 2000; Nagai et al., 2004c) and directly with HF-HRV (Lane et al., 2009).

HEART RATE VARIABILITY

Ventral AC activation has been found in fMRI studies to be significantly correlated with HF-HRV suggesting AC control of parasympathetic autonomic activity (Tang et al., 2009). The pregenual mPFC [BA10/BA32], right superior frontal gyrus [BA10/46)], and left and right parietal cortex [BA40] of the salience detecting/executive FPC cortical orienting system are also positively correlated with HF-HRV, indicating that as activity increases in these cortical areas the vagal breaking action on the heart also increases, reflecting a vagal inhibition of sympathetic influences (Lane et al., 2009).

As mentioned, rapid autonomic changes, including cardiovascular and respiratory changes, such as respiratory rate, respiratory sinus arrhythmia, and heart rate variability (Reyes Del Paso et al., 2013; Tonhajzerova et al., 2013), are thought to occur by way of the parasympathetic NA (Porges, 1995; Standish et al., 1995; Wong et al., 2007; Tonhajzerova et al., 2013), in conjunction with the rostral and caudal VLM (Standish et al., 1995).

Central and autonomic interactions altered by short-term meditation suggest control of parasympathetic activity by the ventral AC [BA25 and BA32] (Tang et al., 2009). This control of parasympathetic activity and the resultant inhibition of the SNS during meditation may occur by way of the AC [BA 25 and BA 32] projections to the NA (Hurley et al., 1991; Buchanan et al., 1994). During meditation greater parasympathetic activity is observed in the lower heart rate and skin conductance, increased belly respiratory amplitude, decreased chest respiration rate, and increased HF-HRV (Tang et al., 2009).

The decreases in respiratory rate, whether spontaneous or intentional, and the increases in HF-HRV that occur during meditation may all reflect the same vagal inhibition of sympathetic influences.

The positive correlation of the FPC cortical areas with HF-HRV also suggests that HF-HRV is low when peripheral arousal is high (Lane et al., 2009). As mentioned, a withdrawal of vagal efferent outflow from the NA is seen during both acute and chronic stress, accompanied, in healthy individuals, by increased sympathetic tone (Porges, 1995; Tonhajzerova et al., 2013). The influence of FPC cortical activity on the vagal nuclei may also contribute to the inverse correlation between cortical and peripheral arousal (Nagai et al., 2004a,b, 2009).

THALAMUS AND CORTEX

The C-NE of the LC has potent and long-lasting effects on thalamic and cortical neurons (McCormick et al., 1991; Coull et al., 1999) and is intimately involved in determining both the level of neuronal excitability and the pattern of activity generated by neurons in thalamocortical systems (McCormick et al., 1991). C-NE, for example, was shown, via alpha 2 adrenergic receptors, to increase functional integration and connectivity from the LC to the parietal cortex and from the parietal cortex to the thalamus and frontal cortex, implicating the LC-noradrenergic system in mediating the functional integration of attentional brain systems (Coull et al., 1999).

Increases in C-NE and serotonin in both the thalamic reticular nucleus (RN) and the lateral geniculate nucleus (LGN) shift the thalamic firing pattern from a spontaneous rhythmic bursting mode to a single-spike mode (McCormick and Wang, 1991). These modes of firing are associated, respectively, with inattention, drowsiness, and sleep or with wakefulness and arousal (Steriade and Llinás, 1988).

Stimulation of the LC, simulating LC burst firing, increases neuronal firing in the LGN resulting in a highly discriminable signal in the LGN. During waking, LGN neurons have a single-spike firing mode when sensory information is faithfully relayed from the retina to the cortex and a burst-firing mode when the transfer of this information is degraded (Holdefer and Jacobs, 1994). During REM sleep the transfer of retinal information to the cortex ceases when the LC and the serotonergic dorsal raphe nucleus stop firing (Hobson and Stickgold, 1994).

EEG WAVES

Large-scale cortical synchrony, which depends on the integrity of corticothalamic feedback, is thought to act predominantly through the RN (Destexhe et al., 1998). Although the fusiform gyrus is implicated in the generation of high amplitude gamma synchrony during meditation (Lutz et al., 2004), it has been suggested that the RN plays a pacemaker function in the genesis of 40-Hz gamma oscillations in the thalamus and cortex during states of focused arousal (Pinault and Deschênes, 1992a). Bilateral lesions of the LC, and local application of the alpha 1 adrenergic antagonist, prazosin, abolished reticular thalamic 40-Hz, gamma firing (Pinault and Deschênes, 1992b), indicating a modulation of this system by the LC.

Data suggests that the AC generates electroencephalographic (EEG) task-related theta waves (Wang et al., 2005). Frontal midline theta rhythm is associated with activation of the parasympathetic nervous system (Tang et al., 2009) and negatively correlated with sympathetic activation (Kubota et al., 2001). The phase of the low-frequency theta rhythm modulates power in the high gamma wave band, with stronger modulation occurring at higher theta amplitudes (Canolty et al., 2006). The task-related increase in theta-phase locking indicates AC theta-phase locking forms part of a large network involving widespread cortical locations, consistent with the widespread coactivation of the AC with other areas as observed with fMRI (Wang et al., 2005). The widespread coactivation has been associated with an activation of the LC (Sturm et al., 1999; Kiehl et al., 2001, 2005; Dien et al., 2003; Calhoun et al., 2006).

There are both direct cholinergic and serotonergic pathways and indirect modulatory LC and AM pathways in EEG activation (Dringenberg and Vanderwolf, 1997, 1998). Increases in LC neuronal activity increases EEG activity in both the hippocampal theta and cortical high-frequency gamma wave bands (Berridge and Foote, 1991, 1996; Berridge, 1998) through its action on the medial septum (Berridge et al., 1996; Smiley et al., 1999).

Alpha waves, on the other hand, are associated with the DMN, which was found to be active during mind wandering in a focused mindfulness meditation study (Hasenkamp et al., 2012). Alpha waves are seen in novice mindfulness meditators, however, a decrease in alpha waves accompanies increased experience in longer term mindfulness meditators (Saggar et al., 2012).

Alpha waves spontaneously occur intermittently during an awake, relaxed, resting state, particularly with closed eyes (Goldman et al., 2002; DiFrancesco et al., 2008), when the vmPFC and DMN are active and they normally stop during salience detecting orienting responses to novel or significant stimuli, or with mental effort (Goldman et al., 2002), when the dmPFC and DAN are active.

Understanding of the origins of the occipital alpha rhythm is incomplete, but a plausible scheme is thought to include a complex interplay between the LGN and RN of the thalamus and the visual cortex (DiFrancesco et al., 2008). The central role of the thalamus in resting state networks is correlated with alpha activity (DiFrancesco et al., 2008) and it has been suggested that the alpha rhythm may be in part generated by the thalamus (Goldman et al., 2002).

In the resting state a decrease in the release of C-NE and serotonin in the thalamus may promote the occurrence of rhythmic oscillations (McCormick and Wang, 1991).

Alpha EEG waves are frequently recorded during studies of transcendental meditation (Travis and Shear, 2010). Beyond the categories of focused and open monitoring meditation, a third meditation category of automatic self-transcending has been proposed to explain the differences in the prevalence of alpha waves (Travis and Shear, 2010).

During mindfulness meditation, increased EEG activity in both theta (Kubota et al., 2001; Cahn and Polich, 2006; Slagter et al., 2009; Tang et al., 2009; Cahn et al., 2013) and gamma (Lutz et al., 2004; Cahn and Polich, 2006; Cahn et al., 2010, 2013) wave lengths have been recorded. The AC and its relationship with the LC may contribute to the changes in theta and gamma waves.

DECISIONS, EVENT-RELATED POTENTIALS, AND THE ATTENTIONAL BLINK

Anterior cingulate activity elevates LC baseline firing (Jodo et al., 1998), and LC phasic burst responses are thought to reflect AC decisions following novel or significant known stimuli (Clayton et al., 2004; Aston-Jones and Cohen, 2005; Nieuwenhuis et al., 2005a).

The P300 event-related potential (ERP) is thought to index AC activated LC phasic burst responses to stimuli (Murphy et al., 2011) and the LC is hypothesized to play a role in mediating the attentional blink (Nieuwenhuis et al., 2005b) as well as the accompanying pupil dilations (Zylberberg et al., 2012).

Lower (phasic) baseline firing in the LC is associated with large phasic bursts of firing to selectively attended stimuli (Aston-Jones and Cohen, 2005) accompanied by proportionately longer refractory periods, thought to be due to the autoinhibitory alpha 2 adrenergic receptors in the LC (Nieuwenhuis et al., 2005b). In contrast, higher (tonic) baseline firing is associated with more frequent smaller bursts to the various stimuli of the present moment, including low salience "distractor" stimuli (Aston-Jones and Cohen, 2005), followed by shorter refractory periods (Nieuwenhuis et al., 2005b).

In meditators, the P3a ERP amplitude to distractor stimuli is reduced (Cahn and Polich, 2009) and they demonstrate an enhanced receptivity to the second target in an attentional blink paradigm (Slagter et al., 2007, 2009; van Leeuwen et al., 2009). A reduced brain-resource allocation to the first target is hypothesized to underlie the enhanced receptivity to the second target (Slagter et al., 2007, 2009) and the shorter refractory periods associated with the reduced phasic burst release of C-NE by the LC are thought to contribute to the enhanced availability to the second target (Nieuwenhuis et al., 2005b).

The increased activation of the AC during meditation would be expected to cause higher tonic LC baseline firing in meditators, while the associated more frequent smaller bursts to various stimuli and their shorter refractory periods may underlie the meditators' enhanced receptivity to the second target as suggested by the existing hypotheses (Nieuwenhuis et al., 2005b; Slagter et al., 2007, 2009).

PUPIL DILATION

Pupil dilation, under constant illumination, is mediated almost exclusively via C-NE release by the LC (Koss, 1986; Einhäuser et al., 2010). Pupil diameter has been hypothesized to reflect both the tonic and the phasic aspects of LC activity, with large baseline pupil diameter equating with high tonic LC activity (Rajkowski et al., 1993) and brief increases in diameter with phasic activity following stimuli.

Pupil dilation following stimuli reflects AC decisions (Aston-Jones and Cohen, 2005; Einhäuser et al., 2010; Preuschoff et al., 2011). The dilation further reflects perceptual selection and predicts subsequent stability in perceptual rivalry (Einhäuser et al., 2008). During meditation, long-term meditators demonstrate enhanced pupil dilation to stimuli (Carter et al., 2005; Brefczynski-Lewis et al., 2007) and, in a study of binocular vision in long-term meditators, their larger pupil dilation was predictive of their subsequent longer durations between binocular shifts (Carter et al., 2005). This again suggests enhanced LC activation in long-term meditators. Humans with dopamine beta hydroxylase deficiency have a complete absence of C-NE and P-NE and they exhibit an abnormally small or absent task-evoked pupil dilation (Jepma et al., 2011).

ATTENTIONAL SET-SHIFTING, SUSTAINED ATTENTION, AND THE STOP OF ON GOING BEHAVIOR

In the cortex, relatively low, moderate levels of C-NE act on the alpha 2 adrenergic receptors to enhance working memory in the DLPFC in an inverted U shaped manner (Arnsten, 2011). Higher levels of C-NE are required to act on alpha 1 adrenergic receptors in order to enhance the executive network functions of attentional set-shifting and sustained attention (Berridge and Arnsten, 2012; Berridge et al., 2012b). Improvement was blocked by the alpha 1-antagonist prazosin (Berridge et al., 2012b). Higher levels of C-NE, from the activation of the LC by the AC, may contribute to the attentional shifting and sustained attention observed during meditation.

During the salience detecting orienting response there is an initial inhibition of ongoing behavior (Foote et al., 1980, 1991; Rasmussen et al., 1986), a stop, including a cessation of movement (Ball et al., 1999).

A stop of on going behavior is required for attentional set-shifting, as seen in meditators. As with attentional set-shifting and sustained attention, the stopping of on going behavior is improved by higher levels of C-NE acting on cortical alpha 1 and beta adrenergic receptors (Lapiz and Morilak, 2006; Berridge and Arnsten, 2012; Berridge et al., 2012b), while more moderate levels, acting on alpha 2-adrenoreceptors, improve working memory in the DLPFC (Arnsten, 2011). Elevated C-NE in the "prelimbic" AC [BA32] improves the stopping of ongoing behavior (Bari et al., 2010).

TASK DIFFICULTY

The synaptic specializations of the dorsal AC area BA32 indicate it has complementary roles, potentially enhancing the inhibition of spontaneous firing in the working memory DLPFC area [BA46] and strengthening excitation in the anterior medial prefrontal cortex [BA10], enhancing the capacity for more difficult, complex multi task operations (Medalla and Barbas, 2010). LC activity, similarly, increases with task difficulty (Rajkowski et al., 2004; Raizada and Poldrack, 2007).

SMA AND PRE-SMA

The AC has connections to the SMA, which mediates the preparation and initiation of movement (Devinsky et al., 1995). The intermediate SMA has been found to inhibit the primary motor area (M1) until a decision is made by the AC, before releasing it to action (Ball et al., 1999), while the pre-SMA has been shown to switch from habitual automatic to volitionally controlled saccades by inhibiting the habitual, automatic action (Hikosaka and Isoda, 2008). The pre-SMA has also been shown to contribute to the free choice of self-initiated actions (Thimm et al., 2012) and to be more active and functionally correlated with the DLPFC during internally compared to externally guided action planning (Rosenberg-Katz et al., 2012).

The SMA and pre-SMA are considered part of the externally directed DAN (Vincent et al., 2008), but they are active during meditation along with the salience detecting/executive FPC network (Brefczynski-Lewis et al., 2007; Manna et al., 2010; Hasenkamp et al., 2012). The length of practice time of meditators, interestingly, was negatively correlated with all of these areas during the shifting phase, indicating that more meditation experience is associated with less activity during the shifting phase (Hasenkamp et al., 2012).

SPINAL MOTOR NEURONS

The supplementary eye fields, frontal eye fields, pre-motor and motor cortices all share reciprocal connections with the LC (Shook et al., 1990). The LC projects extensively to the spinal cord depolarizing and enhancing spinal motor neuron excitability (Fung et al., 1991; White et al., 1991), making them receptive to the initiation of movement, while exercise, itself, spontaneously activates the LC (Warren et al., 1984; Haxhiu et al., 2003). These capacities of the LC may play a role in the attentive enhancement of movement during yoga.

LC BEHAVIOR PATTERNS

TONIC BASELINE FIRING

Higher baseline (tonic) firing in the LC is associated with enhanced labile attention and modest burst firing to various low salience distracter stimuli. This enhanced receptivity to the stimuli of the present moment is thought to optimize learning in unknown novel environments (Aston-Jones and Cohen, 2005).

During one of the earliest western scientific studies of meditation, the Zen masters reported that during meditation they had "more clearly perceived each stimulus than in their ordinary awakening state" (Kasamatsu and Hirai, 1966). Long-term meditators have repeatedly been found to exhibit an enhanced receptivity to stimuli (Jha et al., 2007; Slagter et al., 2007, 2009; Kerr et al., 2008; MacLean et al., 2010; Naranjo and Schmidt, 2012; Cahn et al., 2013; Mirams et al., 2013), including to low salience and habituated standard stimuli (Cahn et al., 2013), suggestive of higher tonic baseline LC activity.

Increased receptivity to stimuli, as initiated by the activation of the FPC orienting system to oddball stimuli, causes a subjective expansion of time (Tse et al., 2004). Such a subjective expansion of time has recently been observed in meditators (Kramer et al., 2013).

PHASIC BASELINE FIRING

In contrast, lower, intermediate, more synchronous phasic baseline firing in the LC promotes larger, robust bursts to attended significant known stimuli, rapid well-learned dominant, autoassociative responses, enhanced selective attention, and reduced responding to distractor stimuli. This pattern is thought to optimize behavior in known familiar environments (Aston-Jones and Cohen, 2005) with a well-known coping response available.

SNS MODULATION OF LC BASELINE FIRING

In the LC, changes in baseline firing, along with their associated subsequent bursting patterns, differentially modulate the state of the brain, the central nervous system, to optimize behavior in either novel or familiar environments, particularly if they are stressful environments.

Similarly, in the peripheral SNS, epinephrine (P-E) and P-NE are differentially released from the adrenal medulla (Mason et al., 1961; Brady, 1967; Frankenhaeuser, 1971; Stoddard et al., 1987; Morrison and Cao, 2000) under stress. Although they do not cross the blood brain barrier, P-E (Holdefer and Jensen, 1987) and P-NE (Svensson et al., 1980; Elam et al., 1984) inversely modify baseline firing in the LC.

During circumstances of novel stress a substantial amount of P-E is released from the adrenal medulla along with a small amount of P-NE (Mason et al., 1961; Brady, 1967; Frankenhaeuser et al., 1968; Frankenhaeuser, 1971). P-E elevates the baseline tonic firing in the LC (Holdefer and Jensen, 1987). This increases the release of C-NE, causing increased cortical arousal, decreased selective attention, and increased receptivity to the novel stimuli of the present moment. By the elevating of tonic baseline firing in the LC, P-E also enhances memory (Holdefer and Jensen, 1987) for the novel events through the increase in C-NE (Lemon et al., 2009; Reid and Harley, 2010).

In contrast to novel stress, under conditions of familiar stress (Mason et al., 1961; Brady, 1967; Frankenhaeuser et al., 1968; McCarty and Kopin, 1978; McCarty et al., 1978), especially with a well-known coping response available (Mandler, 1967; Frankenhaeuser et al., 1968), substantial amounts of P-NE are released from the adrenal medulla with virtually no P-E (Brady, 1967; Frankenhaeuser and Rissler, 1970; Frankenhaeuser, 1971). By elevating blood pressure, P-NE dose-dependently inhibits baseline tonic firing in the LC via the vagus and the NTS (Svensson et al., 1980; Elam et al., 1984). This causes rapid well-known dominant, autoassociative coping responses, increased selective attention, decreased responding to low salience distractor stimuli, and increased resistance to extinction (Craigmyle, N. A., unpublished data). Decreased perception of affect has also been observed (McCubbin et al., 2011). This classic stress and arousal behavior pattern (Easterbrook, 1959; Friedman et al., 1960, 1975; Zajonc, 1965; Eysenck, 1976; Geen, 1976; Geen and Gange, 1977) is consistently associated with relatively low, intermediate, phasic baseline LC activity (Aston-Jones and Cohen, 2005).

INVERSE RELATIONSHIP OF CORTICAL AND PERIPHERAL SNS AROUSAL

As mentioned, there is an inverse relationship between cortical arousal and peripheral SNS arousal (Nagai et al., 2004a,b, 2009; Duschek et al., 2007, 2013). The contingent negative variation (CNV) has been used as an index of cortical arousal during orienting and attention, while changes in skin conductance were measured and pharmacological and biofeedback methods were used to elevate blood pressure, a measure of peripheral SNS arousal. Elevated blood pressure was shown to decrease the CNV amplitude in normotensive subjects (Duschek et al., 2007, 2013).

The dose-dependent inhibition of baseline firing in the LC by elevated blood pressure (Svensson et al., 1980; Elam et al., 1984) may contribute to this inverse correlation of peripheral SNS and cortical arousal.

In contrast, enhanced CNV cortical arousal-related activity in the AC, the midcingulate/SMA and the insula is associated with decreases in peripheral SNS arousal (Nagai et al., 2004b), which may be due to the capacity of these areas of the brain to inhibit the rostral VLM (Viltart et al., 2003), causing a reflex fall in SNS nerve activity and blood pressure (Standish et al., 1995). This relationship may also contribute to the inverse relationship of cortical and peripheral SNS arousal seen during meditation.

PRINCIPAL AREAS MODULATING THE LC AND SNS – DIRECTLY AND RECIPROCALLY

A limited number of areas differentially influence activity in the integrated central noradrenergic LC and the peripheral noradrenergic SNS systems.

AC, SMA, Pre-SMA

These areas have been briefly addressed above.

ORBITOFRONTAL CORTEX

The orbitofrontal cortex (OFC) is another prominent descending cortical projection to the LC (Aston-Jones and Cohen, 2005). Activity in the AC and OFC is negatively correlated and they have complementary and reciprocal roles in monitoring the outcome of behavior (Aston-Jones and Cohen, 2005). While the AC is active in relation to self-generated decision-making, the OFC is active when the decisions are guided by the experimenter (Ullsperger and von Cramon, 2004; Walton et al., 2004), when the decisions and the reward characteristics of the stimuli are predictable (Baxter and Croxson, 2013; Rudebeck et al., 2013), are essentially known, and a coping response is available. Whereas the activity in the AC during salience detection and decision-making elevates tonic baseline firing in the LC enhancing receptivity to the various stimuli of the present moment, activity in the OFC may lower baseline firing in the LC potentiating selective attention and the rapid performance of expected well-known, autoassociative responses.

ASCENDING AUTONOMIC TRACTS

The ascending autonomic tracts from the periphery also influence the LC. Cardiorespiratory, visceral and somatosensory autonomic stimuli regulate LC activity through ascending autonomic tracts with putative implications for psychiatry and psychopharmacology (Svensson, 1987). The cardiovascular stimuli from the autonomic environment seem to predominate over external environmental stimuli with respect to the LC's influence on behavior (Svensson, 1987).

The parasympathetic vagus nerve influences activity in the LC, primarily via the NTS, while the ascending sympathetic lamina 1 STT projects directly and reciprocally to the LC (Craig, 1992).

CENTRAL AUTONOMIC NUCLEI

The LC projects reciprocally to central autonomic nuclei including the sympathetic VLM, the parasympathetic DM, and regions of the NTS. The LC also projects to the region of the parasympathetic NA (Sakai et al., 1977; Westlund and Coulter, 1980). The LC core has been found to project extensively to regions giving rise to parasympathetic outflow, while the subcoeruleus (peri-coeruleus) region projects to sympathetic regions (Westlund and Coulter, 1980). The LC is a distinct part of the central neuronal circuit innervating various regions of the rat heart (Standish et al., 1995).

As mentioned, the NA contains primary source nuclei for the cardiopulmonary branch of the vagus (Standish et al., 1995), has myelinated axons thought to rapidly modulate the function of the heart and lungs (Standish et al., 1995) and some of its neurons simultaneously innervate both the adrenal gland and the stellate sympathetic ganglion (Jansen et al., 1995) through which it can rapidly modulate the SNS.

There are alpha 1 (Boychuk et al., 2012), alpha 2 (Haxhiu et al., 2003), and beta 1 (Bateman et al., 2012) adrenergic receptors in the NA, each differentially modulating NA function. Alpha 1 receptors facilitate inhibitory neurotransmission (Boychuk et al., 2012), while beta 1 adrenergic receptors decrease both inhibitory and excitatory neurotransmission to cardiac vagal neurons (Bateman et al., 2012).

Locus coeruleus activation dilates the airways via NA alpha 2 adrenergic receptors (Haxhiu et al., 2003), while fear and emotional distress may facilitate bronchoconstrictive attacks (Lehrer et al., 1993; Haxhiu et al., 2003; Rosenkranz et al., 2005, 2012). Exercise spontaneously activates the LC (Haxhiu et al., 2003) and dilates the airways (Warren et al., 1984; Haxhiu et al., 2003). The dilation of the airways by the LC via the NA may contribute to the decreased respiratory rate and HF-HRV, which are associated with meditation (Lazar et al., 2005; Tang et al., 2009; Kodituwakku et al., 2012) and yoga. The AC appears to be a critical component in the circuitry that links the development of peripheral symptoms with emotion and cognition in asthma (Rosenkranz and Davidson, 2009). Activation of the LC by the AC may play a role in the beneficial effects of mind–body influences in asthma.

The NA is also, as previously mentioned, closely linked to the rapid expression and regulation of emotional state (Porges, 1995; Tonhajzerova et al., 2013). A withdrawal of the cardiopulmonary vagal efferent outflow from the NA is seen during both acute and chronic stress, which, in healthy individuals, is accompanied by increased sympathetic tone (Porges, 1995), by increased levels of P-NE.

Following bilateral lesions of the LC, animals fail to show normal cardioaccelerator responses to threatening stimuli (Redmond, 1977; Snyder et al., 1977). The loss of the inhibitory influence of the LC on the NA, through its adrenergic receptors, may contribute to this failure.

AMYGDALA

The AM is of particular importance in influencing the LC, SNS, and the AC

The AM forms the core of a second, early-activated emotional salience detecting network or orienting system comprised of the superior colliculus, pulvinar, and AM (Liddell et al., 2005; Luo et al., 2007; Tamietto and de Gelder, 2010; Van den Stock et al., 2011; de Gelder et al., 2012). This system acts as a pre-consciousness early warning system (Liddell et al., 2005; Luo et al., 2007; Tamietto and de Gelder, 2010; Van den Stock et al., 2011; de Gelder et al., 2012), particularly to threatening emotional stimuli, including threatening subliminal stimuli (Liddell et al., 2005). An early activation of the LC following subliminal stimuli has been observed, indicating this AM system may initially activate the LC (Liddell et al., 2005).

The early AM and the later cortical salience detecting orienting networks are reciprocally interconnected, sequentially activated, and both modulate the activity levels in the LC and in the SNS, each contributing differentially to adapt the state of the whole organism to environmental change.

The AM has reciprocal projections to the LC, the AC, and to the NTS and DM, amongst various other regions including the VLM, insula, and OFC (Price and Amaral, 1981; Amaral and Price, 1984; Volz et al., 1990).

The AM projects reciprocally to both the dorsal AC of the dmPFC and to the ventral AC of the vmPFC. The tract between the AM and the ventral AC is a white matter tract (Kim and Whalen, 2009), allowing for rapid transmission. Increased activity in the vmPFC is correlated with increased parasympathetic vagal activity (Lane et al., 2009; Tang et al., 2009) and the vmPFC is thought to exert a tonic influence on the parasympathetic NA during the resting state (Wong et al., 2007). Both the AM and the AC, independently, are required for the occurrence of conditioned bradycardia, the conditioned heart rate decrease that develops in response to significant stimuli (Powell et al., 1997).

Although the AM was long presumed to project to the NA (Schwaber et al., 1982; Volz et al., 1990) to rapidly activate the SNS (Porges, 1995), more recently, this could not be confirmed (Standish et al., 1995). The AM may, however, rapidly modulate activity in the NA through its white matter tract with the vmPFC.

Following stimuli, the AM directly receives an early relatively "crude" version of the stimuli via the superior colliculus and pulvinar in10–20 ms (Luo et al., 2007; Van den Stock et al., 2011). If the stimulus is significant, the AM responds rapidly within 20–30 ms and activates the LC (Liddell et al., 2005), in another10–20 ms (Bouret et al., 2003). These activations occur before the cortical frontal eye fields are activated at approximately 64 ms, the supplementary eye field at 81 ms, and the AC at100 ms (Pouget et al., 2005). All the above activations appear to commence prior to conscious awareness of the stimuli (Fried et al., 2011; Kreiman, 2012).

When conditions allow for cortical processing, the mPFC, both dorsal and ventral, is believed to regulate and control the AM, either increasing or decreasing AM activity (Ohman, 2005; Kim et al., 2011a,b). During rest, in normal low anxiety humans, activity in the vmPFC is positively correlated with the AM, while dmPFC activity is negatively correlated (Kim et al., 2011b).

Following a familiar, stressful, significant stimulus, with a known coping response available, the AM is thought to "take the PFC "off line" to allow faster, more habitual responses mediated by the posterior and/or subcortical structures to regulate behavior" (Arnsten, 1997).

The cortical mPFC, however, can in turn regulate and control the AM (Ohman, 2005; Kim et al., 2011a,b), to either enhance activity in the AM or to take the AM, itself, "off line."

Meditators exhibit lower activity in the AM (Brefczynski-Lewis et al., 2007; Creswell et al., 2007; Lutz et al., 2008), an inhibition of the AM occurs during meditation (Lutz et al., 2008) and decreased gray matter density in the AM emerges over time (Hölzel et al., 2010).

Arnsten (1997) has suggested the AM may take the PFC "off line" by activating the LC, causing high levels of C-NE and dopamine in the cortex to inhibit the PFC – the DLPFC in particular. Interestingly, evidence points to the LC as a common origin for both the C-NE and the dopamine in the cortex (Devoto and Flore, 2006).

The central nucleus of the AM (CeA) projects to the LC. Stimulation of the CeA stimulates the LC, producing a large single or double burst, followed by an extended refractory period (Bouret et al., 2003). In response to a familiar, stressful, significant stimulus, the CeA would be expected to stimulate the LC, eliciting a large burst of C-NE, followed by an extended refractory period, SNS peripheral arousal and elevated blood pressure, resulting in decreased cortical arousal (Duschek et al., 2007, 2013).

The LC projects to the basolateral amygdala influencing memory

Activation of the LC modulates activity in the basolateral amygdala (BLA) by releasing C-NE. The C-NE inhibits spontaneous firing in the majority of the BLA neurons via alpha 2 adrenergic receptors, while exciting others via beta adrenergic receptors (Buffalari and Grace, 2007).

Elevated activity in the LC acts via the BLA beta adrenergic receptors to enhance the consolidation of memory (Roozendaal and McGaugh, 2011) in the hippocampus (McReynolds et al., 2010), and the cortex (Chavez et al., 2013), in both the mPFC (Roozendaal et al., 2009) and in the insula (Bermudez-Rattoni et al., 2005).

Arousal-induced release, or systemic injection of the peripheral adrenal hormones P-E and cortisol (corticosterone in rats) enhances the consolidation of memory via the action of C-NE on BLA beta receptors (Chavez et al., 2013).

Considerable evidence indicates that peripheral action on the vagus nerve stimulates the LC to release this C-NE in the BLA (McIntyre et al., 2012). Systemic administration of P-E has been shown to dose-dependently elevate tonic baseline firing in the LC (Holdefer and Jensen, 1987). In contrast, amphetamines, like P-NE (Svensson et al., 1980; Elam et al., 1984), inhibit LC baseline firing (Holdefer and Jensen, 1987).

Activation of the LC by exercise has also been shown to enhance memory, including in older people and those with the early stages of Alzheimer's disease (Segal et al., 2012).

Following acute stress there is a period of increased connectivity between the AC, LC, and AM, which may contribute to the consolidation of memory for the significant events (van Marle et al., 2010). The LC is active during slow wave sleep contributing to the consolidation and the re-consolidation of memory (Sara, 2010; Eschenko et al., 2012) and is also involved in the successful retrieval of emotional memory (Sterpenich et al., 2006).

Long-term stress induces homeostatic changes in the interrelationship between the AM and the LC

In controls, increased norepinephrine in the BLA inhibited spontaneous firing in the majority of the BLA neurons, with some showing excitation at lower doses but inhibition at higher doses. Norepinephrine also decreased responsiveness of these neurons to electrical stimulation of the entorhinal and sensory association cortices (Buffalari and Grace, 2009). However, following chronic cold stress, norepinephrine led to an increase in the excitatory effects of norepinephrine on BLA neurons and a facilitation of responses to the stimulation of the entorhinal and sensory association cortices (Buffalari and Grace, 2009).

During stress, the CeA is a major source of elevated corticotropin-releasing factor (CRF) in the peri-coerulear LC (Van Bockstaele et al., 2001, 2010), the area of the LC that projects to sympathetic regions (Westlund and Coulter, 1980). CRF activates the LC raising C-NE levels in the posterior parts of the ventral medial (VPm) thalamus (Devilbiss et al., 2012). Although increased levels of LC output can facilitate sensory-evoked responses of VPm thalamic and barrel field cortical neurons in an inverted U dose–response relationship, high levels of peri-coerulear LC infusions of CRF caused a dose-dependent suppression of sensory-evoked discharge in the VPm thalamus and in cortical barrel field neurons resulting in a net decrease in signal-to-noise of sensory-evoked responses (Devilbiss et al., 2012).

PAIN AND THE COERULEOSPINAL CENTRIFUGAL PAIN CONTROL SYSTEM

The Vpm thalamus is the thalamic relay nucleus for the sympathetic STT, which carries the afferent interoceptive information, including pain, to the anterior insula (by way of the dorsal posterior insula) and to the somatosensory BA3a (Craig, 2004, 2009). The branch of the STT that projects to the AC relays in the ventrocaudal portion of the medial dorsal thalamic nucleus (Craig, 2004).

The LC projects reciprocally to the STT (Craig, 1992; Westlund and Craig, 1996). The descending coeruleospinal inhibitory pathway from the LC and subcoeruleus (peri-coeruleus) is one of the centrifugal pain control systems. The function of this LC system is thought to maintain the accuracy of intensity coding in the dorsal horn, while inhibiting nocioceptive signals in order to extract other sensory information that is essential for circumstantial judgment (Tsuruoka et al., 2011).

Activation of the LC can produce profound antinociception (Tsuruoka et al., 2011, 2012; Hayashi et al., 2012) and can inhibit the nociceptive activity of spinal dorsal horn neurons and trigeminal subnucleus caudalis neurons (Hayashi et al., 2012). Nocioceptive signals from visceral organs and cutaneous receptive fields converge on single dorsal horn neurons. Electrical stimulation of the LC inhibited both the visceral (colorectal distention) and the cutaneous pinch responses, with a reduction in the intensity-response magnitude curve without a change in the response threshold (Hayashi et al., 2012).

Fear-induced antinociception also occurs via LC pathways (Biagioni et al., 2013), seizure-induced antinociception involves LC alpha 2 and beta adrenergic receptors (Felippotti et al., 2011) and the LC is thought to play a role in the antinociception caused by stimulation of the motor cortex (Viisanen and Pertovaara, 2010).

Chronic pain stress changes the influence of the AM on the LC from excitation to inhibition (Viisanen and Pertovaara, 2007).

Locus coeruleus responses to noxious stimulation were initially enhanced following experimental neuropathy, however, after 10–14 days microinjections of glutamate into the CeA produced a dose-related inhibition of the discharge rate of LC neurons. There was no significant effect on discharge rates in control groups. Spinal antinociception due to LC electrical stimulation was also weaker in the nerve injured rats. The enhanced inhibition of the LC by the CeA was thought to suppress the noradrenergic pain inhibition and promote neuropathic pain (Viisanen and Pertovaara, 2007).

Long-term pain can increase the likelihood of mood or anxiety disorders by as much as threefold (The Neuroscientist, 2012).

Long-term chronic pain (>28 days) caused an increase in LC bursting activity, tyrosine hydroxylase expression and that of the norepinephrine transporter; and enhanced expression and sensitivity of the inhibitory alpha 2 adrenoceptors in the LC. This was accompanied by an inability to cope with stressful situations, depressive and anxiogenic-like behaviors (Alba-Delgado et al., 2013). As mentioned, increased LC bursting activity is associated with lower, inhibited, LC baseline levels.

Meditation has been repeatedly found to reduce pain (Zeidan et al., 2012).

In a 2012 review of meditation-related pain relief, mindfulness meditation was found to significantly reduce pain through a number of unique brain mechanisms (Zeidan et al., 2012). In meditators during pain, higher activation was seen in the dorsal AC and insula, but was reduced in the medial prefrontal-OFC (vmPFC), DLPFC, and AM. Meditation significantly reduced lower level processing in the primary somatosensory cortex, while the increased activity in the rostral AC and anterior insula was associated with intensity reductions and the decreased orbitofrontal and thalamic activity was associated with reduced unpleasantness (Zeidan et al., 2012).

In meditators, most of the areas of the brain associated with the reduction of pain, including the salience detecting dorsal AC and insula, the primary somatosensory area and the thalamus, receive projections from the ascending STT (Craig, 2004, 2009). The reduced lower level processing in the primary somatosensory area, decreased thalamic activity and the intensity reductions associated with the higher dorsal AC and insula activity could be the result of the LC's profound antinociceptive action on the ascending STT, reducing the response intensity magnitude curve without a change in response threshold (Hayashi et al., 2012). By this route, the AC activation of the LC may contribute to meditation-induced reduction of pain.

VAGUS NERVE STIMULATION

Chemical or electrical stimulation of the vagus nerve alters LC activity and that of its forebrain targets suggesting that the therapeutic effects of vagal nerve stimulation (VNS) may involve the LC-noradrenergic system (George and Aston-Jones, 2010). It has been suggested that the effects of VNS on learning and memory, mood, seizure suppression, and recovery of function following brain damage are mediated, in part, by the release of C-NE in the terminal fields of the LC (Roosevelt et al., 2006). VNS is also being investigated with respect to anxiety (George et al., 2008), inflammation, and the immune response (George and Aston-Jones, 2010).

The initiation of VNS activates the LC (Dorr and Debonnel, 2006), increasing not only the spontaneous (baseline) firing rate, but also the percentage of LC neurons firing in bursts (Manta et al., 2009). The LC has an excitatory influence on the dorsal raphe (Dorr and Debonnel, 2006). Long-term (14 days) VNS increased activity in the serotonin neurons of the dorsal raphe nucleus, as seen with other antidepressant treatments (Manta et al., 2009), through an activation of alpha 1 adrenergic neurons and increased tonic activation of post-synaptic 5-HT1A receptors in the hippocampus (Manta et al., 2013). Long-term VNS, further, significantly increased extracellular C-NE levels in the prefrontal cortex and hippocampus and enhanced the tonic activation of post-synaptic alpha 2 adrenoceptors on pyramidal neurons (Manta et al., 2013).

A recent review discusses some of the beneficial effects of mindfulness-based stress reduction, mindfulness-based cognitive therapy, and Zen meditation to alleviate depression, anxiety, pain, and psychological distress (Marchand, 2012).

The kinds of pain and suffering alleviated by meditative practices, are remarkably similar to those alleviated by stimulation of the vagus. The increased activation of the LC by both practices may contribute to the beneficial similarities.

BLOOD VOLUME, OXYGEN DEMAND, CELLULAR ENERGY METABOLISM, AND INFLAMMATION

The LC–NE network optimizes coupling of cerebral blood volume with oxygen demand through local vasodilation in active brain areas, while constricting volume in other areas (Bekar et al., 2012). Of increasing interest is the modulation by C-NE of glia, astrocytes, oligodendrocytes, and microglia in their critical support functions (Bekar et al., 2008; Chandley and Ordway, 2012; O'Donnell et al., 2012). C-NE, for example, acts on astrocytes to enhance glutamate uptake, while increasing production and breakdown of glycogen (O'Donnell et al., 2012). Microglia, often thought of as the primary immune effector cells of the CNS, represent a major target of C-NE signaling in the cortex (O'Donnell et al., 2012). C-NE modulates microglia disease responses, suppressing inflammatory gene transcription and reducing expression of pro-inflammatory cytokines, while enhancing production of brain-derived neurotrophic factor (BDNF) to promote neuronal survival (O'Donnell et al., 2012). The mechanism by which C-NE reduces the expression of pro-inflammatory cytokines is still a topic of debate, but may involve the regulation of the NF-kB signaling system by B2-adrenergic receptor driven increases in cAMP (O'Donnell et al., 2012).

Yogic meditation downregulated transcripts of pro-inflammatory cytokines, decreasing expression of NF-kB associated pro-inflammatory genes (Black et al., 2013). Mindfulness-based stress reduction training also resulted in a significantly smaller post-stress inflammatory response (Rosenkranz et al., 2013). The regulation of gene expression by yoga, meditation, and related practices has recently begun to be investigated (Saatcioglu, 2013). The activation of the LC, by the AC and by exercise, may again be a contributing factor.

NEUROPLASTICITY

In post-mortem studies of depressed humans a loss of glial cells has been demonstrated in the AC, DLPFC, and OFC, amongst other areas (Chandley and Ordway, 2012). It has been hypothesized that given the intimate functional relationship between C-NE and glia, particularly astrocytes, the glial deficits may be secondary to a deficiency of C-NE (Chandley and Ordway, 2012). Humans with dopamine-B-hydroxylase deficiency, who have no norepinephrine, exhibit a smaller total brain volume (Jepma et al., 2011).

Research indicates that LC neuron loss appears with aging (Shibata et al., 2006) and depression (Shibata et al., 2007), and that such loss is prominent in Parkinson's and Alzheimer diseases (Bekar et al., 2012). A diminished ability to couple blood volume to oxygen demand (Bekar et al., 2012), and to support other neuronal and non-neuronal cellular requirements (Bekar et al., 2008; Chandley and Ordway, 2012; O'Donnell et al., 2012) due to a reduction in C-NE from LC neurons, may contribute to their pathogenesis.

Structural changes are observed in various brain areas of meditators (Lazar et al., 2005; Hölzel et al., 2010; Tang et al., 2010, 2012; Luders et al., 2011, 2013; Grant et al., 2013; Kang et al., 2013; Luders, 2013). The elevated C-NE due to the activation of the LC by the AC may play a role.

DISCUSSION

In early 2012, when the Hasenkamp paper was published and research for this paper began, some aspects of the AC's activation of the LC and inhibition of the SNS to maximize adaptation in changing environments were already known. Included were the increased receptivity to the stimuli of the present moment caused by activating the LC; the possible reduction of stress through the inhibition of the stress associated SNS; the LC behavior patterns and the potential importance of understanding that the LC is not activated in tandem with the SNS, but that stress associated elevated P-NE inhibits the LC dose-dependently enhancing the phasic behavior pattern; that higher tonic base line firing is not associated only with stress and arousal, but with increased receptivity to the stimuli of the present moment, with increased awareness. These aspects were already understood and seemed of significant importance to understanding the neuroscientific process underlying the changes in state initiated by meditation.

During 2012 and 2013, however, numerous papers have been published that further implicate the integrated norepinephrine systems in the enhancement of cortical executive network functions and in the modulation of the AM, NA, VPm, STT, and pain, as well as in the modulation of astrocytes and glia, blood volume, oxygen supply, cellular energy metabolism, inflammation, and even of neuroplasticity.

These aspects were generally unknown in early 2012, and have vastly expanded the understanding of the role of the AC's activation of the LC and inhibition of the SNS in general, and potentially in the beneficial changes initiated by meditation.

The AC and the anterior insula, together, form the cortical salience detecting network, are usually jointly activated, contain numerous recently evolved von Economo neurons, and undergo structural changes in longer term meditators. Reviews of their functions (Craig, 2009; Medford and Critchley, 2010; Menon and Uddin, 2010) implicate them in the capacity for awareness of self and awareness of the moment.

The AC is active during salience detecting and monitoring of the stimuli in the present moment, is naturally activated by novel or significant stimuli and normally ceases activity as the event-encoding cycle ends. During mindfulness meditation the AC is active "at the moment of awareness of mind wandering." This suggests the AC is active "at the moment of awareness" of whatever is occurring now, in the present moment.

During meditation, following the initial "awareness of mind wandering," one "shifts" to "sustained attention," one shifts to sustain the attention of awareness of the present moment.

Without the development of a capacity to intentionally sustain the attention of awareness of the present moment, this quality of attention will normally be lost as the event-encoding cycle ends. The various practices of meditation, however, can develop a capacity to intentionally sustain the attention of awareness of whatever is occurring in the present moment, irrespective of the nature of the stimuli and irrespective of the environment from which they come, whether external, internal, or interoceptive.

As mentioned, the salience detecting/executive FPC cortical orienting network, including both the AC and the insula, shifts between the external DAN and the internal DMN, while the AC and insula receive information from the interoceptive STT. This may allow the AC, in coordination with the insula, to monitor and detect the salience of the stimuli of the present moment from all environments, irrespective of the nature of the stimuli, whether known or Unknown.

Meditation may develop the capacity for an intentional attention of awareness, which activates the AC of the salience detecting/executive FPC cortical orienting network, initiating a variety of physiological cascades through its modulation of the central LC and peripheral SNS norepinephrine systems, via both parasympathetic and sympathetic routes, to maximize receptivity and adaptation in changing environments.

Buddha realized he had found a pathway to the elimination of pain and suffering. The inhibition of the SNS and activation of the LC by the AC during meditation may be a contributing factor worthy of further scientific exploration.

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Plasticity of visual attention in Isha yoga meditation practitioners before and after a 3-month retreat

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Meditation has lately received considerable interest from cognitive neuroscience. Studies suggest that daily meditation leads to long lasting attentional and neuronal plasticity. We present changes related to the attentional systems before and after a 3 month intensive meditation retreat. We used three behavioral psychophysical tests - a Stroop task, an attentional blink task, and a global-local letter task-to assess the effect of Isha yoga meditation on attentional resource allocation. 82 Isha yoga practitioners were tested at the beginning and at the end of the retreat. Our results showed an increase in correct responses specific to incongruent stimuli in the Stroop task. Congruently, a positive correlation between previous meditation experience and accuracy to incongruent Stroop stimuli was also observed at baseline. We also observed a reduction of the attentional blink. Unexpectedly, a negative correlation between previous meditation experience and attentional blink performance at baseline was observed. Regarding spatial attention orientation as assessed using the global-local letter task, participants showed a bias toward local processing. Only slight differences in performance were found pre- vs. post- meditation retreat. Biasing toward the local stimuli in the global-local task and negative correlation of previous meditation experience with attentional blink performance is consistent with Isha practices being focused-attention practices. Given the relatively small effect sizes and the absence of a control group, our results do not allow clear support nor rejection of the hypothesis of meditation-driven neuronal plasticity in the attentional system for Isha yoga practice.

Keywords: meditation, attention, Stroop task, attentional blink, global-local task

1. INTRODUCTION

Behavioral results show that meditation practice increases performance in attentional tasks suggesting improved allocation of attentional resources, enhanced sustained attention skills, faster re-allocation of attentional resources, improved cognitive flexibility, and decreases in automatic responding (Valentine and Sweet, 1999; Carter et al., 2005; Cahn and Polich, 2006; Slagter et al., 2007; Hodgins and Adair, 2010). These changes are most likely linked to structural, anatomical and functional changes observed in meditators compared to control populations (Hoelzel et al., 2011; Luders et al., 2011, 2012; Kang et al., 2013). Lutz et al. (2008) have outlined a theoretical framework for the study of meditation according to which meditation practice involve at least three attention regulation subsystems. Meditation may help train selective attention, which pertains to the selection of information from the flow of sensory inputs. Meditation also requires sustained attention for continuous monitoring of the object of meditation. Finally while meditating, one often has to redirect attention from a source of distraction toward the intended object of meditation. These transient attentional shifts involve executive attention, that is the monitoring and resolution of conflict among thoughts, feelings and mental plans. Although useful to define the scope of our study and interpret our results this taxonomy is likely an oversimplification as the different attentional systems are most likely strongly intermingled. Meditation practices are usually classified depending on the attentional engagement they require, along a continuum from focused attention to mindfulness practices (Cahn and Polich, 2006; Lutz et al., 2007, 2008). Focused attention meditation techniques involve sustained attention on a selected internal or external object of awareness, whereas mindfulness meditation, also known as open-monitoring or open-awareness meditation, involves adopting an attentive and non-elaborative cognitive stance toward anything that may occur from moment-to-moment in the mental field of experience. Recently, the "automatic self transcending" category has been proposed to denote practices marked by the absence of individual control or effort during meditation thus leading to a transcending of the sense of self as a separate choosing agent, a characteristic of meditation practice that likely is related to the notion of non-dual awareness and varies from one practice to another in ways not fully characterized as of yet (Travis and Shear, 2010; Josipovic, 2013).

Isha Yoga, the meditation tradition studied in this article, includes many practices and, specifically during the 3 month retreat studied in this article, three primary practices were done daily which may be categorized into each of these three categories. *Lingasanchalana* meditation, in which the practitioner is seated and focused on one point, with eyes either opened or closed, is primarily a focused attention practice. *Samyama* meditation is a seated meditation involving the instruction to pay attention to the breath with eyes fully or partially open and passively observing thoughts in addition to watching the breath. This is a practice with a focused attention basis in which the instruction is to continually attend to the breath, although there is some open-monitoring/mindfulness component to this practice as well. *Shoonya* meditation is typically done after a set of physical postures and breathing exercises and involves sitting with eyes closed and engaging in a process of conscious non-doing that purportedly creates a distance between ones self and ones body and mind. This practice could be considered a form of open-awareness practice with self-transcending occurring through a non-doing aspect or alternatively conceived as a focused practice in that the explicit focus is on "non-doing"—as soon as one notices mental content arising in awareness the injunction is to attempt to reinstate a "non-doing"/nothingness experience and to use a mantra if necessary to do so. Alternatively, within the Isha yoga tradition, this practice is spoken of as a self-transcending practice and may be in line with the proposed self-transcending style of practice. The nuances of these practices and the best and most inclusive and accurate classification system for meditative practices is beyond the scope of this article. In addition to these three meditation techniques, Isha Yoga also includes practice of diverse yoga postures, breathing and physical exercise as well as chanting.

To assess the extent to which Isha Yoga meditation affects the processing of visual information, we used three attentional tasks corresponding to three different attentional characteristics: the attentional blink task (temporal attention), the Stroop task (conflict monitoring/executive attention and automated responding), and a global-local task (spatial attention to global vs. local aspects of the visual field). The subjects were tested at the beginning and end of a 3-month full time Isha Yoga meditation retreat.

In the attentional blink task (Raymond et al., 1992), subjects tend to be blind to a visual stimulus presented briefly after another stimulus when the first stimulus is consciously perceived. This phenomenon arises because of the limited availability of attentional resources: the brain has difficulty processing the second of the two images presented in rapid succession since it is processing of the first of the two stimuli. However, open-monitoring/mindfulness type meditation, by disengaging some of the brain resources and leading to a more efficient cognitive processing state, has been shown to decrease the magnitude of the attentional blink effect (Slagter et al., 2007; Van Leeuwen et al., 2009).

The Stroop task (Stroop, 1935) uses color names written in congruent and incongruent ink color. Participants are asked to indicate the color of the ink verbally or by pressing a key. When the ink color and the word name mismatch (incongruent case), reaction time to indicate the ink color is slowed down (and accuracy decreased) due to involuntary automated processing of the conflicting semantic contents of the stimuli, relative to the congruent stimulus. This effect is termed the Stroop interference effect and the paradigm thus mobilizes executive attention and conflict monitoring capacities. It has been previously demonstrated that decreases in Stroop interference are seen in long-term meditators with experience in both focused attention and open-monitoring practice typical of Buddhist training regimens (Chan and Woollacott, 2007; Moore and Malinowski, 2009; Teper and Inzlicht, 2013) as well related to meditation interventions including both mindfulness and Transcendental Meditation (Alexander et al., 1989; Wenk-Sormaz, 2005; Anderson et al., 2007) and these improvements have been conceptualized as improvements in executive attention and cognitive flexibility and decreases in automatic responding patterns. We predicted that subjects would perform better after the 3-month retreat related to enhanced cognitive flexibility and decreased automated interference from semantic processes.

Finally, the global-local task is a measure of the dispositional focus of attention at either a global or more local level and the ability to switch between these levels of visual attention. This test is based on the fact that due to the limited attentional processing capacities of the brain, when attending to the global shape of an object less attention is available to attend to the local details and vice versa. Moreover, information in the non-attended level of processing interferes with the attended level of processing due to involuntary capture of attention. Work by Navon (1977) and replicated by others since has found that most people spontaneously show a bias toward the global level of perception indicated by both (1) faster responses to a task to identify the global letter than to identify the local letters when the two letters are incongruent and, (2) greater global biasing on the local task relative to local biasing on the global task. On the local task (instructing press button corresponding to the local letters) when the global letter is incongruent vs. congruent with the local letters there is an increased reaction time/decreased accuracy related to global-biasing. Conversely, on the global task (instructing press button corresponding to the global letter), when the local letters are incongruent vs. congruent with the global letter there is an increase in reaction time/decreased accuracy related to local biasing. There has been limited previous experimental work with the global-local task in relation to meditation one such study has found improvements in Stroop performance in participants with experience in a variety of Buddhist meditation practices relative to controls but no changes on global-local task performance (Chan and Woollacott, 2007). Another study has found that Zen meditators with a predominance of training in both focused attention and open-monitoring practice demonstrate faster reaction times across all stimuli and a decrease in the magnitude of global attentional bias relative to controls (Van Leeuwen et al., 2012). In contrast a group of practitioners with primary experience in focused attention practice alone tended to show local attentional bias instead of the normal global attentional bias, and a 4 day intensive retreat in open-monitoring practice tended to reduce the magnitude of this local attentional biasing such that the reaction times to the two stimuli were more equivalent. These investigators interpreted this set of findings as indicative of the fact that focused attention practices may tend to lead toward local feature biasing whereas open-monitoring practices may lead toward a reduction in biasing to either the local or global levels (Van Leeuwen et al., 2012).

A recent study showed that increased local attention bias during the global task was correlated with an increased magnitude of the attentional blink and that greater global attention bias overall during this task predicted decreased attentional blink consistent with the notion that diffusion of attention may be indexed by both greater relative global compared to local attentional bias and decreased attentional blink magnitude (Dale and Arnell, 2010).

Our hypothesis was that at the end of the retreat our subjects would be able to better redirect their attention than at the beginning (increased attentional flexibility) and would thus show a decrease specifically in the magnitude of the local biasing effect during the global task and global biasing effect on the local task. This was hypothesized based on the fact that while some aspects of the Isha Yoga meditation practices (*Lingasanchalana*, *Samyama*) have a focused attention quality to them, there is also an open-monitoring aspect to the *Shoonya* practice that might lead to a decrease in attentional biasing.

2. METHODS

2.1. PARTICIPANTS

Subjects were tested at the beginning and at the end of a 3-month retreat in the Isha center in Nashville, TN, USA. 103 Isha Yoga meditators participated in the study. All participants signed consent forms and the study was approved by the Quorum independent ethical review committee. 89 of the 103 participants tested at the beginning of the study completed the retreat and were recorded again at the end of the retreat. Seven participants did not understand the tasks correctly despite the training session and were removed from analysis. Thus, results presented here comprise 82 participants (mean age: 37.5 years old; max: 63; min: 21, ±9.4).

2.2. MEDITATION PRACTICE PRIOR TO THE RETREAT

Prior to the retreat the participants had practiced *Shoonya* meditation during an average of 4 years (±2.8 years), 6.5 days a week (±0.5 days). Although we do not have access to data concerning the precise time spent practicing *Shoonya* meditation every day, the Isha Yoga school recommends practicing it at least 15 min twice daily. Only 50 participants practiced *Samyama* meditation prior to the retreat, and they practiced it for an average of 3 years (±2 years), in average 3.2 days per week (±2.1 day). No participant practiced *Lingasanchalana* meditation prior to the retreat.

2.3. DESCRIPTION OF THE PRACTICES DURING THE RETREAT

The 3 month retreat required participants to engage in daily meditative practices. For the first 6 weeks of the retreat all participants practiced *Samyama* meditation for 30-50 min and *Shoonya* meditation for 30 min daily. For the last 6 weeks, they practiced *Lingasanchalana* meditation for 2–3 h every day. Beside pure meditative practices participants also practiced yoga postures (2 h every day) as well as physical exercise (40 min every day) and chanting (1 h every day). Finally during the first 6 weeks of the retreat only they practiced breath watching (1 h a day) and specific body postures called kriyas (2 h a day).

2.4. PROTOCOLE

2.4.1. Recording schedule

At the beginning of the retreat, participants were tested on all three tasks and they were again tested on the same three tasks at the end of the retreat. Due to the relatively large number of subjects participating in the study, the pre- and post-tests could not all be done on the same day. Days of recording for pre-test started from the first day and finished up to 12 days after the retreat started. Recording for the post-tests started 16 days before and finished 3 days after the end of the retreat. We used the number of days relative to the beginning and to the end of the retreat as a statistical regressor to assess if this could have influenced our results (see Statistics).

2.4.2. Task presentation

For all stimulus presentations, we used desktop computers running the Matlab Psychophysics toolbox (v3.0.8) under Windows XP operating systems. Stimuli were presented on a 17” DELL M781 mm CRT computer screen. The computer screen was set to 120 Hz and a resolution of 800 × 600. Two identical computers and screens were used to collect the data. Subjects sat 50 cm from the screen. Before performing the experiment, for training purposes, participants performed a shorter version of each of the tasks (three trials of the attentional blink task, 12 trials of the Stroop task and four trials of the global-local task). During this training phase the participants were allowed to repeat the training tasks again if they had problems understanding them.

2.5. STROOP TASK

The Stroop task consisted of showing the capitalized words “RED,” “BLUE” and “YELLOW,” or the control words “LOT” (control word for “RED”), “SHIP” (control word for “BLUE”) and “FLOWER” (control word for “YELLOW”) on a computer screen (Raz et al., 2007). Three sequences of 60 stimuli each were presented to subjects. Each sequence started with the text “Press the key matching the COLOR OF THE INK as fast as possible - Please use ‘Z’ for red, ‘X’ for yellow, and ‘C’ for blue - Press enter to start.” Subjects were able to rest from 1 to 5 min between sequences. Each sequence of 60 stimuli contained 12 unique stimuli repeated 5 times. Three of the 12 stimuli were the color word with matching ink color. Three of the 12 stimuli were the control words and six of the stimuli were the color words with non matching ink color - Stroop condition. The stimulus sequence was pseudorandomized such that no consecutive stimuli had the same color. The ‘Z,’ ‘X,’ and ‘C’ keys had a small sticker indicating the color they corresponded to. The color was indicated with words (“RED,” “BLUE,” “YELLOW”). This was done to make sure that subjects were not confused during the experiment about which button corresponded to which color. The computer screen background was gray (#808080 - at the midpoint between black and white in the RGB color scale). We used the standard red, blue and yellow inks in the RGB color scale (#FF0000, #0000FF, and #00FFFF respectively) using Arial font and letter size of 9 mm. Stimulus presentation and keystroke latency acquisition were performed using the Matlab psychophysics toolbox (Brainard, 1997). The timing of each trial was as follows: each word was presented until the subject pressed one of the three keys. The word was immediately followed by a feedback word "Correct" or "Incorrect" in black ink and using Arial font and letter size of 4.5 mm based on whether the subject had provided a correct or an incorrect response. The feedback word remained on the screen for 0.5 s. Then a 1-s gray screen was presented until the next trial. Subjects performed 3 runs of 60 stimulus presentations (**Figure 1B**).

2.6. ATTENTIONAL BLINK TASK

In the attentional blink task, series of letters were rapidly presented to subjects (**Figure 1A**). These series of letters contained one or two numbers that subjects were subsequently asked to report. To avoid potential ambiguities between letters and numbers, we used only 21 letters (A, C, D, E, F, G, H, J, K, L, M, N, P, R, T, U, V, W, X, Y, Z) and 8 numbers (2, 3, 4, 5, 6, 7, 8, 9). The sequence length was fixed to 19. Each letter or number was presented in white (gray level 255) on a gray background (gray level 168) for exactly 50 ms followed by 33 ms of a gray screen. The size of the letter was about 2 cm on the screen corresponding to a visual angle of 2.3 degree. A first number T1 was presented at a position chosen randomly between 3 and 11 in the sequence (Slagter et al., 2007). On one third of the trials, no second number was presented (condition T2 absent). On one third of the trials, a second number was presented three letters after the first number (condition T2 short; for example, if the first number was at position 10, the second one was at position 14). At this position (332 ms post T1) the attentional blink effect is expected to be maximal. Finally, on one third of the trials, a second number was presented seven letters after the first number (condition T2 long), 664 ms post T1 which is outside the significant attentional blink time window. After each sequence, participants were asked to enter the first and the second number (0 if they thought there was none) and then confirm their choice before the next trial. Participants were instructed to guess the numbers if they thought a second number was present but were not sure what it was. Subjects were tested on a total of 120 trials. Stimuli presentation latency and screen vertical blanking were carefully monitored using custom Matlab scripts and CRT analog computer monitors were used to ensure that the presentation time on the screen matched the presentation time in the experimental script.

2.7. GLOBAL-LOCAL TASK

In the global-local task, subjects were shown large letters (H and T) on a computer screen. The large letters were made up of an aggregate of small letters that could be congruent (large H made of small Hs or large T made of small Ts) or incongruent (large H made of small Ts or large T made of small Hs) with respect to the large letter. The small letters were 0.8 cm high and the large letters were 8 cm high on the computer screen. A fixation cross was present at all times except when the letters were presented. Letters were shown on the computer screen until the subject responded. After each subjects response, there was a delay of 1 s before the next stimulus was presented. Before each sequence of letters, instruction were shown on a computer screen indicating to subjects whether they should respond to the presence of small (local condition) or large (global condition) letters. We instructed subjects to categorize specifically large letters or small letters and to press the letter H or T on the computer keyboard to indicate their choice. Subject performed a total of 52 trials in 4 sessions of 13 trials each. In sessions 1 and 3, subjects were instructed to focus on large letters and in session 2 and 4 they were instructed to focus on small letters (**Figure 1C**).

2.8. STATISTICS

Since our data did not fit the normal distribution (Kolmogorov–Smirnov test), we used non-parametric statistic Wilcoxon ranksum tests and used Bonferroni correction for multiple comparisons. For all tests, the degree of freedom was 81. For

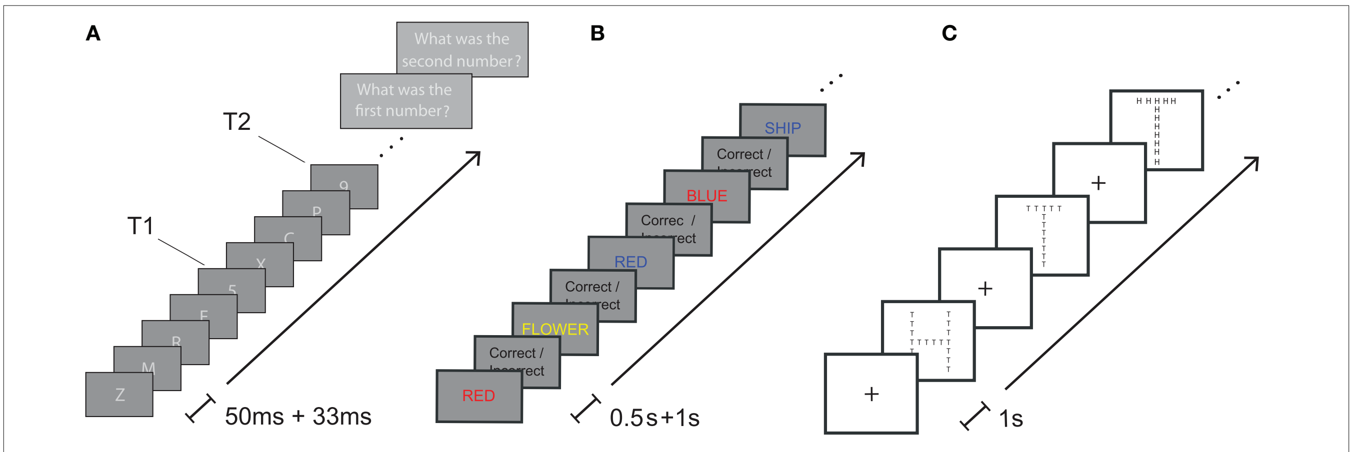

FIGURE 1 | Task paradigms. (A) Attentional blink **(B)** Stroop task **(C)** Global-local task.

assessing the effect that meditation experience and age had on results, we used a general linear model and bootstrap statistics. We used Matlab to perform all statistical tests.

3. RESULTS

3.1. STROOP TASK

3.1.1. Accuracy

In the Stroop task, subjects tended to commit less errors to incongruent stimuli at the end of the retreat ($p < 0.05$, 86.5% correct responses at pre-test vs. 87.4% correct response at post-test) (**Figure 2**). We found no significant difference in accuracy to congruent ($p = 0.9$) or neutral ($p = 0.7$) stimuli between pre- and post-retreat tests. For each subject, we also calculated the Stroop Interference (SI) by subtracting the accuracy score to incongruent stimuli from accuracy score to congruent stimuli. We found a significant diminution of the Stroop Interference after the retreat compared to before the retreat ($p < 0.05$, mean SI at pre-retreat test was 1.8, mean SI at post-retreat test was 0.8).

3.1.2. Reaction time

We did not observe any significant effects in reaction time for any of the comparisons we tested. Specifically, we did not observe a difference in RT for incongruent, congruent, or neutral stimuli when comparing pre- and post-retreat assessments. Similarly, we did not observe a significant difference in the RT Stroop Interference, computed as the difference of RT for congruent and incongruent stimuli for each subject, between pre- and post-retreat assessments.

3.2. ATTENTIONAL BLINK TASK

Attentional blink performances were improved at the end of the retreat when compared to performances at the beginning: the rate of detection of the T2 target within the window of the attentional blink (T2 short; target T2 following a short interval after T1) was 59% at pre-test vs. 70% at post-test ($p < 0.0001$). Significant increases in performance between pre- and post-tests were also found for the targets T1, and T2 long ($p < 0.05$; mean detection rate of T1 at pre-test 84 vs. 87% at post-test; mean detection rate of T2 long at pre-test is 75 vs. 81% at post-test). No significant difference for detection of the absence of T2 (T2 absent) was found (mean T2 absent detection rate at pre-test 55 vs. 61% at post test). However, as shown in **Figure 3**, comparison of post-test improvement between each type of stimulus revealed that performances increased significantly more for detection of T2 presented in a short interval than for any of the other targets (T2 short performance increase vs. T1 performance increase $p < 0.0002$; T2 short performance increase vs. T2 long performance increase $p < 0.001$; T2 short performance increase vs. T2 absent performance increase $p < 0.005$).

To assess potential short term learning effects, we divided subjects trials into 2 groups of equal sizes: the first half and the second half of the trials. Within each pre and post test session, for each type of target, we did not find any significant differences in performances between the first half and the second half of the trials (ranksum test).

3.3. GLOBAL-LOCAL LETTER TASK

3.3.1. Accuracy

At the beginning and at the end of the retreat, participants made significantly less errors on congruent than on incongruent trials during both the global and the local tasks ($p < 0.001$) see **Figure 4**. There were no significant differences in performance between pre- and post-retreat tests in either the congruent or incongruent conditions for the local (congruent condition $p = 0.6$; incongruent condition $p = 0.2$) or global (congruent condition $p = 0.7$; incongruent condition $p = 0.6$) tasks. We computed

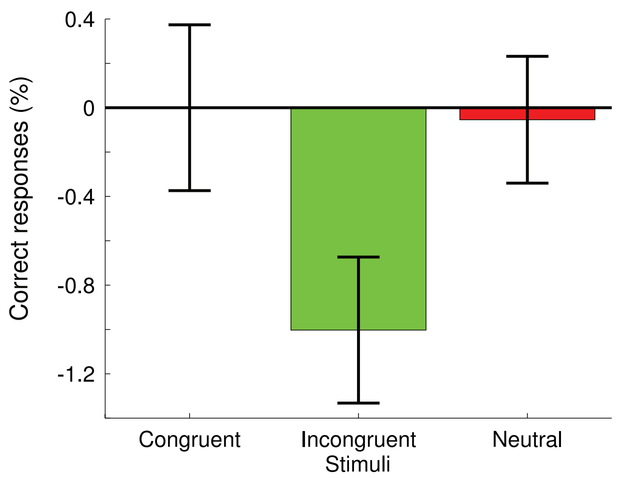

FIGURE 2 | Differences of pre- vs. post-retreat test mean correct responses to the Stroop task for all types of stimuli. Standard error of the mean are shown for each condition.

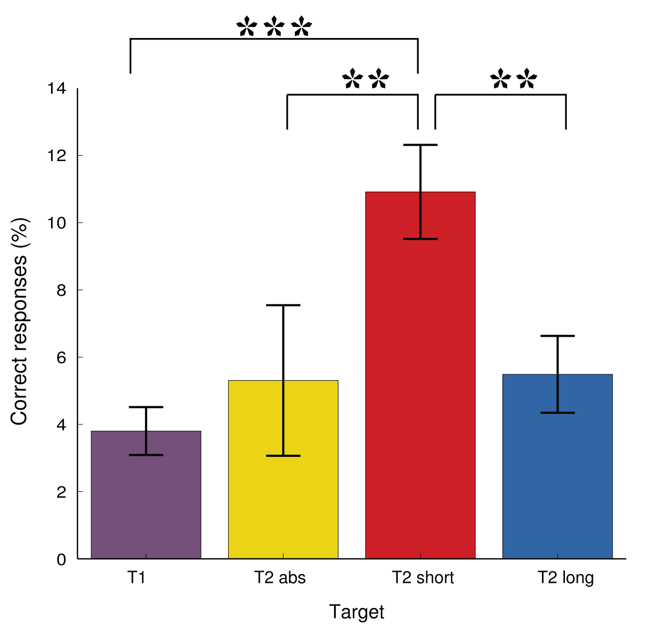

FIGURE 3 | Mean accuracy improvement for each target type between pre and post test in the attentional blink task. Standard error of the mean are shown for each condition. **indicates $p < 0.005$ and ***indicates $p < 0.0005$.

the congruency effect interference score (performance on congruent minus performance on incongruent trials) but did not find significant differences between pre- and post- retreat scores on this measure either (local task: $p = 0.7$; global task: $p = 0.1$).

3.3.2. Reaction times

Participants were significantly faster in responding to congruent than incongruent trials during the global task both before and after the retreat ($p < 0.005$; see **Figure 5**) but we did not find a significant congruency effect for the local task, although we did observe a trend ($p = 0.057$). We found no significant differences between RTs before and RTs after the retreat for any of the specific trial types as a class. However, there was a significant faster mean RT in response to incongruent stimuli in the local versus global task ($p = 0.04$) before the retreat, and only a trend difference ($p = 0.1$) after the retreat.

3.4. ATTENTIONAL BLINK AND GLOBAL-LOCAL PERFORMANCE

We tested the hypothesis that performances in the global-local task would be correlated with performance in the attentional blink task. We divided participants into quartiles based on their scores on the local-interference (defined as the difference between RTs to incongruent and congruent conditions when subjects had to respond based on the global stimuli) and global interference (defined as the difference between RTs to incongruent and congruent conditions when subjects had to respond based the local stimuli) measures, for both pre and post retreat assessments. Low local interference participants had scores within the first quartile (pre retreat, $n = 20$; post retreat, $n = 21$) and high local interference participants had score within the last quartile (pre retreat, $n = 21$; post retreat, $n = 21$). We used linear regression to assess any relationship between attentional blink performances and local interference scores and did not find any significant correlations either before or after the retreat. We did the same analysis using the global-interference measure and similarly found no significant correlations.

3.5. INFLUENCE OF AGE AND PRIOR MEDITATION EXPERIENCE ON TASK PERFORMANCES

We used a general linear model to assess the effect of participants age and prior meditation experience on task performances.

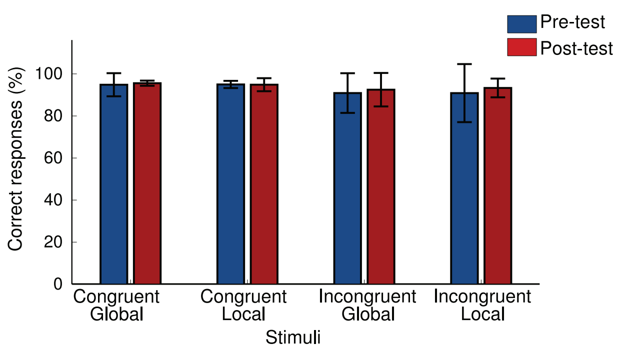

FIGURE 4 | Mean correct responses to the local and the global task in congruent and incongruent condition at pre-test and post-test.

For each task, we computed the correlation between years of *Shoonya* meditation practice (since it was the only meditation practice shared by all participants prior to the retreat, see section 2.2), age of the participants, and performance for each of the tasks for the pre-retreat assessments. In the attentional blink task, age and previous *Shoonya* meditation experience of the participants both had a significant negative influence on T1 response accuracy (age: regression coefficient (reg. coef.) $= -0.46$, $p < 0.005$; previous meditation experience: reg. coef. $= -0.04$; $p < 0.005$) T2 long (age: reg. coef. $= -0.22$, $p < 0.01$; previous meditation experience: reg. coef. $= -0.30$; $p < 0.01$) and T2 short response accuracy (age: reg. coef. $= -0.29$, $p < 0.01$; previous meditation experience: reg. coef. $= -0.14$; $p < 0.01$) but not T2 absent ($p < 0.1$) response accuracy. In the Stroop task, the age and meditation experience of participants did not affect reaction time. However, we observed a significant positive influence of these factors on accuracy to both incongruent (age: reg. coef. $= 0.11$, $p < 0.005$; previous meditation experience: reg. coef. $= 0.16$; $p < 0.005$) and neutral stimuli (age: reg. coef. $= 0.03$, $p < 0.05$; previous meditation experience:reg. coef. $= 0.05$; $p < 0.05$). Both increased age and prior meditation experience significantly correlated with decreases of Stroop interference (age: reg. coef. $= -0.10$, $p < 0.01$; previous meditation experience: reg. coef. $= -0.07$; $p < 0.01$) Finally, there was no significant influence of either age or meditation experience on performance to congruent stimuli. In the global-local task, we did not observe any significant effect of age or meditation experience on accuracy or RT to either type of stimuli.

4. DISCUSSION

We tested 82 meditation practitioners at the beginning and at the end of a 3 month full time meditation retreat using three attentional tasks: an attentional blink task, a Stroop task and a global-local task . Our results show a modest decrease in the magnitude of the attentional blink at the end of the retreat compared to the beginning. Unexpectedly, we also found that previous meditation experience correlated with decreased performance in accurately recognizing both the T1 and T2 stimuli of the attentional blink paradigm. Comparing the magnitude of improved performance on the attentional blink paradigm to previous studies indicated a similar magnitude of improvement in a control cohort of novices with minimal meditation experience and no significant intervention. This is thus casting doubt on the interpretation that this effect was a specific result of meditation during the retreat and more in support of this being related to improved performance secondary to simple learning mechanisms. Comparing pre- and post-retreat assessment of conflict monitoring and automated responding as assessed by the Stroop paradigm we observed decreased Stroop interference related to improved accuracy on the incongruent trials of the Stroop task. Congruent with this, previous meditation experience in our cohort also correlated with increased accuracy on incongruent trials and decreased Stroop interference at the baseline pre-retreat assessment. We found no significant main effects of the retreat on accuracy or reaction time in the incongruent trials of the global-local task although a pattern of relatively faster reaction times on the local task relative to the global task both pre and post retreat indicated that this cohort

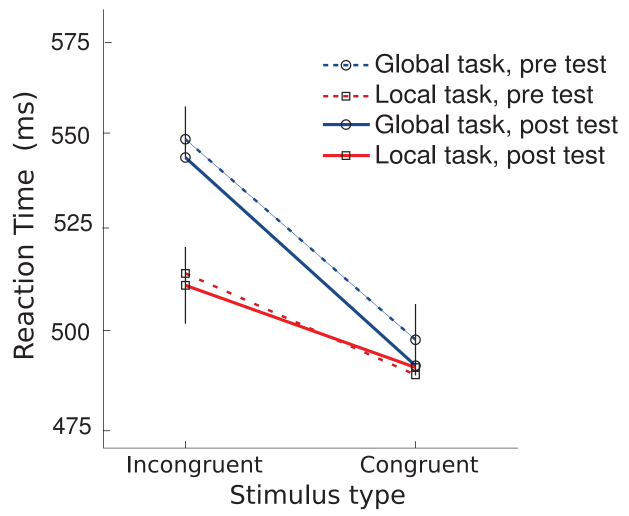

FIGURE 5 | Mean reaction time to respond to global and local features at pre and post test depending on the congruency of the stimuli in the global-local task.

showed an unusual local attentional biasing, possibly related to the practices in this tradition being more in the focused attention domain.

4.1. EFFECT OF RECORDING SCHEDULE

Because of the large number of subjects and our limited data collection capabilities, some subjects were recorded after the beginning of the retreat and some subjects were recorded before the end of the retreat. We thus checked for correlation of pre- and post test performances with pre- and post- test date expressed as the day the test occurred relative to the beginning and the end of the retreat. Overall, we computed 18 regressions scores that did not lead to significant correlation with pre- or post-retreat test date after applying the Bonferroni correction for multiple comparisons.

4.2. ISHA YOGA MEDITATION AND REDUCTION OF STROOP INTERFERENCE

Our results show increased accuracy scores on incongruent Stroop stimuli at the end of the retreat compared to the beginning. In addition, previous meditation experience correlated with more accurate performance at the baseline assessment. These results are in accordance with a previous reports demonstrating less Stroop interference in experienced Buddhist meditators compared to controls (Moore and Malinowski, 2009; Teper and Inzlicht, 2013) as well as in a cohort of diverse long term meditators of different traditions (Chan and Woollacott, 2007). Moreover, decreased Stroop interference after training in mindfulness meditation in college-age students (Wenk-Sormaz, 2005), as well as after training in Transcendental Meditation in older adults (Alexander et al., 1989) have been previously reported, although one report found no changes in Stroop task performance after a mindfulness-based stress reduction (MBSR) intervention (Anderson et al., 2007). The decrease in Stroop interference we report here is consistent with the notion that the flexible executive attention and reduction in automatic responding measured through the Stroop color-word interference task is one of the domains of attention positively affected through this meditative practice.

It is of note that a recent study utilizing EEG concomitantly with Stroop performance (Teper and Inzlicht, 2013) found that, in addition to decreased Stroop interference, experienced meditators showed increased amplitude of the ERN event-related potential known to be related to the engagement of anterior cingulate cortex in conflict monitoring, thus providing some indirect evidence that these Stroop findings may be related to enhanced anterior cingulate functioning related to the long hours of practice during meditation retreat.

4.3. MEDITATION AND REDUCTION OF THE ATTENTIONAL BLINK

We observed an increased detection rate (70%) of the target T2 presented in the short interval after T1 (window of the attentional blink) relative to the pre-retreat test (59%). One previous study assessed the effect of meditation and the attentional blink effect. Slagter et al. (2007) did a pre/post testing before and after a 3 month intensive Vipassana (open-monitoring/mindfulness) meditation retreat with 17 expert meditation practitioners of diverse meditation traditions compared to a group of novice meditators.

Our study found an improvement in the meditation retreat participants equal to the control group participants in the Slagter study (from about 60 to 70% T2-short correct) and not as robust as the meditator group participants in that study (who showed an average of about 60 to 80% T2-short correct). As we did not have a control group to compare the meditator cohort data in this study, we cannot assume that the rather modest improvement in performance was specifically related to the intensive meditation practice during the Isha Yoga retreat. Of note, during the Isha Yoga meditation retreat considered here, participants spent about 1.5–4 h daily sitting in silent meditation whereas in Slagter et al. (2007)'s study open-monitoring Vipassana meditation during the retreat was practiced intensively 10–12 h a day. It is possible that with more intensive practice of sitting meditation the observed effects of Isha Yoga meditation practice would have been more robusts.

The contrast in findings between this study of the effects of the Isha Yoga 3-month retreat and the earlier report before and after a 3-month Vipassana retreat seems to indicate that intensive open-monitoring/mindfulness training may more specifically modulate the attentional capacities underlying the performance of the attentional blink paradigm. This is possibly related to Vipassana practice engaging the attentional mechanisms on present moment awareness with a greater focus on sensitively attending to internal and external experience with concomitant purposeful cognitive non-elaboration on experience. In contrast, the *Shoonya*, *Samyama*, and *Lingasanchalana* practices done in the Isha Yoga retreat have a less explicit focus on open-monitoring and are instead favorising the focused attention spectrum of practice. Consistent with this interpretation, in contrast to the negative correlation we obtained between previous Isha Yoga meditation practice and attentional blink performance at baseline, Van Leeuwen et al. (2009) showed that older adult expert meditation practitioners with extensive experience in both focused attention and open-monitoring practice did not show the same decrease in attentional blink performance relative to young adults as older non-meditators, seeming to implicate more pure open-monitoring practice as important to improving attentional blink performance.

Although our modest improvement in performance and lack of a control cohort precludes our attributing the improvements that we did observe in the attentional blink paradigm to the meditation practiced in retreat, it is also possible that some of this improvement may have been due to the "open monitoring" aspect of the diverse Isha Yoga meditation practices. Indeed, Olivers and Nieuwenhuis (2005, 2006) demonstrated that the attentional blink can be attenuated if instead of concentrating hard on the task, the subject is asked to simultaneously perform an additional task or even simply instructed to concentrate less on the task. It is possible that at the end of the retreat our subjects might have engaged a more diffuse attentional deployment, preventing them from allocating too much attentional resource to the initial T1 stimulus in the stream of stimuli.

Overall we take the smaller improvement in attentional blink performance in this Isha Yoga retreat cohort relative to the previous Vipassana retreat cohort assessed by Slagter et al. (2007) using a very similar attentional blink paradigm as likely related to the difference in attentional deployment in more pure open-monitoring practice resulting in greater diffusion of attention and resultant optimization of attentional resources on this task assessing temporal attention capacities. Indeed, the fact that meditation experience in the Isha Yoga cohort actually correlated with worse attentional blink performance at the pre-retreat assessment tends to argue that this form of meditation practice did not specifically lead to improved attentional blink performance.

4.4. GLOBAL-LOCAL TASK

Both at the beginning and at the end of the retreat, participants were faster to respond in the local task than in the global task to stimuli with incongruent global and local features. Moreover, participants were faster to respond at the global level when stimuli were congruent than when stimuli were incongruent and the speed of responding was thus biased by local features. However, there was only a trend difference in reaction time between congruent and incongruent stimuli when responding to the local level at both the beginning and end of the retreat, indicating a decreased magnitude of global biasing relative to local biasing. These results suggest that overall this global-local paradigm tended to evoke in this cohort a non-standard tendency for local processing to predominate over global processing. Previous literature (Navon, 1977) has demonstrated that most individuals show a global precedence effect and thus respond more quickly on a global compared to a local task when shown stimuli with conflicting local and global features. Thus it seems likely that this cohort of Isha Yoga meditation practitioners shows a greater tendency toward local processing, which may be related to their meditation practice. In particular, given previous reports of focused attention practices leading to greater local processing precedence (Van Leeuwen et al., 2012) this finding seems to further support that Isha Yoga meditation practices are primarily concentrative in nature.

The only pre-/post- differences in performance on the global-local task found was related to slight decrease in the magnitude of the faster reaction time to incongruent stimuli in the local relative to global task condition. This finding indicates a possible slight relative increase in global attentional processing after the retreat, somewhat in line with the hypothesized increase in global attentional biasing that we predicted might accompany improvements in attentional blink performance. However this metric is not as specific and robust a metric of global processing as the global-local interference effects which were not found to be affected by the retreat so reading much into this finding is unwarranted.

It is of note that the one previous study assessed the global-local task as well as Stroop performance in experienced meditators vs. controls also found improvements in Stroop task performance but no effect of meditation in performance on the global-local task (Chan and Woollacott, 2007). Although we did not replicate the results of Dale and Arnell (2010) showing a correlation between greater attention to the local level in the global-local Navon task and greater magnitude of the attentional blink, we did demonstrate the complementary finding that meditators in this tradition of more focused attention practices show biasing toward the local processing on the Navon task and those with greater pre-retreat practice also tended to display greater attentional blink amplitude.

Another explanation pertains to the type of meditation we studied. Other types of meditation involving visualization such as those practiced in Tibetan Buddhism might be expected to engage a more robust effect compared to Isha Yoga meditation which does not involve any visualization. For example, Carter et al. (2005) have found higher performance in the maintenance of bistable visual stimuli in Tibetan Buddhist meditators practicing meditation requiring to focus on one point (real or imagined), compared to the same meditators practicing compassion meditation, consistent with the now well established notion that different meditation practices engage attentional processes in very different ways and thus have different effects on many aspects of the attentional system.

5. CONCLUSION

Our study reinforces that increased cognitive flexibility and decreases in automatic responding as indexed by the Stroop task is one likely concomitant to diverse forms of meditative practice including Isha Yoga practices which involve more focused attentional mechanisms as well as some explicit focus on self-transcending. The results point toward a negligible effect of this form of more focused meditation on the efficiency of temporal attentional resource allocation indexed by the performance on the attentional blink task in contrast to the improvements previously observed with open-monitoring practices. Lastly, there is some indication that this form of practice may predispose individuals toward greater local precedence in spatial visual attention instead of the more typical global precedence seen in the population through performance on the Local-Global task. The Stroop task result is the most robust since increases in accuracy in the task seen between pre- and post- recording is reinforced in the observed correlation between previous meditation experience and improved performance on this task. All of these effects would be much more reliably interpreted in the presence of a control group, which is the primary limitation of this study.

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A suspended act: increased reflectivity and gender-dependent electrophysiological change following Quadrato Motor Training

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Quadrato Motor Training (QMT) is a specifically-structured walking meditation, aimed at improving reflectivity and lowering habitual thought and movement. Here we set out to examine the possible effect of QMT on reflectivity, employing the Hidden Figures Test (HFT), which assesses both spatial performance (measured by correct answers) as well as reflectivity (interpolated from correct answers and reaction time). In the first study ($n = 24$, only females), we showed that QMT significantly improves HFT performance, compared to two groups, controlling for cognitive or motor aspects of the QMT: *Verbal Training* (identical cognitive training with verbal response) and *Simple Motor Training* (similar motor training with reduced choice requirements). These results show that QMT improves HFT performance above the pre-post expected learning. In the second study, building on previous literature showing gender-dependent effects on cognitive performance, we conducted a preliminary pilot examining gender-dependent effect of training on reflectivity and its electrophysiological counterparts. EEG analyses focused on theta, alpha and gamma coherence. HFT performance and resting-state EEG were measured in 37 participants (20 males), using a within-subject pre-post design. Following training, HFT performance improved in both genders. However, we found a gender-dependent difference in functional connectivity: while theta and alpha intra-hemispheric coherence was enhanced in females, the opposite pattern was found in males. These results are discussed in relation to neuronal efficiency theory. Together, the results demonstrate that QMT improves spatial performance, and may involve a gender-dependent electrophysiological effect. This study emphasizes both the importance of studying gender-related training effects within the contemplative neuroscience endeavor, as well as the need to widen its scope toward including "contemplation in action."

Keywords: motor training, reflectivity, spatial cognition, EEG coherence, gender

INTRODUCTION

Reflectivity is the capacity of humans to exercise introspection, by examining one's conscious thoughts and feelings, resulting in the inhibition of habitual thought or behavior. Quadrato Motor Training (QMT) is a specifically-structured walking meditation, aimed at improving reflectivity. The QMT requires a state of enhanced attention, as it combines dividing attention to the motor response and cognitive processing for producing the correct direction of movement to the next point in the Quadrato space (Paoletti and Salvagio, 2011; Dotan Ben-Soussan et al., 2013). Due to the increased awareness to the body and its location in space, in response to very specific instructions, QMT can be conceived of as "Mindful movement." Mindful movement is a general term for practices that involve bringing awareness to the detailed experience of movement, such as when practicing walking meditation or yoga (Kabat-Zinn, 2009). Yet, in comparison to other Mindful movement practices, the QMT has the advantage of being a relatively short training (possibly several minutes), and can be relatively easily practiced in limited spaces. These unique aspects render the QMT a technique warranted of scientific exploration, with the future aim of implementing this technique in various health promoting and educational setups.

Reflectivity can be directly measured by a spatial task assessing Field Dependence-Independence (FDI) (Glicksohn and Kinberg, 2009), named the Hidden Figures Test (HFT). Here, we set out to investigate a possible QMT-induced increase in reflectivity using the HFT. We additionally utilized electroencephalography (EEG), in the attempt to relate changes in reflectivity with functional connectivity, measured by coherence, while taking into consideration gender effects for both measures (Jausovec and Jausovec, 2005; Aliakbari and Tazik, 2011). This study is referred to as Study 2, subsequently. However, as HFT performance is considered to improve following learning (Witkin et al., 1971a,b; Stericker and LeVesconte, 1982; Woodfield, 1984; Ludwig and Lachnit, 2004), it is hard to disentangle the QMT-induced improvement in HFT performance from the regular learning curve. To this end, we report the results of a study, referred to hereafter as Study 1, where HFT performance was tested in a pre-post design in a QMT group compared to two control groups, showing that QMT significantly enhanced HFT performance, well above the other groups which showed no significant change.

The construct of reflectivity has been conceptualized as a tendency to gather more information, more carefully and systematically, compared to impulsive performers (Messer, 1976). Reflective individuals are suggested to implement an analytic process and are considered more cognitively mature compared to impulsive individuals (Rozencwajg and Corroyer, 2005). Importantly, reflectivity has been found to be modifiable by training (Messer, 1976). One way to measure reflectivity is by means of a spatial task of embedded figures, originally designed to assess FDI (Glicksohn and Kinberg, 2009). FDI describes two contrasting ways of processing information, Field Dependence (FD) and Field Independence (FI), this being the most studied cognitive style (Witkin et al., 1977), and is the mode by which learners approach, acquire and process information (Witkin and Goodenough, 1981). Individuals located toward the FD end have difficulty in separating incoming information from its contextual surroundings, and are more likely to be influenced by external cues and to be non-selective in their information uptake. In contrast, FI individuals have less difficulty in separating the essential information from its context, and are more likely to be influenced by internal than external cues, and to be more selective in their information input (Riding and Cheema, 1991; Zhang, 2004). Glicksohn and Kinberg (2009) examined individual performance on embedded figures tests. Using reaction time (RT) and the number of correct detections, they postulated four templates of performance, indicative of: (1) FI—participants detect more embedded figures, and do so quite quickly; (2) FD—participants detect fewer embedded figures, and do so quite slowly; (3) impulsiveness (Imp)—individuals detect fewer embedded figures, and do so quite quickly; and (4) reflectiveness (Ref)—individuals detect more embedded figures, and do so quite slowly. It should be noted here that reflective individuals are significantly more FI than impulsive ones (Messer, 1976), and that both of these groups (FI and Ref) are thought to exhibit better performance in learning and memory tasks (Blackman and Goldstein, 1982). Here, we intend to adopt such a finely-tuned approach to the study of possible QMT-induced reflectivity, profiling individual differences. It should be considered, however, that participants tend to generally perform better on embedded figures tests after practice (Witkin et al., 1971a,b; Stericker and LeVesconte, 1982; Woodfield, 1984; Ludwig and Lachnit, 2004), hence such an improvement does not necessarily indicate an increase in reflectivity. However, within such improvement, four patterns may be discerned (Kepner and Neimark, 1984): (1) stable FI, namely high scores (number of figures detected) at both test and retest; (2) stable FD, namely low scores at both times; (3) improvement from test to retest, including (but not necessarily) a move from FD to FI; and (4) a decline in performance. Hereafter, we consider pattern 3 to operationalize an increase in reflectivity.

Depraz et al. (2000) have described the subtle dynamic of becoming more reflective in three interdependent phases: first, *suspension* from the habitual act of mind and body, then redirection of *attention* inwardly, and finally *receptivity* toward the experience. Contemplative practices can be expected to increase reflectivity, based on two arguments. First, various contemplative practices entail an improvement in attention (Brefczynski-Lewis et al., 2007; Chambers et al., 2008; Lutz et al., 2008, 2009). Second, contemplative practice, through the three phases of reflectivity (suspension, a shift of attention inwards and receptivity), enables one to disrupt normal cognitive and perceptual functioning, and hence to become more FI or reflective (Depraz et al., 2000; So and Orme-Johnson, 2001). However, there is surprisingly little research on contemplation-improved reflectivity, most of it measuring directly only the related measure of FI, and reporting conflicting results. While some studies have not found significant changes (Kurie and Mordkoff, 1970; Goldman et al., 1979), others report FI to increase following meditation (Linden, 1973; So and Orme-Johnson, 2001). Here, we study directly both reflectivity and FI. As voluntary control and planning require reflective consciousness (Legrand, 2007), we hypothesize that the QMT will induce an on-going suspension of the habitual act of moving, resulting in increased reflectivity and FI.

Meditation practices have been consistently related in EEG studies to increased power and coherence within the theta (4–7 Hz) and alpha (8–13 Hz) frequencies (Alexander et al., 1987; Aftanas and Golocheikine, 2001; Travis, 2001; Travis et al., 2002, 2009; Baijal and Srinivasan, 2010). Alpha activity increases were suggested to reflect increased relaxation; while theta increased activity has been related to heightened attention, decreased anxiety and low thought content (reviewed by Cahn and Polich, 2006). In contrast, the results relating to gamma activity (>25 Hz) have been scarce and much less consistent, some reporting increased gamma activity (Lutz et al., 2004) while others reporting decreased activity (Faber et al., 2004; Berkovich-Ohana et al., 2012, 2013; Lehmann et al., 2012). While meditation research examined both power and functional connectivity, research examining whole-body contemplative movement practices, such as Tai Chi and Qigong, has mostly focused on power, reporting increased frontal theta and alpha activity (reviewed by Cahn and Polich, 2006). As EEG coherence changes in the context of contemplative practices are usually confined within the theta, alpha, and gamma bands, our study focuses on these bands in the analyses.

Results regarding the connection between FDI and EEG coherence are confusing. While some studies found that FI participants display less inter-hemisphere alpha coherence, suggesting more hemispheric specialization (O'Connor and Shaw, 1978; Oltman et al., 1979; Zoccolotti, 1982), others have found that FI participants had higher alpha coherence compared to those who were FD (Colter and Shaw, 1982). Nevertheless, we hypothesized that our participants should exhibit more reflectivity and FI, hence an increase in inter-and intra-hemispheric EEG coherence, especially within the alpha and theta bands (Colter and Shaw, 1982). Gender may, however, moderate this, given that:

(1) baseline EEG coherence is higher in females than in males (van Beijsterveldt et al., 1998), though this might be reversed in the gamma band (Jausovec and Jausovec, 2010); (2) an increase in both alpha and theta coherence from baseline to task is more prominent in females than in males (Beaumont et al., 1978; Volf and Razumnikova, 1999).

It is important to consider that gender-dependent differences have been frequently observed in both the motor and the cognitive realms (e.g., Kimura, 1992; for review, see Diamond et al., 1983; Baron-Cohen and Hammer, 1997). The different gender-dependent functional connectivity effects have been related to gender differences in brain structures, especially within the corpus callosum (Corsi-Cabrera et al., 1997; Jausovec and Jausovec, 2005). Hence, in the first study we studied only females to reduce intra-group variability. In the first study, we set out to study the effect of QMT on HFT performance by comparing the QMT to two control groups: *Verbal Training* (VT, identical cognitive training with verbal response) and *Simple Motor Training* (SMT, similar motor training with reduced choice requirements). As will be shown, results indicated that only the QMT group, and not the control groups, showed better HFT performance. In the second study we set out to examine gender-dependent differences, comparing the effects of QMT for male and female participants on reflectivity, as well as studying the possible EEG counterparts. As will be shown, both genders exhibited better HFT performance and reflectivity following the QMT, albeit showing an opposite EEG pattern. These results are discussed in light of neuronal efficiency theory.

STUDY 1

METHODS

Participants and design

A total of 24 female (28 ± 3 years in age) students participated in the study, none of whom practiced QMT before (for the detailed procedure, see Dotan Ben-Soussan et al., 2013). In order to avoid gender-dependent differences in performance (Terlecki et al., 2008) and reduce intra-group variability we focused on female participants. Data were collected both before and after a single training session lasting 7 min in each of three training groups (the participants having been randomly allocated to these): (1) Quadrato Motor training (QMT—3 choices and whole-body response, $n = 9$); (2) Simple motor training (SMT—1 choice and whole-body response, $n = 7$); and (3) Verbal training (VT—3 choices and verbal response, $n = 8$). The collected data included the HFT, reported here. Other measures included EEG and an Alternative Uses task, reported elsewhere (Dotan Ben-Soussan et al., 2013).

Training groups

Quadrato Motor Training (QMT). Briefly, the participant stood at one corner of a 0.5 m × 0.5 m square and made movements in response to verbal instructions given by an audio tape recording. There were three optional directions of movement. The instructions directed participants to keep the eyes focused straight ahead, hands loose at the side of the body. They were also told to immediately continue with the next instruction and not to stop due to mistakes. At each corner, there were three possible directions to move. The training thus consisted of 12 possible movements (**Figure 1**). Training consisted of a sequence of 69 commands, lasting 7 min.

Two variables that were addressed in other studies of motor learning are limb velocity and the decision regarding the responding limb (Criscimagna-Hemminger et al., 2002; Donchin et al., 2003). In order to control these parameters, we used a movement sequence paced at a rate of an average of 0.5 Hz (similar to a slow walking rate), and we instructed the participants to begin all movements with the leg closest to the center of the square (a detailed description can be found in Dotan Ben-Soussan et al., 2013).

Simple Motor Training (SMT). The SMT group provided similar motor performance as the QMT group but with reduced cognitive demands. This group moved from corner to corner on the square in exactly the same manner as the QMT group (pace, duration, auditory cue), but their movement was consistently 1-2-3-4-1 etc. The participants heard the same recordings as the QMT group. However, while the QMT group was told that each number represented a different corner of the square, the SMT group was told to simply begin at a certain corner and to continue to the next corner clockwise in response to the instructions. That is, regardless of the number specified on the tape, they always moved in the same sequence. This reduced the uncertainty and the cognitive demand, compared to the QMT group.

Verbal Training (VT). The VT group was designed to reduce motor load while keeping the same cognitive load and uncertainty. The participants, who were instructed to only make verbal responses, stood 1 m in front of the square, but did not move to the corners. Instead, they responded to the taped commands verbally by stating what direction of movement would be required in order to reach the corner specified by the command. For example, for a movement from corner 1 to corner 2, they were required to say "straight." All other training parameters were kept identical to the QMT (pace, duration, auditory cue).

Hidden figures test

We employed a computerized version of the Hidden Figures Test (HFT, detailed in Glicksohn and Kinberg, 2009), generated using E-Prime 1.1 (Psychology Software Tools). The participants were required to locate a simple figure embedded within a complex figure, both of them appearing on the screen, side by side (**Figure 2**). The figures ranged in size between 10.5 × 4 cm and 12 × 6.5 cm, and were viewed from a comfortable viewing distance. The participants were allocated 30 s for each of 16 trials. Based on the data collected by Glicksohn and Kinberg (2009), we split the test into two even sets of 8 tasks, matched for degree of difficulty, defined as number of hits for item/(number of hits + number of false alarms for item) in that study ($n = 80$). The two sets were presented in a counterbalanced order across participants. Before the test, one practice trial was given. The participant attempted to locate the simple figure as quickly as possible, within the time allocated. On detecting the figure, the participant pressed a button, and the complex figure was presented again, so that the participant could

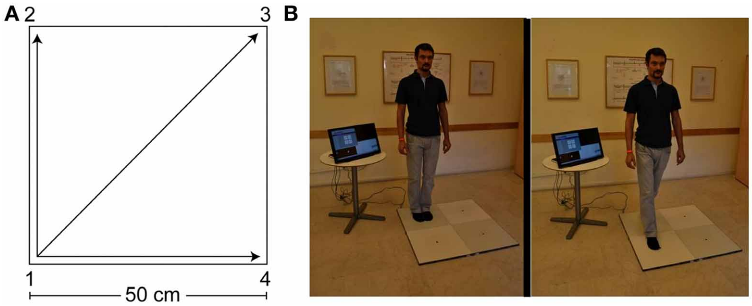

FIGURE 1 | The Quadrato Motor Training (QMT). (A) A graphical illustration of the QMT. **(B)** A participant during the QMT while waiting for the next instruction (left) and following the instruction (right).

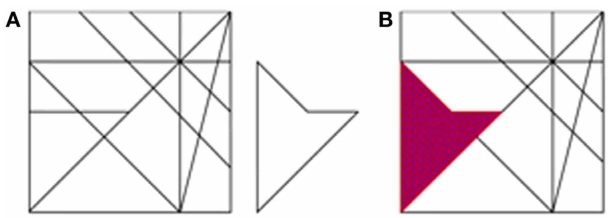

FIGURE 2 | The Hidden Figures Task (HFT). (A) An example of one trial. **(B)** The correct response for trial A (purple).

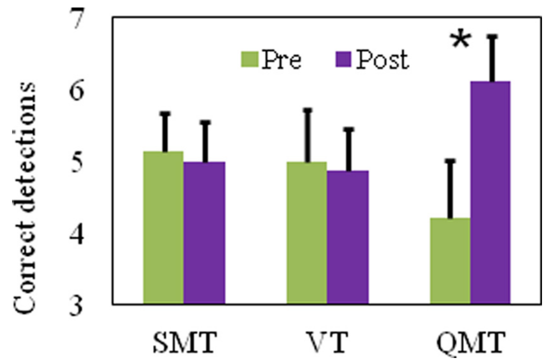

FIGURE 3 | Number of correct detections in the HFT task as a function of Group and Training (mean ± SEM, *$p < 0.05$).

indicate the embedded figure for the experimenter. Two scores were obtained for each trial: correct/incorrect detection, and reaction time (RT). All RTs were subsequently log-transformed to normalize the data, and mean log(RT) was computed for each participant.

Statistical analyses

To answer the question regarding the effects of QMT on HFT performance, we ran a Group (QMT, SMT, VT) × Training (pre, post) analysis of variance (ANOVA) for correct HFT responses, adopting the Greenhouse-Geisser criterion. Whenever needed, we added *post-hoc* t-tests.

RESULTS

We report a significant Group × Training interaction [$F_{(2, 21)} = 5.95$, $MSE = 0.63$, $p < 0.01$] for the number of correct detections in the HFT. For QMT, correct detections significantly increased [$t_{(8)} = -2.86$, $p < 0.05$] in contrast to SMT and VT which showed no change following training (see **Figure 3**).

To summarize Study 1, the QMT-induced improved performance on the HFT was significantly higher compared to the two control groups, which emphasized either the cognitive or the motor training of QMT, but not both. The two control groups showed no improvement, indicating that in this setup there is no significant improvement due to the pre-post HFT learning itself. Subsequently, in Study 2, as a continuation of Study 1, we wanted to examine whether similar effects could be observed in male participants following QMT.

STUDY 2

METHODS

Participants and design

A total of 37 volunteers (29 ± 4 years in age) participated in the study, which was conducted both in Israel (10 females—out of which nine participated in Study 1 in the QMT group, and 8 males) in the MEG unit at the Gonda Brain Research Center, and in Italy (7 females, and 12 males) in the cognitive neurophysiology laboratory of the Research Institute for Neuroscience Education and Didactics. All participants were right-handed with no medical history that might affect their EEG. The study was approved by the ethics committee of Bar-Ilan University. Upon entering the lab, the participant signed a written informed consent. Then, we recorded baseline EEG for 5 min (2.5 min eyes open and fixed and then 2.5 min eyes closed). Subsequently, the HFT Task (see section Hidden Figures Test) was presented. All data were collected both before and after a single QMT session lasting 7 min. In order to pool the female participants together and all male participants together, we conducted two t-tests (the first for comparing the participants who took part in Study 1 to the additional 8 females; and the second for comparing the Israeli and Italian male participants). The two independent t-tests revealed no differences in performance in the HFT within the female and male groups, allowing us to pool our participants.

Hidden figures test

The task was the same as in Study 1. In addition to the analysis conducted as in section Hidden Figures Test, based on Glicksohn and Kinberg (2009), four profiles were defined: (1) Field Dependent (FD) = low success + long RT; (2) Field Independent (FI) = high success + short RT; (3) Reflective (Ref) = high success + long RT; (4) Impulsive (Imp) = low success + short RT. High success was defined as an above-median number of correct detections at baseline (median = 4); long RT was defined as an above-median Log(RT) at baseline (median = 4.21).

Electrophysiological measurements

EEG data were recorded using a 65-channel geodesic sensor net (Electrical Geodesics Inc., Eugene, USA), sampled at 500 Hz and referenced to the vertex (Cz) with analog 0.1–200 Hz band-pass filtering. Impedance was usually kept under 40 kΩ, lower than the customary 50 kΩ with this system (Ferree et al., 2001). EEG signals showing eye movements or muscular artifacts were manually excluded, and bad channels were replaced using spatial interpolation (Perrin et al., 1989). The data were referenced offline to average reference. The first 32 non-overlapping, artifact-free epochs of 2.048 s duration were extracted from each electrode for further analysis from the eyes-closed resting state period, as previously reported (Dotan Ben-Soussan et al., 2013). Coherence values were calculated from the multitapered pair-wise cross-spectra. The coherence values were normalized using Fisher's z transformation. We calculated coherence within the theta, alpha, and gamma frequencies (4–7, 8–13, 25–45 Hz, respectively). Notably, gamma effects are at risk of contamination by muscle activity from scalp and neck (Whitham et al., 2007) and saccade-related spike potentials (SP) due to eye movements (Yuval-Greenberg and Deouell, 2009). In order to minimize this risk, and as SP is elicited at the onset of small saccades, which occur during eyes-open fixation (Martinez-Conde et al., 2004), our report focuses on eyes-closed conditions. Furthermore, to eliminate muscle artifacts, we used three additional steps for caution. First, we carefully visually inspected the raw data, manually extracting artifact-free epochs. Second, as the EMG peaks at 70–80 Hz (Cacioppo et al., 1990), we used much lower frequencies of 25–45 Hz. And third, we excluded from statistical analyses all the circumference electrodes, closest to eyes, neck and face muscles (Berkovich-Ohana et al., 2012).

For the sake of data reduction and statistical comparisons, we chose one central electrode site in each region of interest. Since frontal, central, temporal and parietal areas are important for cognition and action, we chose to focus on bilateral frontal, central, temporal, and parietal electrode sites (F3, F4, C3, C4, T7, T8, P5, P6) (**Figure 4**). We defined electrode "pairs of interest" (POI), on the basis of prior knowledge concerning movement and meditation (Andres et al., 1999; Lutz et al., 2004, 2007).

Statistical analyses

In order to answer the question of gender-difference in HFT performance, we ran a Gender × Training (pre, post) analysis of variance (ANOVA) for the two measures of HFT: (1) number of correct detections; (2) mean log(RT). Whenever needed, we added *post-hoc* one-tailed t-tests. Change in number of correct detections was calculated by subtracting the number of correct figures detected before QMT from the number of correct detections following QMT. Change in log(RT) was calculated by subtracting pre from post QMT log(RT).

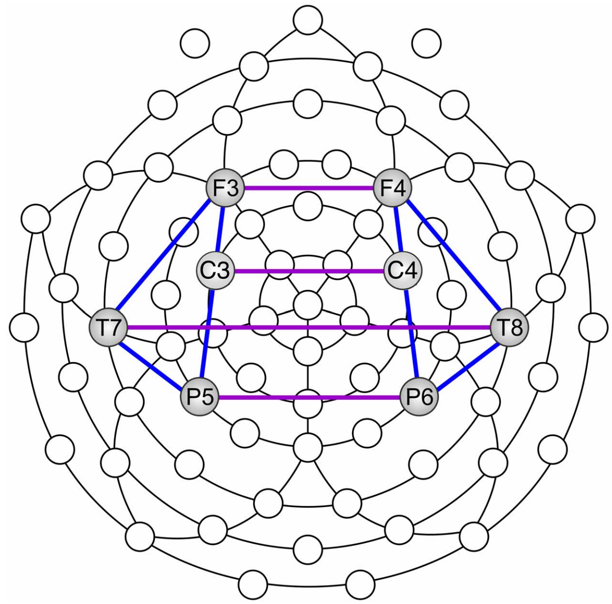

FIGURE 4 | Scalp locations used to calculate EEG coherence: inter-hemispheric (purple) and intra-hemispheric (blue).

Then, in order to study the possible gender-dependent electrophysiological counterparts of the QMT effects, we ran six ANOVAs for the z-transformed theta, alpha and gamma coherences, for intra- and inter-hemispheric connections separately. For intra-hemispheric coherence, we ran a 4-way ANOVA: Gender × Training × Hemisphere × Electrode Pair (F-T, F-P, T-P). For inter-hemispheric coherence, we ran a Three-Way ANOVA: Gender × Training × Bilateral Electrode Pair (F-F, C-C, T-T, P-P). For all the ANOVAs we adopted the Greenhouse-Geisser criterion.

RESULTS

HFT

We found a significant Training effect [$F_{(1, 35)} = 9.57$, $MSE = 1.66$, $p < .005$] for the number of correct detections (**Figure 5A**), which extend the results of Study 1 to males; but not for mean log(RT). The Gender × Training interaction was not significant for either measure. No difference in performance between the male and female participants was found either at baseline, or following training, for either measure (**Figures 5B,C**). As can be seen from **Figure 5**, on average there is an increase in the detection of one more figure following QMT, and the test-retest correlation found here of 0.57 ($n = 37$, $p < 0.0001$) is relatively high, though is lower than the .78-.92 range found for the GEFT (Kepner and Neimark, 1984). This correlation is comparable to the correlation that we have computed between the two sets derived from the HFT of a previous study (Glicksohn and Kinberg, 2009),

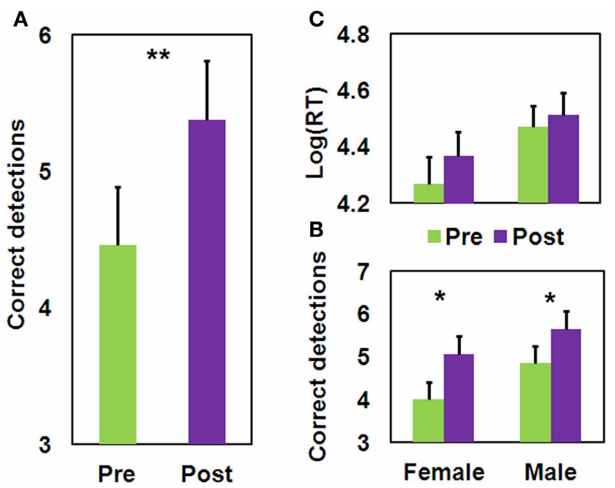

FIGURE 5 | Pre-post difference in performance on the HFT task (mean ± SEM). (A) Main effect for pre-post difference in number of correct detections; **(B)** Pre-post difference in number of correct detections as a function of Gender; **(C)** Pre-post difference in mean log(RT) as a function of Gender; (*$p < 0.05$; **$p < 0.005$).

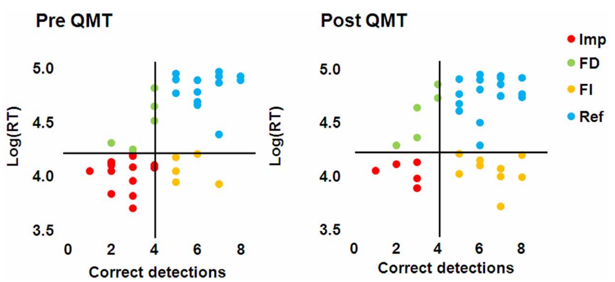

FIGURE 6 | HFT performance and RT correlation pre and post QMT. Quadrants show grouping of participants into Impulsive (Imp), Field Dependent (FD), Field Independent (FI), and Reflective (Ref) groups.

which is.67 ($n = 80$, $p < 0.0001$). An overall view of the relationship between HFT performance (see section Results) and RT is presented as a scatter plot (**Figure 6**). Of the 37 participants, 12 (6 females) exhibited a trend toward reflectivity or FI following QMT. The results show increased reflectivity in both genders.

A positive correlation was found between the change in score for the two change in number of correct detections and change in log(RT) measures ($r = 0.36$, $p < 0.05$, $n = 37$), indicating that better performance on the HFT following QMT is related to longer latency of correct response. Again, we can compare this to the respective difference scores computed for two sets derived from the HFT of the previous study, which is 0.22 ($n = 76$, $p = 0.053$). Thus, it is not simply the case that QMT leads to *faster* RT, as reported elsewhere for a simple reaction time task (Dotan Ben-Soussan et al., 2013), rather that performance on the HFT is indicative of reflectiveness (more correct detections coupled with longer RT; Glicksohn and Kinberg, 2009).

Electrophysiological data

Of importance to the question related to training-induced gender-dependent effects, the first set of three ANOVAs yielded within the theta band a significant Gender × Training interaction [$F_{(1, 35)} = 11.32$, $MSE = 0.03$, $p < 0.005$]. As seen in **Figure 7A**, while the female group demonstrated significantly increased intra-hemispheric theta coherence [$t_{(16)} = -2.56$, $p < 0.05$], this was significantly decreased in the male group [$t_{(19)} = 2.57$, $p < 0.05$]. A similar pattern was found within the alpha band, the Gender × Training interaction being significant [$F_{(1, 35)} = 7.22$, $MSE = 0.05$, $p < 0.05$]. As seen in **Figure 7B**, while the female group demonstrated significantly increased intra-hemispheric alpha coherence [$t_{(16)} = -2.02$, $p < 0.05$], this was significantly decreased in the male group [$t_{(19)} = 1.76$, $p < 0.05$]. No such interaction was found for intra-hemispheric gamma coherence.

The second set of three ANOVAs yielded a significant Gender × Training interaction for both theta [$F_{(1, 35)} = 11.05$, $MSE = 0.02$, $p < 0.005$] and alpha coherence [$F_{(1,35)} = 5.92$, $MSE = 0.06$, $p < 0.05$]. As seen in **Figures 7C,D**, while the female group demonstrated significantly increased inter-hemispheric theta coherence [$t_{(16)} = -2.46$, $p < 0.05$], theta and alpha coherence significantly decreased in the male group [$t_{(19)} = 2.74, 1.81$, respectively, $p < 0.05$]. *Post-hoc* analysis revealed a significant increase in temporal alpha coherence in the females who did not improve having low HFT performance at baseline [$t_{(4)} = -4.87$, $p < 0.01$], while an opposite pattern was observed in males. More specifically, frontal alpha coherence significantly decreased in the males who improved [$t_{(6)} = 2.84$, $p < 0.05$]. Although not significant, a similar trend occurred for intra-hemispheric alpha. In addition, a significant positive correlation was found between change in theta and alpha coherence, both for intra- and inter-hemispheric connections ($r = 0.75$, and 0.79, respectively, $p < 0.0001$, $n = 37$), in accordance with previous reports (Sauseng et al., 2002; van Albada and Robinson, 2013).

In addition, a significant Gender × Training × Electrode Pair interaction was found for inter-hemispheric gamma coherence [$F_{(3, 105)} = 3.01$, $MSE = 0.01$, $p < 0.05$]. As seen in **Figure 8**, only the female group demonstrated post-training increased inter-hemispheric bilateral temporal gamma coherence [$t_{(16)} = -2.16$, $p < 0.05$].

Marginally significant differences were found between the female and male groups at baseline for inter- and intra- hemispheric gamma coherence [$t_{(35)} = 1.97, 1.96$, $p = 0.06$], but not for theta or alpha. Following QMT, a significant difference was found for intra-hemispheric theta and alpha [$t_{(35)} = 2.80, 2.79$, $p = 0.008$]. A similar difference was found for inter-hemispheric theta and alpha [$t_{(35)} = 2.36, 3.38$, $p < 0.05$] but not for gamma coherence.

To summarize Study 2, following training, reflectivity improved for 32% of the participants. Importantly, while a similar trend of improved reflectivity was observed in both genders, there was a differential effect in EEG coherence for males and females. More specifically, temporal alpha increased in the females, while an opposite pattern was observed in males. In addition, the female group demonstrated post-training increased inter-hemispheric bilateral temporal gamma coherence

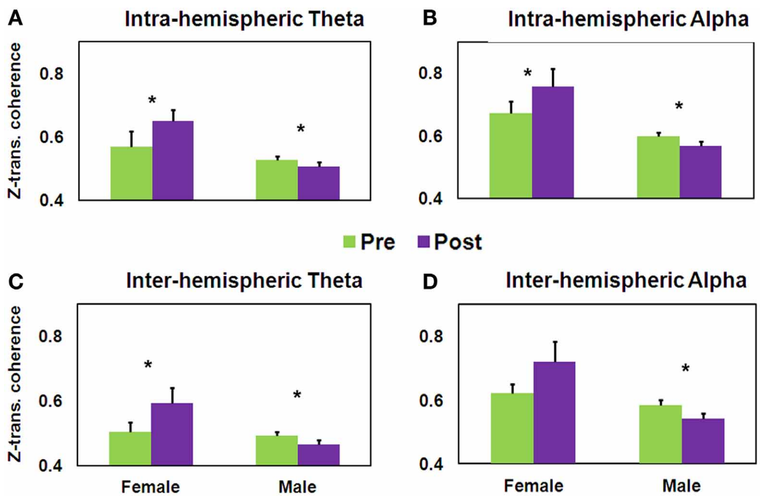

FIGURE 7 | Pre-post differences in *z*-transformed coherence as a function of Gender. Intra-hemispheric coherence for **(A)** theta and **(B)** alpha frequency bands; and inter-hemispheric coherence for **(C)** theta and **(D)** alpha frequency bands (mean ± SEM, $*p < 0.05$). Note: these are coherence and not squared coherence values.

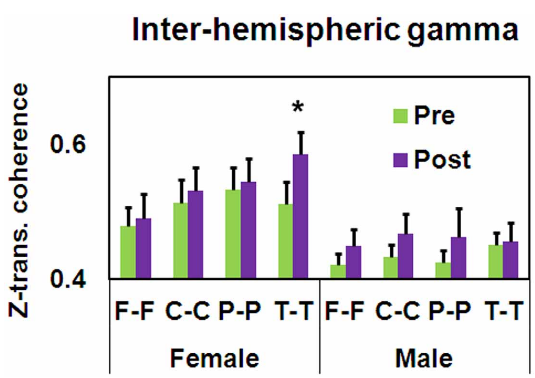

FIGURE 8 | Pre-post differences in *z*-transformed gamma coherence as a function of Gender and Electrode Pair (mean ± SEM, $*p < 0.05$).

DISCUSSION

QMT IMPROVES REFLECTIVITY

The behavioral result of Study 1 has demonstrated that a session of QMT improved performance in the HFT task. This was in contrast to SMT and VT, representing the motor and cognitive aspects of the training, respectively. In addition, Study 2 indicates that training enabled our participants to become more reflective, as well as more FI. The current results suggest that a short practice (7 min) of QMT can be advantageous for improving reflectivity. This supports the claim raised by Depraz et al. (2000) that although reflectivity can sometimes be thought to require a long duration of time to manifest itself, it might be triggered faster, especially in situations we are not accustomed to in our daily life. The current results strengthen previous claims that simple cognitive tests measuring solely reaction time are not sufficiently sensitive to evaluate changes in higher cognitive functions (Dietrich and Sparling, 2004; Dotan Ben-Soussan et al., 2013) such as reflectivity.

What could be the cause of the QMT-improved reflectivity? The three inter-dependent phases described for the dynamics of a reflective act include suspension, redirection of attention inwardly and receptivity, with suspension of habitual activity being the most important to initiate the reflective act (Depraz et al., 2000). In relation to that, it could be argued that given the continual state of attending and waiting for the next instruction during the QMT, the participants were obliged to enter this state of *suspending* the tendency for habitual movement, that of moving where and when you want. In fact, the QMT requires re-instantaneous suspended acts. The suspended movement that begins the process of reflectivity is "forced" here by a different instruction at each step of the QMT. That is, the relatively long inter stimulus intervals (1200 ms) between current location and next location, as well as waiting within the position until the next instruction in the QMT can be regarded as empty time, a time of silence. However, even when it is very brief, a silence of a few seconds can appear exponentially longer (Depraz et al., 2000). Pockett (2003, p. 63) has suggested that when one is "actively engaged in the external world" (as these participants had to be) then "time slows down." We thus suggest that it is this bodily awareness required in the QMT combined with attending that reduce reactivity and increase reflectivity (Depraz et al., 2000; Bishop et al., 2004; Kirk et al., 2011; Greenberg et al., 2012). Furthermore, the QMT requires dividing *attention* inwardly and outwardly, simultaneously listening to the instruction as well as attending to the position of the body in space. In line with that, Depraz et al. (2000) have related to the inner/outer distinction, claiming that the time of relative emptiness (represented here as the time with no specific instructions except the attending, waiting for the next instruction) enables the transition from "looking for" to "letting come," which in turn leads to and further requires a state of receptiveness, which in turn removes the inside/outside distinction

(Depraz et al., 2000), and creates a "space for silence" related to increased reflectivity and expansion of time (Dawson, 2003; Paoletti and Salvagio, 2011).

In support of this claim, it was previously shown that another form of contemplative practice, Mindfulness meditation, dilates the subjective time experienced, in comparison to control participants (Berkovich-Ohana et al., 2012). Indeed, accumulating findings show that Mindfulness brings one back to greater awareness to the present moment (Farb et al., 2007; Kabat-Zinn, 2009; Brewer et al., 2011; Berkovich-Ohana et al., 2012; Vago and Silbersweig, 2012) and to the body (Farb et al., 2007, 2012; Price and Thompson, 2007; Kerr et al., 2013). Possibly, similar to Mindfulness, QMT increases attention to the body and to the present moment by requiring attendance to the coming instruction and consequently responding to it. This in turn enables a state of increased reflectivity.

It could be suggested that increased reflectivity was only for one third of the participants that we report due to the short training. Possibly, a longer session, or a longer-term training with similar short sessions might result in increased percentages of enhanced reflectivity. However, these hypotheses can only be studied in a follow-up study.

GENDER-DEPENDENT ELECTROPHYSIOLOGICAL CHANGES

We hypothesized that better performance on the HFT would be related to increased alpha coherence, and that QMT would increase coherence, and more so in females. As it turned out, both hypotheses were supported by the results for the female group, and were opposite for the male group, hence underscoring the importance of studying gender differences.

As a starting point, we observed overall gender differences in pre-QMT resting state coherence, indicative of trait effects, with males exhibiting lower coherence (both intra- and inter-hemisphere) in the theta, alpha and gamma bands compared to females. These results are consistent with a previous study of highly intelligent individuals, reporting that males displayed greater decoupling (mostly of frontal brain areas), whereas females showed the opposite pattern, namely of more coupling (mostly between frontal and parietal areas) (Jausovec and Jausovec, 2005). This is further in line with the idea of differential brain organization in males and females (Volf and Razumnikova, 1999; Amunts et al., 2000; Mohr et al., 2005), whereby females consistently display higher inter-hemispheric coherence at rest and during cognitive task performance compared to males (Beaumont et al., 1978; Corsi-Cabrera et al., 1997; Volf and Razumnikova, 1999). The higher female coherence was previously interpreted as reflecting higher collaboration between the hemispheres or less hemispheric specialization for females (Amunts et al., 2000; Mohr et al., 2005; Ramos-Loyo and Sanchez-Loyo, 2011), suggesting that the left hemispheric is more dominant for different abilities, such as language and navigation in males, in comparison to females (Volf and Razumnikova, 1999; Ramos-Loyo and Sanchez-Loyo, 2011). The decreased trait coherence observed in the male group in the current study may thus be related to increased hemispheric specialization in males in general.

Training-related gender differences

Showing a similar pattern as the differential gender trait differences, QMT-induced electrophysiological changes included significantly increased theta and alpha coherence in females, in support of our hypothesis, while the opposite was found for males. The increased theta and alpha coherence observed in the female group is consistent with studies examining electrophysiological changes following meditation. Meditative practices, irrespective of gender, have consistently been related to increased coherence, especially inter- and intra-hemispheric theta and alpha coherence (Alexander et al., 1987; Aftanas and Golocheikine, 2001; Travis, 2001; Travis et al., 2002, 2009; Cahn and Polich, 2006; Baijal and Srinivasan, 2010). Unfortunately, gender-related analyses within meditation reports are scarce, as either gender is not reported at all (e.g., Lutz et al., 2004), or there are no gender-specific baseline differences, hence these are not subsequently considered (Travis et al., 2009), or not mentioned (e.g., Aftanas and Golocheikine, 2001; Travis et al., 2002; Baijal and Srinivasan, 2010). Although gender differences have not yet been systematically investigated in previous electrophysiologically-based meditation studies, some gender differences in behavioral measures were found following meditation. For example, while Qigong meditation was found to contribute positively to addiction treatment outcomes in both genders, female participants reported significantly more reduction in anxiety and withdrawal symptoms than did the male group (Chen et al., 2010). An opposite pattern was observed for TM, for which reduced drinking rates was reported among male university students but not in female students (Haaga et al., 2011). Our finding of QMT-induced gender-related differences in coherence is in accord with another study reporting gender-related electrophysiological differences. In this study (Duregger et al., 2007), a motor related evoked potential (contingent negative variation—CNV) was shown to manifest differently in females, showing higher frontal activation, compared to males, showing higher temporoparietal activation. The more frontal brain area was related to motor preparation reflecting a higher level of cognitive involvement in females compared to males, while the higher male temporoparietal brain activity was interpreted as reflecting brain processes related to other sensory processing (Duregger et al., 2007). Related to this, it is important to keep in mind the gender-dependent differences frequently observed in motor and cognitive realms (Baron-Cohen and Hammer, 1997). More specifically, while women are better in fine-motor coordination (e.g., placing pegs in pegboard holes) men are better in target-directed motor skills, such as guiding or intercepting projectiles (Kimura, 1992). Finally, there are gender differences in brain morphology in relation to spatial cognition and mental rotation performance: while females have more gray matter in the parietal lobe than males, males have greater parietal surface area (Koscik et al., 2009). Koscik et al. (2009) further concluded that the structural gender difference could be a neurobiological substrate for the gender difference in mental rotation performance. In light of the above studies, showing gender-dependent strategies and neural structure, the current results of gender-dependent electrophysiological change following training could be interpreted as reflecting different strategies to achieve the same cognitive and motor goal.

The gender-dependent results may further be explained by the neuronal efficiency hypothesis, which claims that better performance is associated with more efficient brain functioning, that is to say, decreased cortical activation (Haier et al., 1988), indicated by lower event-related desynchronization (ERD). This hypothesis was examined in different tasks, such as spatial cognition (Neubauer et al., 2002; Grabner et al., 2006). One study examining gender-dependent changes in neuronal efficiency and the effects of training on a mental rotation task (Neubauer et al., 2010), reported that while a general increase in neural efficiency from pre to post-test was found for males, it was observed in females only in the 3D version and not in the 2D presentation of the task. In addition, previous studies have also shown that males and females display neuronal efficiency and an inverse IQ–activation relationship in just that domain in which they usually perform better, i.e., females in the verbal domain, and males in the visuospatial domain (Neubauer et al., 2005). Important to the current results, it was further suggested that neural efficiency in males is reflected in local cortical activation (as measured with the ERD-method), whereas neural efficiency in females is manifested in the functional coupling of several brain areas, as assessed by EEG coherence (Neubauer and Fink, 2003). Following this line of thought, training should lead to an increase in neural efficiency, namely, to a decrease in cortical activation from pre- to post-test (Kelly and Garavan, 2005; Neubauer and Fink, 2009; Neubauer et al., 2010) in a gender-dependent manner. Thus, the QMT-induced electrophysiological changes may amplify resting state gender trait differences.

LIMITATIONS OF THE STUDY

It should be kept in mind that Study 2 is a preliminary attempt to examine the gender-dependent effects of training. Although Study 2 may be confounded by practice, in Study 1 as well as in previous research (Dotan Ben-Soussan et al., 2013), we have demonstrated that the cognitive change, namely improved spatial cognition and creativity, is QMT-specific, and does not occur in the two control groups. In addition, we have previously demonstrated a QMT-specific effect on EEG coherence, in contrast to the two control groups (Dotan Ben-Soussan et al., 2013). Nevertheless, as suggested by one of our reviewers, a future study incorporating a larger number of participants could deepen the research regarding the electrophysiological gender-dependent effects of QMT.

Obviously, a longitudinal design is warranted to elucidate the long-term effects of QMT. Furthermore, this study lacks phenomenological reports, especially valuable when studying subtle mental states such as reflectivity (Varela et al., 1991; Depraz et al., 2000). Undoubtedly, future QMT studies in our lab will incorporate qualitative in-depth interviews. Taken together, this study should be considered as an exploratory pilot study, warranting further exploration.

SUMMARY AND POSSIBLE IMPLICATION

The first important finding in this report is that one short (7 min) QMT session improves spatial cognition, as opposed to the two control groups reported in Study 1. In addition, following training reflectivity improved for 32% of the participants. As QMT enhances spatial performance and may increase reflectivity, it would be worthwhile to examine it in the context of different learning and impulsivity-related disorders. Given that coherence alterations have long been observed in ADHD and dyslexia (Dhar et al., 2010; Barry et al., 2011), future studies should examine the effects of QMT in these populations. Critically, the advantage of QMT training lies in its simplicity of training, and minimal space needed compared to other movement contemplative practices, such as martial arts or walking meditation.

Our results suggest that the underlying electrophysiological mechanism by which QMT exerts its effect differs between genders. This has been discussed in light of gender-related brain specialization, as well as the neuronal efficiency hypothesis. This study emphasizes both the importance of studying gender-related training effects within the contemplative neuroscience endeavor, as well as the need to widen the scope of contemplative neuroscience toward including "contemplation in action" such as QMT.

AUTHOR CONTRIBUTIONS

Conceived and designed the experiments: Tal Dotan Ben-Soussan, Joseph Glicksohn, Aviva Berkovich-Ohana. Performed the experiments: Tal Dotan Ben-Soussan. Analyzed the data: Tal Dotan Ben-Soussan, Aviva Berkovich-Ohana, Joseph Glicksohn. Contributed analysis tools: Tal Dotan Ben-Soussan, Aviva Berkovich-Ohana, Joseph Glicksohn, Abraham Goldstein. Wrote the paper: Tal Dotan Ben-Soussan, Aviva Berkovich-Ohana, Joseph Glicksohn, Abraham Goldstein.

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Zen and the brain: mutually illuminating topics

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Zen Buddhist meditative practices emphasize the long-term, mindful training of attention and awareness during one's ordinary daily-life activities, the shedding of egocentric behaviors, and the skillful application of one's innate compassionate resources of insight-wisdom toward others and oneself. This review focuses on how such a comprehensive approach to training the brain could relate to a distinctive flavor of Zen: its emphasis on *direct experience*, with special reference to those major acute states of awakening that create deep transformations of consciousness and behavior. In Japanese, these advanced states are called *kensho* and *satori*. Ten key concepts are reviewed. They begin by distinguishing between the concentrative and receptive forms of meditation, noticing the complementary ways that they each train our normal "top–down" and "bottom–up" modes of attentive processing. Additional concepts distinguish between our two major processing pathways. The self-centered, egocentric frame of reference processes information in relation to our body (our *soma*) or to our mental functions (our *psyche*). The other-centered frame of reference processes information anonymously. Its prefix, *allo*- simply means "other" in Greek. Subsequent concepts consider how these useful Greek words—ego/allo, soma/psyche—correlate with the normal functional anatomy of important thalamo ↔ cortical connections. A plausible model then envisions how a triggering stimulus that captures attention could prompt the reticular nucleus to release GABA; how its *selective* inhibition of the dorsal thalamus could then block both our higher somatic and psychic cortical functions; so as to: (a) delete the maladaptive aspects of selfhood, while also (b) releasing the direct, all-inclusive, globally-unified experience of other. Two final concepts consider how the long-term meditative training of intuitive functions relates to certain kinds of word-free spatial tasks that involve insightful creative problem-solving.

Keywords: Zen, meditation, egocentric, allocentric, thalamic model of enlightenment

> Only those contents of consciousness can be developed that correspond to the organization of the brain.
>
> Walter R. Hess (1881–1973)

INTRODUCTION

These words by Hess suggest that the following pages will invoke neurophysiological explanations, not loose metaphysical notions. That said, this review proposes that neuroscientists and Zen trainees can learn a few things from each other's models of consciousness. What does Zen training emphasize during its long-term approach to meditation? First, the mindful training of attention and awareness during one's *ordinary* daily life activities. Second, shedding the layers of maladaptive habits, overly self-centered attitudes and behaviors that waste time and energy. Third, enhancing one's innate, intuitive resources of insight-wisdom. Fourth, applying these fresh insights skillfully, with increasing compassion, both toward all other beings and one's own well-being.

These emphases are part of a long path of brain training that can lead toward more adaptive traits of character. The path emerges along that broad interface between two crucial domains, self and other. The former represents the distinctive interior consciousness of our personal self. The latter refers to that other consciousness representing the environment outside our skin. An important aspect of this path is epitomized in the historical account of a man, originally called Siddhartha. The records indicate that his behavior was substantially transformed after he emerged from a major state of awakened consciousness. Thereafter, he would be known as the "enlightened" one, the Buddha.

During the four decades since Hess died, the neurosciences have continued to learn more about the organization of the brain. Still, some readers may question: is it appropriate in this special issue of Frontiers for a neurologist to speculate about how such an acute episode could have transformed a 35-year old man like Siddhartha? On the other hand, only secular explanations will be tentatively proposed. They will address fundamental issues at the crucial interface between self and other. In order to focus on such an interface, this review leaves to other contributors the complex topic of correlating meditation with neuroimaging data. Left to its closing pages is the discussion of subtle incremental deconditionings of the maladaptive self, and a consideration of how such changes could emerge along a continuum of practical intuitive, creative, problem-solving *traits*. A glossary at the end helps to define useful terms.

The next pages summarize aspects of 10 key conceptual issues that are raised either in four books previously published or the one now in press. The Zen approach to training specifically targets unwarranted self-centeredness. It studiously avoids first-person references. This principle is not possible to achieve in this kind of review which necessarily refers to the author's several publications.

TEN KEY CONCEPTUAL ISSUES

The first concepts summarize Zen meditative practice in terms of psychological phenomena. Later concepts suggest principles of neural organization that govern important physiological mechanisms. These mechanisms are involved both during our normal modes of ordinary consciousness, and in our normal modes of ordinary *sub*conscious processing. Moreover, many of their phenomena surface in the foreground of the kinds of advanced extraordinary states of consciousness that are often called "awakening" or "enlightenment." The Japanese terms for these brief states are *kensho* and *satori*. Samples of frontier research will later be cited which appear to have fertile interdisciplinary implications.

ZEN MEDITATIVE TRAINING

This meditative approach trains attention by focusing body and mind on the ongoing, *mindful* perception of each present moment as it really exists right now. Gradually, an increasingly calm awareness becomes the setting for the emergence of more subtle introspective memory skills. These are *automatic* "recollections". They serve useful, self-correcting ends. (Austin, 2011, pp. 95–96, 98). Their subconscious meta-cognitive memory functions were always inherent in the original meaning of the ancient Pali term, *sati*. A newly-coined word, "remindfulness," can serve a useful purpose. It simply acknowledges this involuntary, helpful overview memory capacity. (Austin, 2011, pp. 94–98) When Emerson pointed to the surge of this natural, insightful, affirmative mode of "guidance," he used the apt phrase, "lowly listening" to describe its *re*mindful qualities (Austin, 2011, p. 145).

THE BROAD SCOPE AND DEPTH OF LONG-TERM ZEN TRAINING

One doesn't "learn" Zen meditation in just a few days or weeks. The major target during the early months and years is one's self-centered *I-Me-Mine* complex and its unfruitful, maladaptive, emotional attachments. (Austin, 1998, pp. 43–47, 50–51; Austin, 2006, pp. 13–14) Long-term monastic training goes on to address the diverse existential, instinctual, and emotional aspects of the personality that cause unnecessary suffering. None of these ingrained egocentric attitudes surrender without a struggle. During meditative retreats (Austin, 1998, pp. 138–140), trainees benefit from many opportunities both to endure their own liabilities and to uncover their innate assets, while being guided by an authentic teacher (Austin, 1998, pp. 119–125; Austin, 2006, pp. 64–69).

THREE DEVELOPMENTS IN THE NEUROSCIENCES HAVE CONVERGED IN RECENT DECADES

A. Neuroscience research has identified two basic network systems of attention operating at the cortical level. (Austin, 2009; Corbetta and Shulman, 2011; Kubit and Jack, 2013, pp. 29–34). Here, in a provisional sense, several aspects of their functional anatomy may be summarized when using such terms as *dorsal* and *ventral*, upper and lower, "top–down" and "bottom–up," more voluntary and more involuntary.

Research in meditators indicates that our dorsal attention system for top–down attention becomes more involved during the narrowly focused, *concentrative* meditative practices. (Austin, 2009, pp. 39–43) In contrast, the ventral attention system *orients itself* reflexively toward the subtler forms of bottom–up attention and global awareness. These become cultivated more gradually during the other kinds of meditative practices that are more openly *receptive*.

B. Neuroscience research has also made major contributions to the neural correlates of self/other issues. Two major processing pathways have been identified, also dorsal and ventral in their early course. These networks provide consciousness with two anatomically separate versions of "reality" that are soon blended seamlessly (Austin, 2009, pp. 53–64). Our self-consciousness is most familiar with the "feeling" of the first version. **Figure 1** illustrates how the dorsal pathway can tap into the specialized touch and proprioceptive resources inherent in the parietal lobe. This overlapping is convenient, because these senses of touch and proprioception help us manipulate important tangible items located inside that lower field of space lying *nearest* our body.

The figure helps to appreciate that this upper, occipito-*parietal*, *egocentric* processing pathway follows a trajectory that is closest to, and overlaps, those same *lateral* and *superior* cortical regions which also represent the body schema of our *somatic*, physical self. So, can this upper pathway be described as asking only a *one*-word question: "Where?" No. A hungry person, seeing an apple within reach, instantly refers all lines of sight from this apple back to his or her own physical axis of self in order to grasp it. Therefore, this upper pathway seems poised to ask a much longer question. This highly practical question is structured in terms that correspond with the three dimensions of our personal space: "Where is that apple *in relation to Me and My body?*" (Austin, 2009, pp. 54–55, 58–59).

The ventral pathway relies on other specialized refinements, those associated with its capacities for seeing and hearing. Notice the lower origin of this other cortical pathway. It begins in the inferior occipito-*temporal* region and extends toward the inferior frontal region. Such a trajectory confers a very different, *allocentric* perspective. (Austin, 2009, pp. 55–74) *Allo*, from the Greek, simply means "other." Why is the existence of this hidden other-referential pathway so unfamiliar to us? Because such a silent "frame of reference" begins to operate *anonymously*. It asks the question, "*What* is that object?" Instantly, subconscious pattern-recognition skills identify that object. Simultaneously, other skills decode what that object *means*. (Austin, 2009, pp. 130–149) When Freud coined the useful

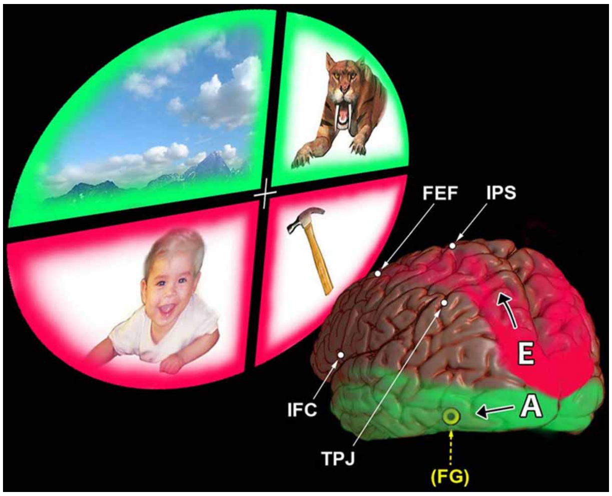

FIGURE 1 | Egocentric and allocentric attentive processing; major differences in their efficiencies. This view contrasts our top–down dorsal *egocentric* networks with those other networks representing our ventral *allocentric*, bottom–up pathways. The reader's vantage point is from a position behind the *left* hemisphere, looking at the lower end of the occipital lobe. This person's brain is shown gazing up and off to the left into quadrants of scenery. The items here are imaginary. The baby and the hammer are within reach, in the space down close to the person's body. The scenery above and the tiger are off at a distance, out of reach. Starting at the top of the brain are the two modules of the *dorsal*, top–down attention system: the intraparietal sulcus (IPS) and the frontal eye field (FEF). They serve as the attentive vanguards linked with our subsequent sensory processing and goal-oriented executive behavior. Notice how they are overlapped by the upward trajectory of the *upper* parietal → frontal egocentric (E) system. This is a self-referential system. Its arching red pathway is shown as beginning in the upper occipital region. Notice that a similar red color also surrounds the *lower* visual quadrants containing the baby (at left) and the hammer (at right). Why? To indicate that this dorsal, "northern" attention system attends more efficiently—on a shorter path with a lesser "wiring cost"—to these *lower* visual quadrants. This enables our parietal lobe senses of *touch* and *proprioception* to "handle" easily such vitally important tangible items down close to our own body. In contrast, our two other modules for cortical attention reside lower down over the outside of the brain. They are the temporo-parietal junction (TPJ) and the regions of the inferior frontal cortex (IFC). During bottom–up attention, we activate these two modules of the ventral attention system chiefly on the *right* side of the brain. There, they can engage relatively easily the networks of allocentric processing nearby (A). The green color used to represent these *lower* temporal → frontal networks is also seen to surround the *upper* visual quadrants. Why? This is to suggest the ways this lower ("southern") pathway is poised *globally* to use its two different specialized systems of pattern recognition. One is based on our sense of *vision*, the other on our sense of *audition*. Both serve not only to identify items off *at a distance* from our body but also to infuse them instantly with meaningful interpretations. The yellow FG in parenthesis points to this lower pathway's inclusion of the left fusiform gyrus. This region, hidden on the undersurface of the temporal lobe, contributes to complex visual associations, including our sense of colors.

diagnostic term, *agnosia*, he could then apply it to the isolated *loss* of visual meaning caused by a discrete lesion which had damaged a patient's temporal lobe (Austin, 2009, pp. 130–135).

Our ordinary conscious processing remains unaware that it is deploying a seamless blend of these two complementary—upper and lower—categories of spatial reference. (Austin, 2009, pp. 57–58) Such ignorance vanishes *when the entire upper version drops out*. Zen parlance applies the following metaphor of selfless "emptiness" to this abrupt release from all former attachments to the intrusive self: "The bottom falls out and releases its bucket-full of water." (Austin, 2009, pp. 191–193) *Now the lower version's allocentric processing stands unveiled*. Its innate subconscious capacities, perceived in isolation, are revealed for the first time. This "awakening"—this fresh perspective of "real" reality, infused with instant recognition and meaning—is an awesome surprize. (Austin, 2006, p. 361–371).

C. Neuroscience research has also begun to attach a shorthand term, "default network," to a large consortium of heterogeneous regions. The three largest regions occupy the *medial* prefrontal cortex, the *medial* posterior parietal cortex, and also the lateral cortex of the angular gyrus. Included within this triad and its several extensions are representations of both intrinsic, autobiographical and topographical association functions. (Austin, in press) The more rostral parts of this coalition contribute to an impression of personal sovereignty: our self as *the sole psychic* agency, its operations consistent with those of a private, autonomous *I-Me-Mine*. (Austin, 2009, pp. 74–75) Yet if each such mental notion about our personal self is to lodge in memory as a coherent event, it helps to encapsulate it within the context of some particular local scene. (Austin, 1998, pp. 390–391) These topographical, scenic details are essential if this locale is to serve as the "frame" enabling each event memory later to be used for purposes of navigation. (Austin, 2009, pp. 72–74) Only when each intimate episode is anchored both in one particular place in *our* own environment, and in one particular moment of *our* own "*time frame*" can these separate episodes become organized into a detailed, useful, lifetime, personal narrative.

How can any three-pound brain normally maintain such a life story, packed with notions that its omni-self is truly an ongoing, functioning agency? Not surprisingly, the early PET studies showed that the coalition of self-referential regions required an especially active ongoing metabolism even during seemingly "resting" conditions. Functional MRI signals arising from this consortium became even more activated (above such arbitrary "baselines") when researchers assigned discrete self-referential tasks to their normal subjects. (Austin, 2006, pp. 204–207; Austin, 2009, pp. 75–76, 266–267) Subjects who tried to meditate in thought-free silence in the scanner discovered how much their "monkey-mind" wandered during the so-called "resting" state of quasi-"baseline" consciousness.

Importantly, fMRI signals from these same (mostly medial) intrinsic networks were acutely reduced (below baseline) at the instant that a sudden external stimulus event captured a subject's attention. Further fMRI research revealed a second important finding: the activity of these chiefly medial, self-referential cortical regions varied *inversely* with the activity of the lateral attention regions. (Austin, 2009, pp. 98–108) These separate self and attention regions co-participated—but in *opposite directions*—in the peaks and valleys of a slow, spontaneous, *endogenous* rhythm. This *reciprocal* rhythm required no external stimulus. It recurred *slowly*—around three times a minute—on its *own* largely independent cycle (Austin, 2011, pp. 32–34).

The Swiss physiologist, Walter Hess, was co-awarded the Nobel Prize in 1949. His pioneering research documented the dynamic switching capacities that lurked in the deep central diencephalic regions of the brain (Austin, 1998, pp. 190, 194, 232, 635–636). Extensions of that research make plausible today's hypothesis that some regions in the axial core of the brain—in and around the thalamus—might qualify as the deep origins for these reactive and spontaneous shifts that occur up in the recent cortical fMRI data. After all, these are fast and slow, switchings *on* and switchings *off*. They are enlisting separate cortical regions that make crucial commitments *either* to attention *or* to the representations of the self. Moreover, these regions respond not only within both hemispheres simultaneously, but also in a *reciprocal* manner (Austin, 2006, pp. 197–198, 427–428). Were Hess alive today, he would surely be encouraging neuroscientists to identify which basic mechanisms *organize* these two remarkable anticorrelated physiological feats.

MAJOR AWAKENED STATES ARE EXPERIENCED AS SELFLESS

The annals of Zen demonstrate more than an early, historical emphasis on the mindful training of attention and awareness (Austin, 1998, pp. 69–73). They also document numerous examples during which a sudden external stimulus—like the unexpected "CAW" of a crow—served not only to instantly capture attention but also to precipitate states of awakening (Austin, 1998, pp. 452–457; Austin, 2006, pp. 303–306; Austin, 2009, pp. 109–117; Austin, 2014, Chapters 5, 6). So, one wonders: could Siddhartha's legendary "awakening," two and a half millennia ago, also represent a comparable event? Indeed, it was said that this state of enlightenment was triggered, before dawn, when he looked *up* and saw the brilliant "morning star" (Austin, 2011, pp. 77, 209). The ancient astronomers were familiar with this bright celestial object. They recognized the obvious fact that it traveled on a path, unlike a star. They gave the name, Venus, to this distinctive planet whose brilliance still lights up our Eastern sky before sunrise.

Explicit statements about selflessness entered the Buddha's earliest discourses. Examples of no-self sentences are found in two of the ancient Udana sutras: "When no you remains, then this, *just this*, will be the end of your suffering." "Getting free of the conceit that "I am" is truly the ultimate happiness." (Austin, 2014, Chapter 1; Austin, 2011, vi) Scientists have reason to be skeptical: could any rigorous common ground ever link old Buddhist legends with neurobiology? (Austin, 1998, pp. 1–7, 677–683). On the other hand, might what neuroscience is learning about the neurophysiological origins of selfhood help explain how *selflessness* could occur?

OUR NORMAL UNIFIED THALAMO-CORTICAL CONNECTIVITIES

Intricate interactive circuitries merge thalamic functions with those of our cortex (Austin, 2006, pp. 167–176). What is special about the three *limbic* nuclei in the front of our dorsal thalamus? Why could they play a crucial role in modulating these to-and-fro, rapidly oscillating connections between thalamus and cortex? Because these are the three thalamic nuclei poised to relay *over-emotionalized* messages from our limbic system up to pertinent parts of our self-referential cortex and to receive reverberations from them. Indeed, these three limbic nuclei interact with most of those same medial cortical association regions that item 3C had just singled out. Recall that these key regions of neocortex appear to be organized in a manner that can represent major attributes consistent with the autobiographical aspects of our psychic self that are linked to its topographical memories (Austin, 2009, pp. 87–94) (Please see **Figure 2**).

Figure 2 illustrates which limbic nuclei and cortical regions are organized to become co-activated either during an acute surging emotional overload or during subsequent un-checked ongoing ruminations (Austin, 1998, pp. 347–352, 567–570; Austin, 2006, pp. 239–265, 396–398; Austin, 2009, pp. 223–247; Austin, 2011, pp. 160–162). They include: (a) the *medial dorsal* nucleus and its several connections with the *medial prefrontal cortex* in particular; (b) the *anterior* thalamic nucleus and its connections, including those with the *posterior cingulate* cortex in particular; (c) the *lateral dorsal* nucleus and its connections with the event-memory-linked topographical and navigational functions of the *retrosplenial* cortex.

The thalamus serves as an important "pacemaker" for the brain. All of our sensations ascend through its nuclei (except for smell) on their way up to our cortex. Yet these bi-directional thalamo ↔ cortical connections, over-simplified here in **Figures 1**, **2**, only hint at some explanations for how we might *normally* represent our omni-self's ordinary perceptions, emotions, and its journal entries into long-term memories. The question remains: how could a brain drop off the *deep* layers of the maladaptive self during the awakened states of kensho and satori?

THE INHIBITORY ROLE OF THE RETICULAR NUCLEUS OF THE THALAMUS AND ITS EXTRA-RETICULAR ALLIES

A thin layer of nerve cells caps the rounded contours of the thalamus (Austin, 1998, pp. 267–271, 591, 605; Austin, 2006, pp. 176–178). This is the *reticular nucleus*. Existing fMRI data don't list it. Do not be misled. Its neurons release GABA (gamma aminobutyric acid), a *powerful inhibitory* neurotransmitter. Could this GABA play a "self-annihilating" role? Yes. How? By virtue of its selective capacities to readjust the synchrony of our usual thalamo ↔ cortical oscillations (Minn, 2010; Austin, 2011, pp. 35–37). Included in this selectivity are the capacities to dissociate visual functions in the ventral and dorsal streams (Austin, 2014, Chapter 11).

A simple analogy helps illustrate how the release of GABA might shift our waking consciousness away from its usual, dominant self-centered role. Try on a set of active, noise-canceling headphones. They generate a profile of sound-wave oscillations. These are 180° out of phase with those frequencies causing undesirable background noise. When the headphones are switched on, their selective tuning accomplishes two goals simultaneously: you hear the music coming through clearly; you block out the loud rumble of distracting traffic noise.

The reticular nucleus does not act alone. It has two, lower level, extra-reticular inhibitory allies (Austin, 2006, pp. 178–179)

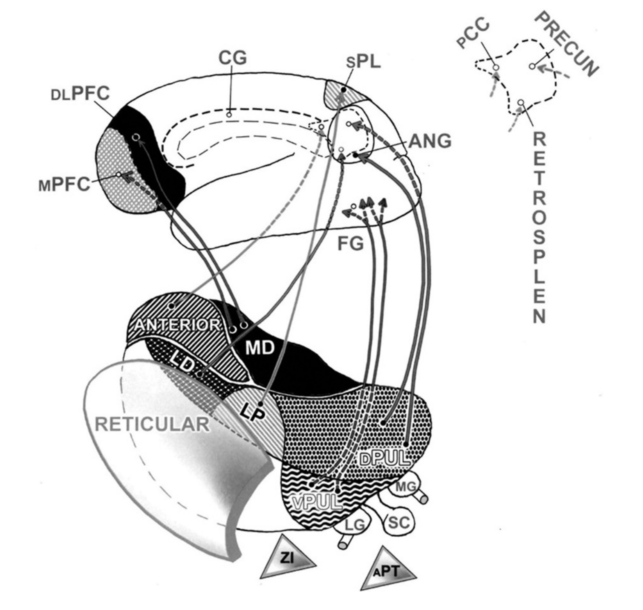

FIGURE 2 | Thalamocortical contributions to the dorsal egocentric and ventral allocentric processing streams. This composite view shows the pathways (normally bi-directional) which connect the thalamus with the cortex. For convenience in viewing, only left-sided structures are shown. These connections supply key regions both on the outside and inside of the left hemisphere. Pathways predominate from all five nuclei in the dorsal tier of thalamic nuclei. Up front are the three limbic nuclei. The *medial dorsal* (MD) thalamic nucleus projects to the prefrontal cortex, both to its medial (MPFC) and to its outer, dorsolateral (DLPFC) surfaces. The deep medial area of cortex in the back of the brain is shown enlarged at the top right. Here, the projections from the two other adjacent dorsal nuclei of the limbic thalamus can also be seen reaching this medial cortical surface (dashed lines). Thus, the *anterior thalamic nucleus* projects to the *posterior cingulate cortex* (PCC) (a major connection hub), and the *lateral dorsal nucleus* (LD) projects to the *retrosplenial cortex* (RETROSPLEN), a major memory-based resource for recollection. Down at the bottom right, one path leads up from the *dorsal* pulvinar (DPUL) to the *angular* gyrus (ANG) on the *outer* cortical surface. Dashed lines indicate that a second path from this dorsal pulvinar leads up to the *precuneus* (PRECUN) on the *medial* parietal surface. Other projections from the *lateral posterior* (LP) nucleus supply the *superior parietal lobule* (SPL), our major somatosensory *association* region. These connections help to anchor each person's subliminal sensory impression: I exist as an independent, tangible, physically-articulated body schema. Relatively few pathways are shown emerging from the thalamus to serve the lower, allocentric processing stream. However, messages from the *ventral pulvinar* (VPUL) would pass first through the region of the *fusiform gyrus* (FG) on the undersurface of the temporal lobe. These associations ramify, to become further refined on their way forward and upward through the other-referential networks in the rest of the temporal lobe that lead on toward the frontal lobe. The figure shows three important GABA inhibitory nuclei, artificially detached at the bottom. They are the *reticular nucleus*, the *zona incerta* (ZI), and the *anterior pretectal nucleus* (APT). Two sensory relay nuclei of the thalamus are also shown at the bottom right. The *lateral geniculate nucleus* (LG) relays visual data to the occipital cortex. The *medial geniculate nucleus* (MG) relays auditory information to the auditory cortex. The *superior colliculus* (SC) in the midbrain relays its reflexive visual and related polymodal messages quickly through both the dorsal and ventral pulvinar to the cortex. Its counterpart, the inferior colliculus, plays a similar auditory role. Not shown are two *somatic* sensory relay nuclei in the ventral tier. These medial and lateral divisions of the ventral posterior nucleus lie in front of the ventral pulvinar. They relay sensation from the head and body, respectively. *cingulate gyrus* (CG).

(**Figure 2**). The *zona incerta* releases its GABA on higher-order thalamic nuclei (including the medial dorsal nucleus). The *anterior pretectal* nucleus projects to both the medial dorsal and lateral dorsal nuclei of the limbic thalamus. It also stands poised to modulate the diversity of relevant functions among the somatosensory, intralaminar, and other nuclei that are included within the ventral and medial thalamus (Sherman and Guillery, 2013).

AN INSTRUCTIVE ZEN "MINI-KOAN": WHICH DIRECTION DO YOU FACE, WHEN YOU WANT TO MOVE STRAIGHT "AHEAD"?

Most self-orientations operate automatically. A covert motivation urges our first leaning forward. Instantly—too fast for thought—it commits us to "head" in one particular direction (Austin, 2006, pp. 106–108). If such subconscious systems are to resolve the riddle posed above, they first need to "know" where our own head is already located, and be capable of using visual information from our eyes that confirms the direction toward which the rest of our face is assumed to be pointing.

In short, we're using a subconscious, direction-sensitive, personal "behavioral compass" (Austin, 2006, pp. 172–174). Why might two nuclei of the limbic thalamus (anterior [dorsal] and lateral dorsal) be assigned some role in establishing this covert behavioral compass? Perhaps because this subcortical network does more than add to our static notions of being a private, interior self. Perhaps it could also be preparing us to lean, move, and navigate. How? By accessing subconscious links to hidden memories, to reconstructions of past events that had "taken place," as we say, in the scenery *outside* our skin. We had encoded useful personal/local details during these remote prior events (Austin, 1998, pp. 390–391; Austin, 2009, pp. 259–260). These had served to frame the topographical signature representing each new, memorable spatial environment.

Recent fMRI evidence indicates how we retrieve two such events from memory (Elman et al., 2013). One event is newly-learned; the other is old and familiar. The newly-learned event was the outside appearance of one particular building. When subjects retrieved this building from recent memory they activated their *anterior* angular gyrus, supra-marginal gyrus, posterior cingulate and posterior precuneus (Austin, 2009, pp. 252). However, they activated different regions when they retrieved a long-familiar location from memory. This was a different building, the appearance of which was linked to intimately personalized resonances. In contrast, this more meaningful, self-centered, older recollection correlated with different activations. These occurred in the *posterior* angular gyrus (along the *ego*centric, E, parietal processing pathway of **Figure 1**), and in the lateral occipital cortex. Moreover, the medial regions now activated included the *anterior* precuneus *and* retrosplenial cortex, as well as the parahippocampal gyrus and the medial prefrontal cortex. Emerging from such subliminal topographical contrasts is the suggestion that when *I* become familiar with a place, *I* tend to regard it almost as though it had become *part of Me and was on My* "turf."

DIFFERENT ROLES FOR THE DORSAL AND THE VENTRAL THALAMIC NUCLEI DURING EXTRAORDINARY STATES OF CONSCIOUSNESS

Item 5 explained how the five nuclei of the dorsal thalamus contribute to the normal overly-dominant egocentric attitudes of our psyche and soma. Item 6 then drew attention to selective capacities of deep inhibitory systems. It suggested that these GABA systems could have the potential to dissolve one's psychic and somatic association functions from the field of consciousness during *kensho*. The words, *anatta*, no-self, and non-*I* are among the standard terms used to describe the resulting selfless attributes of this advanced state (Austin, 2009, pp. 118–121). This abrupt dissolution at the core of the sense of self is noteworthy for two reasons. It can help explain why the deep roots of primal fear also drop out of kensho's field of waking consciousness, as does all personal sense of the passage of time (*achronia*) (Austin, 2006, pp. 378–383; Austin, 2009, pp. 193–196).

What other networks could remain active in a brain during kensho? What evidence offers a potential explanation for the fresh impression of unity that prevails throughout the whole "new" field of conscious experience? Leading the list of candidates would be the brain's lower allocentric pathways. Their "other" frame of reference is not a new category of experience. This anonymous perspective had always been there, its contributions playing only a hidden, subordinate role. (A in **Figure 1**) Now liberated from the dominant subjectivities of the former intrusive self, these other-referential resources could be openly expressed in an undiluted, disinhibited manner. Such a release from prior suppression could then be further enhanced in the course of a disinhibitory rebound (Austin, 2006, pp. 416, 418, 421).

Different observers bring an array of cultural and personal expectations to the vast topic of "enlightenment" (Boyle, 2013). Suppose a curious reader were to press one neurologist-witness to distill the 18 characteristics of kensho's awakening into only two simplified sentences (Austin, 1998, pp. 542–544). The language—strange on any page—might sound something like this:

- In empty anonymity, this now-unveiled other-referential mode is liberated into the foreground of consciousness, reifying the perfection of the whole mental field with a meaningful global objectivity beyond reach of mere words (Austin, 2006, pp. 329–333, 383–387).
- An astonishingly fresh impression of immanent reality prevails throughout this non-dual state of "Oneness": all things, seen selflessly in the total absence of fear, are comprehended "as *they* really are."

What seems to vanish in kensho's fresh perspective? Certainly not the world in 3D. What vanishes is only the former self's intrusive sense of sovereignty over it. When the former egocentric self no longer remains the "owner" of its ongoing perceptions, then the environment opens up to reveal percepts that are experienced with utmost "objectivity" (Austin, 1998, pp. 43–47, 263–267, 591–621; Austin, 2006, pp. 327–356, 414–432; Austin, 2009, pp. 85–94; Austin, 2011, pp. 163–165).

Shodo Harada Roshi (2000) aptly describes such a major transformation. It is an emptiness that cannot be conceptualized: "a state of being empty of ego, but full of what can come through [i.e., allo-perception] when that ego has been let go of."

Do not conclude that the gradual diminution of the ego during decades of authentic Zen training will remove that pragmatic sense of self which enables one to resolve life's complexities by adapting to them in an increasingly mature, realistic, matter-of-fact way. Rather is the training oriented toward dissolving those negative, neurotic distortions of ego defenses imposed by one's overconditioned self-centered attachments (Austin, 1998, pp. 34–36). Longitudinal multidisciplinary studies will be required in order to specify which precise sequences of neural mechanisms need to mature in order for genuine wisdom and compassion to evolve. This caveat holds both for the kinds of decades-long research required to study normal control populations (Vaillant, 2012) or a carefully-matched cohort of long-term meditators (Austin, 2006, pp. 352–356, 399–401; Austin, 2009, pp. 221–262).

A different model of organization and reorganization is proposed for that alternate state of consciousness termed internal absorption (Austin, 1998, pp. 469–479; Austin, 2010). Internal absorption represents a preliminary state, one not uncommon during the early years among trainees who mediate regularly. Paradoxical phenomena enter its intensified awareness: vision "sees" into a vast, pitch-black ambient space; audition "hears" the "sound of absolute silence," perception loses every *physical* sense of self from head to toe. In a quest for preliminary explanations of internal absorption, its agenda of 16 descriptors again leads us to the frontiers of neuroscience research.

A plausible model for such sensate phenomena can also begin on the basis of a GABA blockade (Austin, 1998, pp. 589–590; Austin, 2006, pp. 313–322; Austin, 2009, pp. 98). This inhibition could be applied to the lowermost regions in the back of the thalamus. (Please refer to **Figure 2**) Inhibition down here could prevent impulses from rising up to the cortex through the lowermost ventral sensory *relay* nuclei. They include the lateral geniculate, medial geniculate, ventral posterior medial and lateral nuclei, respectively.

A DESCRIPTIVE CONTINUUM OF INTUITION: ORDINARY CREATIVE INSIGHTS AT ONE END; EXTRAORDINARY STATES OF AWAKENED INSIGHT-WISDOM OFF TOWARD THE OTHER

Carl Jung (1875–1961) understood the key role of intuition. It supplies, he said, that "superior analysis, insight or knowledge which consciousness had not been able to produce" (Jung, 1969; Austin, 1998, pp. 545–553). Could long-term meditative training do more than cultivate a person's attention and affirmative traits of character? Could it also influence subconscious, intuitive mechanisms that subtly enhance a person's *flexible* creative problem-solving behavior? (Austin, 2003, 2014, Chapter 14).

Two recent experiments by Strick et al. (2012) are germane. The 63 meditators in their first experiment had completed 6 months to 5 years of prior Zen practice. In the evening, between 6 and 9pm, one group (led by a Zen master) then meditated for 20 min. The second Zen group served as controls. They relaxed at the same time, without meditating, also for 20 min. Both groups then went to individual cubicles. There they performed three sets of five Remote Associates Tests using a computer screen. (For example, given three words, search your associations for that one fourth word which they all share in common.) The subjects who had just meditated solved more test items (7.00) than did those who had merely relaxed (5.94), $p = 0.02$.

In the second experiment, the response times of 32 Zen meditators were measured during similar word association tests. Again, the subjects who had just meditated solved more Remote Associates Test items than did their controls (6.82 vs. 4.87), $p < 0.01$. They also solved them faster (taking only 13.22 vs. 16.37 s), $p < 0.05$. In addition, the groups were then asked to free associate to a new collection of different questions. However, in this instance, each of the 20 questions might have not just one, but three or four possible answers. (e.g., "Name one of the four seasons.") Moreover, this time—*before* each question—a priming word-answer appeared *subliminally* on the screen (e.g., "Summer"). No subject could "see" this hidden, priming word consciously, because it lasted only 16 ms.

Now the question was: could meditation unveil any of their *subconscious* sensitivities? If so, would this hidden awareness enable the subliminal priming word to reshape the answer? The meditators' answers did match the hidden priming words at the $p = 0.06$ level, just short of statistical significance. In contrast, the relaxed control group showed no priming effect.

The Remote Associates Test is often interpreted as a task for verbal creativity that combines an initial divergent search with convergence functions. Therefore, the experiments suggest that these particular Zen meditators (tested in the *evening*) showed evidence consistent with an enhancement of creative processing after having meditated (Austin, 2009, pp. 125–130, 154–188). Why should researchers in the future specify the hours during which they conduct their cognitive experiments? Because many normal subjects may not reach their performance maximum for working consciousness until the later hours between 7 and 9 pm (Austin, 1998, pp. 338–347). In this regard, Shannon et al. (2013) made an intriguing observation. In normal subjects, the medial temporal regions show greater local fMRI connectivities in the morning hours. In the evening hours, more connections open up that will link the frontal and parietal neocortex with the striatum and brain stem.

In their study of creativity, Colzato et al. (2012) interpreted this Remote Associates Task as a way to index the competence of convergent thinking, and assessed the productivity of divergent thinking with the Alternate Uses Task. Their 19 meditators had been practicing mixtures of concentrative and receptive forms of meditation for an average of 2.2 years. The task for each subject was to spend only 35 min a day (on each three separate days) either in concentrative meditation, or in receptive meditation, or in a baseline control condition. The data suggested that 35 min of focused meditation (only) did not sustain convergent thinking processes toward a single solution, but that a separate 35 min of receptive meditation did support divergent thinking processes.

Our normal ordinary, intuitive quests for meaning become successful only when we repeatedly apply subtle convergent and divergent attentive processing mechanisms with appropriate flexibility. Many of these flexible interactions integrate the functions of fronto-temporal and fronto-parietal lobe networks in particular (Austin, 2009, pp. 130–173). However, diverse phenomena unfold quickly during advanced alternate states of consciousness. They present unusual blendings of different attributes. The two sentences condensed in item 8 suggest that the flash of *selfless* insight-wisdom (Skt: *prajna*) is extraordinary for two reasons. First, for the way it dissolves self-centered processing; second, for the way it liberates other functions that are consistent with enhanced modes of allocentric attentive processing (Austin, 2009, pp. 178–188, 199–214). The egocentric vacancy in the core of the psyche leaves an extraordinary impression: all root origins of selfhood and deep natural survival angsts seem to have dropped off. This acute, ineffable release from the deepest instincts of primal fear is especially liberating (Austin, 1998, pp. 569–570; Austin, 2006, pp. 232–237, 357–387; Austin, 2014, Chapter 14).

RELEVANT EVIDENCE FROM RECENT EXPERIMENTS IN NON-MEDITATING SUBJECTS

Insight *happens*. Insight is not driven by logic-tight sequences of deliberate thought. For centuries, Zen masters emphasized that advanced degrees of insight (Skt: prajna) played a key transforming role in the Buddhist meditative Path. The masters also warned their trainees: steer clear of those heavy burdens imposed by word language, ruminating thoughts, and fixed conceptual barriers (Austin, 2009, pp. 150–152; Austin, 2014, Chapters 3, 6, 8). Does any contemporary research into the pros and cons of language appear to support such an orthodox empirical stance?

The first task for the normal subjects studied by Bergen et al. (2007) was straightforward: listen to words that would be spoken in the form of simple, short, recorded sentences. The whole meaning of each sentence hinged on where, in space, each event could have taken place. The two possibilities were either higher *up*, or lower *down*, in the extrinsic environment. For example, in some sentences the subjects could hear an up-word ("sky") being spoken. Other sentences would specify a down-word ("grass"). The subjects' next task was a simple visual discrimination: they indicated by a button press whether they saw a circle or a square. Each visual target appeared either at a higher, or lower place on the computer screen. They could see each ○ or □ clearly, during a long 200 ms interval. Some subjects took 30 ms *longer* to signal this discrimination. What caused this slowing? Why had they hesitated? Notably, the delay occurred when they saw either this square, or this circle, in that very *same*—upper, or lower—location, the same place which had just been inferred by that up-or-down word-language inserted into the prior sentence. When did these prior spatial nouns or verbs cause the greater interference delays? When both the visual and the auditory processing converged during those tasks that were chiefly referable to the *upper* visual fields. **Figure 1** suggests that these upper visual fields are represented by the lower occipital ↔ temporal lobe pathways.

How do words interfere with other brain functions? Could word entanglements that arise among language networks (perhaps especially in our left hemisphere) sometimes compete for neural resources with nearby intuitive processing mechanisms? Could such obstacles, acting either directly or indirectly, block the free-flowing access to adjacent networks that might otherwise help us express innate degrees of selfless, insight-wisdom?

In this regard, a different kind of experiment has examined the ways the right and left hemispheres function in normal subjects (Chi and Snyder, 2011, 2012). In these studies, the brain is being stimulated by the gentle flow of *direct* current. This technical approach is called *transcranial direct current stimulation* (tDCS). This direct current is delivered at low amperage to the *scalp* over the right and left anterior temporal regions, *simultaneously*. However, the left anterior temporal scalp electrode serves as the negative pole (–). This cathodal pole tends to *hyper*polarize the resting potentials of nerve cells in the underlying left anterior temporal lobe. This makes these left nerve cells *less* excitable. In contrast, the right anterior temporal scalp electrode serves as the + pole. This anodal pole tends to *de*polarize the resting potentials of the underlying nerve cells on the right side. What is the net result of these modulations? Notice that this result generates the asymmetrical expression of temporal lobe functions. Those pathways on the right side become *more* readily excitable. Those on the left side—the side dominant for language—become *less* excitable (Austin, 2014, Chapter 13).

These normal subjects received transcranial direct current stimulation to the scalp in this manner for only 10–17 min. Next they were challenged to solve either some difficult "matchstick" tests (Austin, 2009, pp. 183–184) or to solve another, very difficult, "connect-the-9-dots" test. In brief, the data showed that tDCS substantially improved the subjects' creative problem-solving performance for up to the next hour beyond that which occurred either in the sham controls, or when the directions of current flow were reversed. These results have implications both for the kinds of complications introduced by our words and for the nature of the kinds of insights we use during creative processing.

IN SUMMARY

It turns out that old Greek words, plus a few old words used in Zen, overlap with concepts recently evolving in neuroscience. The results can be mutually illuminating *if* their correlations are interpreted with appropriate caution. A longitudinal perspective is essential. Thirty-five year old Siddhartha had devoted six long years to a rigorous spiritual quest before he happened to glance *up* before dawn at that legendary morning star (Austin, 1998, pp. 7–8).

Is it feasible to attempt to develop a theoretical neural basis for such an "awakening" of insight-wisdom? The 10 topics just reviewed in this condensed version are the latest sample emerging from several decades spent exploring testable hypotheses (Austin, 1998, xvi; Austin, 2006, xvi; Austin, 2009, xvi; Austin, 2011, pp. 169–177). Some of these have the potential to clarify thorny issues increasingly important to meditators, researchers, and to society in general (Austin, 2012, in press).

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GLOSSARY

Achronia: A state of consciousness lacking all sense of time, resulting in the impression of eternity.

Allocentric: Other-referential. The term serves as a useful contrast to our dominant mode of egocentric (*self*-centered) consciousness. Additional terms emphasize the anonymity implicit in allocentric processing. They include: stimulus-centered, object-centered, observer-independent.

I-Me-Mine: A descriptive psychological construct. It helps define the personal self in operational terms.

Kensho: Seeing into the essence of reality. The beginning of true long-term meditative training; a prelude to the depths of satori.

Koan: An enigmatic statement serving as a device for concentration.

Limbic thalamus: The three most rostral nuclei in the dorsal thalamus: the medial dorsal, anterior, and lateral dorsal nuclei. They are intimately connected both with the limbic system and with particular regions of the overlying cortex.

Prajna (Skt): The flashing insight-wisdom of enlightenment.

Remindfulness: The overview intuitive functions that tap into memory to provide us with subconscious forms of affirmative guidance. These normal recollection functions are implicit in an ancient Pali word, *sati*, that is usually translated only as mindfulness.

Reticular nucleus of the thalamus: The thin outer layer of GABA nerve cells capping the dorsal thalamus in particular. It plays a pivotal, normal inhibitory role in shaping our thalamo ↔ cortical interactions.

State: A temporary condition involving mentation, emotion, or behavior.

Trait: A distinctive ongoing quality of attitude, character or behavior. Traits can be transformed incrementally in the course of long-term meditative training, especially when reinforced by deep insightful *states* of awakening.

Zen: A form of Mahayana Buddhism which emphasizes a systematic approach to meditative training and to the development of character. Its two major schools—Rinzai and Soto—developed in China when Indian Buddhism evolved in the cultures of Taoism and Confucianism, and later spread to Japan.

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Ventral-subgenual anterior cingulate cortex and self-transcendence

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Self-transcendence (ST) is one of specific human experiences often related to harmony with nature or feeling oneness with others or the self as an integral part of the whole universe. The Temperament and Character Inventory (TCI) is a widely used personality measure, and ST is one of personality dimensions (Cloninger, 1994; Cloninger et al., 1994). Previous studies showed that ST has significant positive correlation with the sgACC encompassing a ventromedial portion of the prefrontal cortex (vmPFC) using TCI and PET scan (Hakamata et al., 2013). Meanwhile, sgACC/vmPFC activity has been shown to be significantly decreased in patients with anxiety, major depression and mood disorders (Drevets et al., 2008; Shin and Liberzon, 2010; Kühn and Gallinat, 2013). Altogether, these findings suggest that sgACC/vmPFC play an important role in emotion regulation and ST (Hakamata et al., 2013).

ACC as a part of the brain's limbic system, appears active in many neuroimaging studies (Bush et al., 2000; Posner et al., 2007). In general ACC is involved in cognitive (dorsal division) and emotional (ventral/rostral part) processing (Bush et al., 2000). The sensitivity of the ACC to both reward and pain, and evidence for ACC coupling to cognitive and emotional areas during resting state and task performance, support the role of ACC in self-regulation or self-control including emotional, cognitive and autonomic control. Particularly, v/sgACC and adjacent mPFC area involves in emotional control and autonomic regulation (Luu and Posner, 2003; Posner et al., 2007), consistent with many meditation findings (Hölzel et al., 2011; Tang et al., 2012b; Tang and Posner, 2013).

Meditation often exemplifies positive emotion, pleasant feeling and ST experience in practitioners (Cahn and Polich, 2006; Tang et al., 2007). Studies showed ST is positively related to meditation practice (Levenson et al., 2005). One meditation-category—automatic self-transcending includes techniques designed to transcend their own activity and improve ST (Travis and Shear, 2010). Substantial evidences indicate that ACC plays a key role in meditation training (Hölzel et al., 2011). For example, compared to non-meditators, long-term Vipassana meditators showed stronger activations in the rostral ACC and adjacent medial PFC bilaterally for the meditation condition (contrasted to arithmetic task). Greater ACC and mPFC activations in meditators may reflect processing of distracting events and emotional processing (Hölzel et al., 2007, 2011). Compared with a memory training control, compassion training elicited activity in a neural network including pregenual ACC, medial orbitofrontal cortex and striatum—brain regions previously associated with positive affect and affiliation (Klimecki et al., 2013a,b). In the same vein, 5 days of one form of meditation—integrative body–mind training (IBMT) improves vACC activity compared to same amount of relaxation training (Tang et al., 2009). Meanwhile, 5 days of IBMT also reduces stress, improves positive emotion and self-report of feeling oneness with nature (Tang et al., 2007). Further, 10 days of IBMT increases white matter connectivity surrounding ACC and this brain structural change correlates with emotional regulation (Tang et al., 2012a,b). These results indicate that meditation accompanies positive emotion, ST experience, and ACC functional and structural changes.

ST related meditation not only induces brain and behavioral changes, it often involves brain (mind) and body cooperation indexed by central (CNS) and autonomic (ANS) nervous system interaction (Cahn and Polich, 2006; Hölzel et al., 2011). Studies have begun to explore interaction and dynamics between CNS and ANS (Critchley et al., 2003; Tang, 2009; Tang and Posner, 2009; Tang et al., 2009; Hölzel et al., 2011; Critchley and Harrison, 2013). For instance, using heart rate variability (HRV), and high- and low-frequency power in the cardiac rhythm, ACC activity related to sympathetic modulation of heart rate was observed (Critchley et al., 2003). We measured the physiological and brain changes at rest before, during, and after 5 days of IBMT and relaxation training. During and after training, the IBMT group showed significantly better physiological reactions in heart rate, respiratory amplitude and rate, and skin conductance response (SCR) than the relaxation control. Differences in HRV and EEG power suggested greater involvement of the ANS in the IBMT group during and after training. Imaging data demonstrated stronger v/sgACC activity in the IBMT group. Frontal midline ACC theta was also correlated with high-frequency HRV, suggesting control by the ACC over parasympathetic activity (Tang et al., 2009). These results indicate that brief IBMT induces better regulation of the ANS by a midline v/sg ACC brain system. This changed state probably reflects training in the coordination of body and mind given in the IBMT but not in the relaxation group. These results indicate body-brain works together to maintain certain consciousness states such as ST that may be related to different performance (Tang et al., 2007; Xue et al., 2011; Tang et al., 2012a,b). Our findings suggest meditation training could induce altered states of consciousness which may allow us to explore the neuroscience of consciousness based on how alterations in normal consciousness result in functional or/and structural brain changes and plasticity. These alterations in consciousness can affect long-term cognitive, affective and social activities, and may help understand the disease states or disorders of consciousness such as coma, vegetative state, etc. (Tang et al., 2013).

In summary, growing empirical evidences indicate meditation has potential to develop ST—a positive relationship between self and other that transcends self-focused needs and increases prosocial characteristics (Hölzel et al., 2011; Tang et al., 2012a,b; Vago and Silbersweig, 2012). Future studies could examine the relationship between ST and short-term or long-term meditation, and how meditation shapes the perspectives on the self, self-others, self-nature and its underlying mechanisms using multimodal neuroimaging, physiological, psychosocial and genetic methods.

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Alterations in the sense of time, space, and body in the mindfulness-trained brain: a neurophenomenologically-guided MEG study

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Meditation practice can lead to what have been referred to as "altered states of consciousness." One of the phenomenological characteristics of these states is a joint alteration in the sense of time, space, and body. Here, we set out to study the unique experiences of alteration in the sense of time and space by collaborating with a select group of 12 long-term mindfulness meditation (MM) practitioners in a neurophenomenological setup, utilizing first-person data to guide the neural analyses. We hypothesized that the underlying neural activity accompanying alterations in the sense of time and space would be related to alterations in bodily processing. The participants were asked to volitionally bring about distinct states of "Timelessness" (outside time) and "Spacelessness" (outside space) while their brain activity was recorded by MEG. In order to rule out the involvement of attention, memory, or imagination, we used control states of "Then" (past) and "There" (another place). MEG sensors evidencing alterations in power values were identified, and the brain regions underlying these changes were estimated via spatial filtering (beamforming). Particularly, we searched for similar neural activity hypothesized to underlie both the state of "Timelessness" and "Spacelessness." The results were mostly confined to the theta band, and showed that: (1) the "Then"/"There" overlap yielded activity in regions related to autobiographic memory and imagery (right posterior parietal lobule (PPL), right precentral/middle frontal gyrus (MFG), bilateral precuneus); (2) "Timelessness"/"Spacelessness" conditions overlapped in a different network, related to alterations in the sense of the body (posterior cingulate, right temporoparietal junction (TPJ), cerebellum); and (3) phenomenologically-guided neural analyses enabled us to dissociate different levels of alterations in the sense of the body. This study illustrates the utility of employing experienced contemplative practitioners within a neurophenomenological setup for scientifically characterizing a self-induced altered sense of time, space and body, as well as the importance of theta activity in relation with these altered states.

Keywords: space perception, time perception, body perception, magnetoencephalography (MEG), theta rhythm, neurophenomenolgy, mindfulness meditation

INTRODUCTION

Long-term contemplative practitioners offer an exclusive opportunity to study unique mental states, due both to their heightened introspective abilities, as well as their ability to intentionally alter subtle aspects of consciousness (Lutz et al., 2007). Here, we employ long-term Mindfulness meditators to study unique states of alteration in the sense of time and space, which have not yet been neuroscientifically investigated.

One of the characteristics of altered states of consciousness is a *joint* alteration in the experience of time and space (Tart, 1972; Glicksohn, 1993; Baruss, 2003; Glicksohn and Berkovich-Ohana, 2011), which has been called by Fingelkurts and Fingelkurts (2006) "a sense of timelessness, spacelessness." The incidence of mutual alteration in the experience of time and space is so common that it led Walter Stace, the well-known scholar of mysticism, to include one characteristic named "non-spatial and non-temporal" (1960, p. 110) in his definition of the universal core of mystical experience. According to Suzuki, *sunyata*, the Buddhist concept of emptiness, means: "absolute emptiness transcending all forms of mutual relationship…There is no time, no space, no becoming, nothingness…when the mind is devoid of all its possible content" (in Stace, 1960, p. 109). Similarly, in Vedic psychology, transcendental consciousness, which is a state achieved through the practice of Transcendental Meditation in which the individual's mind transcends all mental activity to experience the simplest form of awareness, is characterized by being unbounded in space and time (Alexander et al., 1987).

Cognitively, an altered sense of time can be viewed as the limit for the functioning of the cognitive timer, the breakdown of apparent duration (Glicksohn, 2001). Apparent duration, in turn, is closely related to spatial perception (Boroditsky and Ramscar, 2002; Glicksohn and Myslobodsky, 2006; Srinivasan and Carey, 2010; reviewed by Walsh, 2003). Neuroscientific evidence suggests common underlying mechanisms for spatio-temporal processing (Basso et al., 1996; Walsh, 2003; Danckert et al., 2007; Oliveri et al., 2009a), as do linguistic (Boroditsky and Ramscar, 2002; Núñez and Sweetser, 2006; Casasanto, 2008, 2010) and psychophysical studies (e.g., Sarrazin et al., 2004; Oliveri et al., 2009a,b; Srinivasan and Carey, 2010). An altered experience of space has been called by Stanley (1898) "space annihilation," again in relation to the time dimension. An altered sense of time and space has hardly been studied scientifically, the major obstacle being the production of these experiences in the lab (but see the hypnosis experiment of Aaronson, 1970).

Phenomenologically, altered states of consciousness are frequently accompanied by a joint alteration in both the experience of time and space, as noted above, but also in bodily perception (Tart, 1972; Travis and Pearson, 2000; Shanon, 2003; Vaitl et al., 2005; Hunt, 2007; Ataria and Neria, 2013). Hence, we hypothesized that an altered sense of time and space would be related to an altered sense of body. An altered sense of body is conceptualized as a disrupted sense of spatial unity between self and body, where the self is not experienced as being confined within the boundaries of the body. A possible candidate mediating this connection is the insula, related to both proprioception and the sense of time (Craig, 2002, 2009a,b).

Mindfulness meditation (MM) practice focuses on cultivating a non-judgmental awareness of momentary experience (Kabat-Zinn, 2003) with the aim of liberation from human suffering (Olendzki, 2003; Dreyfus and Thompson, 2007). While not being the goal of training, long-term practice is often accompanied by altered states of consciousness (Stace, 1960; Goleman, 1988; Shapiro, 2008). This makes MM practitioners potentially familiar with alteration in the experience of both time and space. In addition, advanced practitioners have been documented as not only being able to produce voluntary alterations of subtle consciousness-related experiences within laboratory settings, but also to provide refined first-person descriptions of these experiences (Lutz et al., 2007). This renders MM practitioners ideal candidates for the study of such unique states, which have hitherto been quite unexplored.

Here, we study the experience of alteration in the sense of time and space by collaborating with a select group of 12 long-term MM practitioners in a neurophenomenological setup. All of the participants have experienced these states in the past (see Methods), and thus possess a frame of experiential reference. The participants were asked to volitionally produce two distinct states, which we *a priori* named "Timelessness" and "Spacelessness" (outside time and space, respectively). In order to rule out the involvement of attention, autobiographic memory or imaginative processes (Szpunar et al., 2007), participants were also asked to produce control states of "Then" and "There" (be in the past and in another place, respectively). The data were analyzed in terms of "Timelessness" vs. "Now" and "Spacelessness" vs. "Here," and contrasted with "Then" vs. "Now" and "There" vs. "Here" (two target and two control contrasts, respectively). In particular, we investigated whether there would be similar neural activity underlying both these states of "Timelessness" and "Spacelessness." Specifically, we hypothesized that: (1) the control conditions, "Then" and "There," would yield overlapping activity in an autobiographic memory network; (2) "Timelessness" and "Spacelessness" conditions would overlap in a different network, related to alterations in the sense of body, including the insular cortex; and (3) phenomenologically-guided neural analyses would yield further insight into the underlying physiology of the alteration in the sense of time and space.

METHODS

PARTICIPANTS

Sixteen practitioners participated in this study, of whom two were excluded due to self-reported severe tiredness and back pain, respectively, during the data recordings. Two others were excluded as they practiced different forms of meditation (not MM), in an attempt to homogenize the group. The remaining participants practice within the Theravada tradition. Participants were right-handed (3 females, age 44.9 ± 10.9 years, range: 31–64) and healthy, with no history of mental or neurological diseases. All participants were long-term practitioners with an average of 16.5 ($SD = 7.9$, range: 9–34) years, and 11,225 ($SD = 9909$, range: 1290–29,290) total hours, of meditation practice. The study was approved by the Research Ethics Board of Bar-Ilan University. The participants gave their written consent and were financially compensated.

PRE-RECORDING PROCEDURES

The participants were introduced to the lab, then filled out forms (research consent, personal details, formal practice estimate) and Hood's (1975) Mysticism scale, to test for previous experiences of alteration in the sense of time and space. The experimenters explained to the participants each part of the experiment, and it was made certain that the participants understood the tasks. Altogether, this part took 45–60 min.

Hood's (1975) MYSTICISM SCALE (MSCALE)

Hood's (1975) Mscale is a general measure of self-transcendent experience, based on Stace's (1960) conceptualization of eight dimensions of transcendence. This is a 32-item scale, where the items are grouped into eight components of experience: *Positive affect, Religious quality, Noetic quality, Ineffability, Unifying quality, Inner subjective quality, Ego quality*, and *Temporal and spatial quality*, the last being an experience of "timelessness" and "spacelessness." The results of the last item were used to assess whether participants had previous experiences of altered sense of time and space, of interest for this report. The four statements pertaining to this item were: (1) I have had an experience which was both timelessness and spacelessness; (2) I have had an experience in which I had no sense of time or space; (3) I have never had an experience in which time, place, and distance were meaningless; and (4) I have never had an experience in which time and space were non-existent. Participants were requested to indicate on a five-point scale from −2 (*definitely not true*) to +2 (*definitely true*), the extent to which each of 32 statements is true of their own experiences. After reversing appropriate items, these responses are converted to a five-point Likert scale, from 1 (*low*) to 5 (*high*), where indecision is scored as 3.

The mean score for the Mscale was 4.30 ± 0.40, indicating that participants experienced mystical states high above the indecision point. Importantly, mean score for the sub-scale of *Temporal and spatial quality* was high, 4.47 ± 0.67. Thus, participants had previous acquaintance with the concurrent experience of alteration in the sense of time and space. For comparison, the mean Mscale score in a population of 191 religious participants was 3.58, and the *Temporal and spatial quality* was 3.42 (Lazar and Kravetz, 2005). This indicates that meditation practice increases the occurrence of alteration in the sense of time and space experiences high above mere religious tendency.

EXPERIMENTAL TASKS

The experiment comprised seven MEG recording sessions. Each session was followed by an interview conducted via the intercom system, during which brain activity was not recorded. The participants were encouraged to stretch their limbs and relax during the interviews, but were requested not to move and to keep their eyes closed while performing the tasks. To correct for head and body movements during the interviews, head-shapes were re-registered at the beginning of each session. A 20-min break was suggested to the participants after completing the 5th session of the experiment, during which refreshments were offered. Total time in the MEG was around 2 h.

The two sessions reported here are the "Time" and "Space" sessions (3rd and 4th, respectively), which were preceded by a resting state and a time production session, and followed by a "Self" session, reported elsewhere (Dor-Ziderman et al., 2013). The participants were asked to volitionally bring about alterations in their experience of time and space, in a manner which had been previously explained. Each of the two sessions comprised 3 conditions, each repeated 3 times in succession for 30 s (**Figure 1**). A recording with instructions for each condition was sounded (<2 s), after which the participant performed the requested task for 30 s. At the end of the 30 s, a short sound was heard indicating the participant to stop, and then the next instruction was delivered. The session was followed by a structured interview conducted via the intercom system.

The specific instructions for the three conditions in the "Time" session were:

"Now"—"Try to be in the present moment"
"Then"—"Try to be in the near past (in the same place—the lab)"
"Timelessness"—"Try to be outside time"

The specific instructions for the three conditions in the "Space" session were:

"Here"—"Try to be here"
"There"—"Try to be elsewhere (at the moment, with the experimenters outside the shielded MEG room)"
"Spacelessness"—"Try not to be in the center of space"

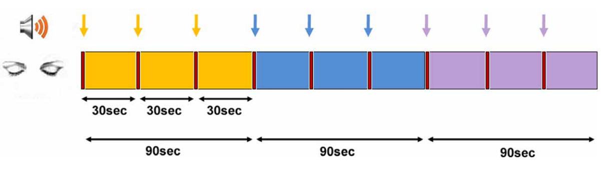

FIGURE 1 | Experimental protocol. The time and sequence of conditions in the two MEG sessions of "time" and "space." Yellow—"There"/"Then," blue—"Here"/"Now," and purple—"Timelessness"/"Spacelessness" conditions. All epochs were initiated by an auditory cue (marked by arrows).

SUBJECTIVE REPORTS

Phenomenological analyses

Participants were asked, immediately after each session, to describe their experiences during the session, following a semi-structured interview. The reports of the "Timelessness" and "Spacelessness" conditions were carefully analyzed by the first author. Two broad themes emerged: "sense of time and space," and "bodily boundaries," each including several categories of experience. Subsequently, participants were allocated into one of three categories for the "sense of time and space" theme, and into one of four categories for the "bodily boundaries" theme. The reports were then given to four other judges for anonymous rating. A classification of any report to one of the categories was accepted based on the majority (minimum three out of five) (**Table 1**).

For the "sense of time and space" theme, three categories emerged, all along a continuum of increasing alteration in the sense of time and space:

(i) Regular sense of time and space (regular TS)—regular experience of time and space.
(ii) Change in the sense of either time or space (Change either TS)—an alteration in the usual sense of time or of space.
(iii) Change in the sense of both time and space (Change both TS)—an alteration in the usual sense of both time and space.

For the "bodily boundaries" theme, four categories emerged, the first three along a continuum of alteration in bodily boundaries and egocentric frame of reference:

(i) Regular bodily boundaries (regular BB)—regular experience of bodily boundaries, fully egocentric experience.
(ii) Lower bodily boundaries (lower BB)—weaker than usual experience of bodily boundaries, bodily expansion, a reduction in the egocentric experience.
(iii) Substantial loss of bodily boundaries (Substantial loss BB)—very weak, and occasionally a total loss of experience of bodily boundaries, strong bodily expansiveness, a strong reduction in the egocentric frame of reference.
(iv) Out-of-body experience (OBE)—an extracorporeal egocentric perspective (floating outside one's body and perceiving one's physical body from a place outside one's body), with normal or distorted bodily boundaries.

Table 1 | Classification of participants to phenomenological categories and groups.

ID no.	Timelessness description	Category: Body boundary	Category: Sense of time/space	Spacelessness description	Category: Body boundary	Category: Sense of time/space	Group
11	The fact that I tried to reach this state obstructed it. The moment there was intention there was a narrowing of the space. But there were moments where I felt outside time and space. There was a vanishing of bodily sensations, although there was awareness to awareness itself. The purest form of the sensation was there, but un-restricted. There was relaxation and widening. The body was not present. There were no body sensations in the Timelessness moments. In the pure awareness moments there was no awareness to bodily boundaries. There was spatial expansion.	Substantial loss BB	Change both TS	The bodily dimension expanded but there was no sense of boundless space, rather that body dimensions have changed. The body was wider and wider. The body as physical image was absent. There was a sense of open space without the bodily dimension. The mechanism that senses time was absent. There was a sense of immediateness, without a center aware of temporality.	Substantial loss BB	Change both TS	BTS
12	It was a sense of un-knowing. It was actually close to the present moment. I had to let go of the present moment, and it was subtle. Entering this experience was through the present moment, and then I had to leave the world of experience in order to let go of the present moment. I focused in not knowing the moment. Like letting-go, falling. The bodily sensation disturbed and I had to let go of it again and again, as it returned automatically.	Lower BB	Change both TS	It was a sense of spaciousness, boundlessness, the center was not so interesting, there was no clarity where the center is and where is the periphery. There was no quality of border. Sensations were minimal compared to the "Here" condition; the sense of space occupied 90% of awareness. Maybe there was a slight increase in a visual sense of blackness, maybe because associating space. I was not aware of my self - boundaries. There was a sense of timelessness in the background.	Substantial loss BB	Change both TS	BTS
5	There was relaxation and letting-go, emptiness, experience of bliss. Quiet, wide, something wider than the body. Like a long line crossed me and continued beyond me. More open, something relaxed in the muscles. A wide experience with un-defined boundaries. A sense of dissolving, that I am dissolving, my body dissolving.	Substan ial loss BB	Change either TS	The metaphor is an amoeba, everything spreads. A sense of nothingness, emptiness. A sense of expansion. There's quiet, the hearing sharpens. A part of the time I was outside myself, in another world. There was no time.	Substantial loss BB	Change both TS	BTS
13	It was hard not to think of time, to be outside time. After a while I started worrying about the time. It was most similar to being in the present moment, not being occupied with time. There was no alteration in sensation, it was more mental, but everything felt wider, and there was no awareness to bodily and self boundaries.	Substantial loss BB	Change either TS	When I was outside the center of space the mind became more spacious and exploring. There was no self-reference. A state of wide and spacious mind. There was less emphasis on the body, more on the mental space. Time seemed less important, not well defined.	Lower BB	Change both TS	BTS

(Continued)

Table 1 | Continued

ID no.	Timelessness description	Category: Body boundary	Category: Sense of time/space	Spacelessness description	Category: Body boundary	Category: Sense of time/space	Group
14	There was an expansion of the chest. I lost discrimination between different body parts. It felt pleasant, like a huge hammock. A sense of expansion. There was a spatial change, I was aware both of the bodily boundaries as well as a pleasant dissolution, something liquid-like.	Substantial loss BB	Change either TS	It was like being in the tub hole where all the water drains. Self-forgetfulness. A sense that everything drains to me. Like wood barks, the space outside, and suddenly a collapse into my body. Like nylon that you stretch and let go of repeatedly... Bodily sensations were wider. Bodily space was larger. Much less awareness to my self boundaries. There was no change in the sense of time.	Lower BB	Change either TS	BTS
4	The mind was in the present moment, as this is the gate to timelessness. I felt pressure to succeed, and that time was too short to enter a "blackout," which is for me a Timelessness dimension. There was awareness to body and breath, I was aware of the subject-object duality.	Regular BB	Regular TS	I released the subject-object contrast, and then the center of space became endless, without a reference point in the middle. There was a sense of floating in a sea of being. Experiences arise, but no emotions, no sounds. Everything was a part of one conscious experience. The dichotomy between subject and object dissolved. There was no reflective awareness of "this is a sound." Everything was a part of a singular event. The experience of the body faded. There was a sense of body in the background, not in front of consciousness. There were no self boundaries, only fusion with everything that exists. There was a change in the sense of time, time lost its linearity.	Substantial loss BB	Change both TS	NTS
9	All the time I focused on visualizing black, as if I see darkness, not considering anything related with time. There was no sensory alteration, but I was less aware of how much time passed. There was awareness to space, but lower than usual. Fifty percent of the time I was not aware of my bodily boundaries.	Substantial loss BB	Change both TS	I was imagining that the body is un-real, fragmented all over the place, breaking apart. I used perception—the mind is not mine, it's only processes in time. It's not I who is thinking, thoughts exist, simply energy. It's not me who is in the space. There was no alteration in bodily sensations. I was not aware of the mental side, and less aware of the physical side. There was an alteration in the sense of time. When I related to the body as non-existent it became abstract and time was less relevant.	Regular BB	Change either TS	NTS
1	I wasn't outside time. I tried not to localize myself, not knowing where I am in time, not to control my thoughts, not even to here. There was an alteration in bodily sensation in the direction of less, I cannot define it.	Lower BB	Regular TS	I let myself be very big, expand. There was little awareness to different body parts, more something like not exactly I. Mainly a sense of expansion, something open and wide. Little bodily boundaries compared to the usual feeling. Little instances of awareness to my boundaries. There was no change in the sense of time.	Lower BB	Change either TS	NTS

(Continued)

Table 1 | Continued

ID no.	Timelessness description	Category: Body boundary	Category: Sense of time/space	Spacelessness description	Category: Body boundary	Category: Sense of time/space	Group
6	The mind could not produce this condition. There was a sense of the body, many bodily sensations.	Regular BB	Regular TS	It was hard to differentiate space from time. It was a little more successful than the Timelessness condition, but didn't put me outside space. I let myself rest within the sensations, than the sense of time and space becomes vague, there was just presence.	Regular BB	Change either TS	TS
2	It started with momentary experience, as I usually enter timelessness through momentary experience. I tried to dim concrete signs of momentary experience, like body and breath. I tried to be less focused on what is happening now, like sensory experience.	Regular BB	Regular TS	It was like before with Timelessness. I started with momentary sensation of my body lying down, and then I tried to expand the experience. Meaning, to dim bodily boundaries and to see if I can experience myself wider, extended, less physically bounded. The focus was trying to dim bodily boundaries; I gave less attention to what is happening in the time domain.	Lower BB	Regular TS	NTS
16	It was like floating, trying to remain in a letting go state. The bodily boundaries did not change, there was no sensory change, it was more mental.	Regular BB	Regular TS	I tried to be in a state of rest where it's as if I lose my center, my thought, and it alternated. A pleasant bodily sensation. A regular sense of self. Much less sense of time.	Regular BB	Change either TS	NTS
8	It was very hard to maintain, every sound disturbed it, it was about being very quiet and concentrated, a very visual experience. It jumped to my mind "I'm floating outside the earth and atmosphere." I saw the time-line from a bird view. There was no awareness of momentary physical sensations, only awareness to bodily boundaries. I took myself to a different space, I wasn't here. But I was with my body, just floating in outer space. The body was identical, I wasn't floating as consciousness, but as a body.	OBE	Change both TS	The body stayed in bed but I saw myself from the corner of the room. The first time (first 30 s) it was continuous. The second time it was hard to maintain and I kept entering and leaving my body. In the third time I came back to the corner and it was more successful. Outside the body I felt short and small, like a little child, I shrank. I went in and out of bodily borders. It's hard to say if there was any temporal change. The third time seemed too short.	OBE	Change both TS	Excluded

Yellow and cyan, sentences pertaining to body or to time/space, respectively. BB, bodily boundaries; OBE, Out of body experience; TS, time and space; BTS, Both time and space; NTS, Not both Time and Space.

In line with this analysis, 11 participants could be placed along a continuum of alteration in bodily boundaries and egocentric frame of reference. As the OBE could not be placed along the continuum of reduction in egocentric frame of reference, the sole participant having this experience was excluded from all subsequent analyses (see **Table 1**). The remaining 11 participants were included in the subsequent analyses, and were regarded as being placed along one continuum: at one end were those who experienced a weak and gentle shift, while at the other end were those who experienced a profound shift. This is in line with Shapiro (2008) who states that unique meditative states "need to be seen along a continuum. On one hand of the continuum are "full blown" mystical experiences, at the other, more common alterations of perception" (p. 25). Next, we set out to differentiate between participants along the higher and lower ends of the above continuum, by creating two groups (**Table 1**):

(1) Both Time and Space (BTS) group—during the two conditions of "Timelessness" and "Spacelessness," participants experienced a change in both themes of phenomenal

experience (i.e., do not belong to "Regular BB" or "Regular TS").

(2) Not both Time and Space (NTS) group—during the two conditions of "Timelessness" and "Spacelessness," participants did not experience a change in both themes of phenomenal experience (i.e., belong to "Regular BB" or "Regular TS").

Testing for differences between the BTS and NTS groups, there were no significant differences in age or practice experience, as well as mean score for the Mscale or the sub-scale of *Temporal and spatial quality*.

Success and stability ratings

Participants were asked to verbally rate, on a 1–10 scale (1—"very low," 10—"very high"), their success (defined here as: how strong was the experience, on average, across the 90 s allocated for each condition) and stability (defined here as: how stable was the experience during the 90 s allocated for each condition) in performing each of the tasks. Subsequently, a Three-Way ANOVA was conducted, with Session (Time/Space) × Condition (Then/There, Here/Now, Timelessness/Spacelessness) × Measure (success, stability) on these ratings. There was no difference between success and stability (**Figure 2A**), hence we will focus subsequently on success. We found only a main effect for Condition [$F_{(2, 20)} = 18.5$, $MSE = 5.07$, $p < 0.0001$]. The "Timelessness" and "Spacelessness" conditions were rated as significantly less successful compared to "Here" and "Now" [$t = 3.80$, $p = 0.011$ and $t = 3.99$, $p = 0.0045$, respectively, Bonferroni-corrected *post-hoc* paired t-tests], but showed no significant difference between them. When comparing scores for the "Timelessness" and "Spacelessness" conditions between the BTS and NTS groups, no significant difference was found. **Figure 2B** depicts the rating for the "Timelessness" vs. "Spacelessness" conditions, showing the BTS and NTS groups to be similarly distributed. This is in contrast to the phenomenological difference found between the groups. We suggest that the discrepancy stems from different levels of self-criticism, as well as different personal expectations. In fact, some of the most-experienced practitioners scored their success as being lower compared to the less-experienced practitioners. Altogether, our results emphasize the need to collect verbal reports in addition to self ratings when conducting neurophenomenological analyses.

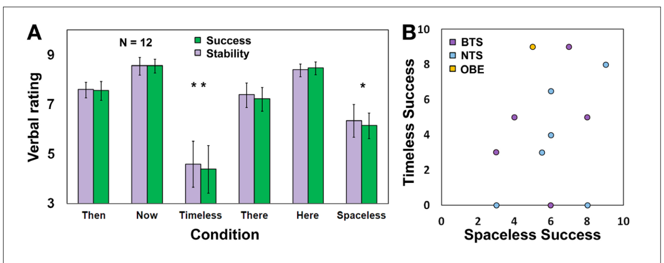

FIGURE 2 | Rating of task success and stability. (A) Participants' rating (Mean ± s.e.m., $n = 12$) for success and stability during the different conditions. $^{*}p < 0.05$, $^{**}p < 0.005$, Bonferroni-corrected; **(B)** A scatterplot for the Timelessness vs. Spacelessness rated success. BTS, Both time and space; NTS, Not both Time and Space. Yellow dot refers to one OBE participant.

An additional observation is that the "Timelessness" scores were more variable compared to the "Spacelessness" scores. The reason for this is that two of the three participants reporting zero success in the "Timelessness" condition belong to the Burmese Mahasi school, which adheres strictly to the "Progress of insight" which is an inner "map" of how insights unfold through 16 developmental stages of insight knowledge. This tradition encourages an experience of "cuts" in consciousness, which are considered the culmination of these stages, and are called fruition (*phala*). Nanarama (1983) describes this state: "consciousness… transcends the continuous occurrence of formations and aligns upon non-occurrence" (p. 117). The fruition is mentioned here in some length, as it turned out that these two participants attempted to reach this acquainted state unsuccessfully during the short time allocated to the "Timelessness" condition, which affected their rating of success. However, after the Time session, it was emphasized that the experimenters did not expect these unique fruition states during the short lab procedure, thus their scores for the "Spacelessness" condition increased markedly, to 6 and 8.

MAGNETOENCEPHALOGRAPHY (MEG)

MEG data acquisition

MEG recordings were conducted with a whole-head, 248-channel magnetometer array (4-D Neuroimaging, Magnes 3600 WH) in a magnetically-shielded room. Reference coils located ~30 cm above the head oriented by the x, y, and z axes were used to remove environmental noise. Head position was indicated by attaching 5 coils to the scalp and determining, to a 1 mm resolution, their position relative to the sensor array before and after measurement. Head localization was performed before and after each set of tasks to determine degree of head movement. Head shape and coil position were digitized using a Pollhemus FASTTRAK digitizer. Brain signals were recorded with a sampling rate of 1017.25 Hz and an analog online 0.1–400 Hz band-pass filter. The instructions for each condition were presented using E-prime 1.0 and delivered via a STAX SRS-005 amplifier and SR-003 push-pull electrostatic ear speakers coupled by a vinyl tube to silicon earpieces to prevent magnetic noise within the shielded room. Task performance ratings were collected using a LUMItouch photon control response box.

MEG data cleaning and preprocessing

Data processing and analysis was performed using Matlab® R2009b and FieldTrip toolbox for MEG analysis (Open source software for advanced analysis of MEG) (Oostenveld et al., 2011). Data were cleaned for line frequency (by recording on an additional channel the 50 Hz from the power outlet, and subtracting the average power-line response from every MEG sensor), and 24 Hz building vibration (measured in x, y, and z directions using 3 Bruel and Kjaer accelerometers) artifacts (Tal and Abeles, 2013). The data from the 3 "Time" and 3 "Space" conditions were then segmented into non-overlapping 2-s epochs. Each epoch was visually examined for muscle and jump artifacts (in the MEG sensors). Contaminated epochs were discarded. No malfunctioning MEG sensors were identified. To ensure the removal of all heartbeat, eye and muscle artifact, an independent component analysis (ICA) was performed on the data (Jung et al., 2000).

Segmented data were down-sampled to 339 (1017/3) Hz to speed up data decomposition. The data were then decomposed into a set of independent components (248, equal to the number of sensors) ordered by degree of their explained variance. Components indicating heartbeats or eye movements were determined from a visual inspection of the 2D scalp maps and time course of each component. The remaining components were then used to reconstruct the pre down-sampled data.

Sensor-level analyses

The first 4 s of each task (3 tasks of 30-s in each condition) were omitted so as to allow the participants sufficient time to enter the states. This decision was made after consulting an expert meditator as to the study design, and following two self-pilot runs (with Aviva Berkovich-Ohana and Yair Dor-Ziderman, also long-term practitioners). From the remaining data in each condition, the first 32 epochs were used for further sensor-level analyses. These 2-s epochs were multiplied by a Hanning taper, and subjected to a Fast Fourier Transformation (FFT) for the frequencies ranging from 4 to 45 Hz. This resulted in a power spectrum with a frequency resolution of 0.5 Hz for each epoch. The power spectra were then averaged across the epochs of each condition and across the theta (4–8 Hz), alpha (8–13 Hz), beta (13–25 Hz), and gamma (25–45 Hz) frequency bands, thus obtaining mean power for each condition, participant and frequency band.

Sensor-level cluster-based statistics were assessed, and corrected for multiple comparisons, using a Monte-Carlo nonparametric permutations approach (Maris and Oostenveld, 2007). This approach was chosen as it does not make any assumptions on the underlying distribution. Finally, 2D t-value scalp topographies marking the significant clusters were created.

Source-space projection

Localization was performed for all frequency bands. Sources were estimated using Synthetic Aperture Magnetometry (SAM, Robinson and Vrba, 1999). SAM is an adaptive non-linear minimum-variance beamformer algorithm. It calculates the signal covariance from the MEG sensor data and uses it in conjunction with a forward solution for the dipoles at each 3D brain voxel (of a specified size) to construct optimum spatial filters. The spatial filtering suppresses interference of unwanted signals from other locations.

For source estimation, the pre-ICA data were used. Data were band filtered (using the SAM default IIR filter) for each participant and condition and frequency band. Covariance matrices, and subsequently SAM weights, were computed for each 5 mm cubic voxel using the data from the two conditions participating in each signal change calculation, for each frequency-band-filtered time-series data. For each voxel, the data were multiplied by the weights, thus creating "virtual sensor" time-series, which were then transformed via FFT to the frequency domain, thus deriving power values. The next step involved calculating, for each frequency of each sensor of each participant, a power signal (SC) metric, for estimating activity differences between contrasted conditions. For normalization, SC was computed using a log ratio. More specifically, for sensor S, frequency f, and power values of conditions A and B, $SC[S(f)] = log(A/B)$. Each participant's SC values for each of the comparisons were then collapsed across all sensors, and averaged across the frequency bands specified above in the sensor-level analysis.

To facilitate group analysis, head models were constructed by co-registering each participant's SAM volume to a previously obtained MRI scan (T1-weighted anatomical images acquired with high-resolution 1-mm slice thickness, obtained by Aviva Berkovich-Ohana, by means of a 3T Trio Magnetom Siemens scanner located at the Weizmann Institute of Science, Rehovot, Israel), based on the position of the fiduciary markers established during the digitization phase. Each participant's MRI and its co-registered SAM volume were then transposed into a common Talairach anatomical space (Talairach and Tournoux, 1988). Voxel-level group statistics, for each comparison and frequency band, were conducted using one-sample t-tests against the null hypothesis that the SC measures came from a continuous, normal distribution with a zero mean, and corrected for multiple comparisons based on a Monte Carlo simulation of random noise distribution (using AFNI's 3dClustSim module) (Forman et al., 1995).

RESULTS

MEG SENSOR-LEVEL RESULTS

We first tested for significant differences in power between the "Here" and "Now" conditions, which were considered to be the baseline states for the other conditions. Importantly, there were no significant differences between them in any of the four frequency bands tested. Testing the "Spacelessness" vs. "Here" and the "Timelessness" vs. "Now" contrasts, we found clusters of significant differences only within the theta band ($p = 0.014$, and $p = 0.049$, respectively). **Figure 3** provides 2D topographic representations of the sensor-level t-values for these two significant contrasts. As could be expected, the two contrasts evidence a different topography. The significant clusters for "Spacelessness" vs. "Here" occur predominantly over bilateral central-frontal electrodes, while "Timelessness" vs. "Now" shows central and right lateralized theta activity. However, there is an overlapping region (right central), which is further explored at the source level.

MEG SOURCE LOCALIZATION ESTIMATES

To examine the neural activity underlying the conditions of "Timelessnes" and "Spacelessness," "Timelessness" was compared

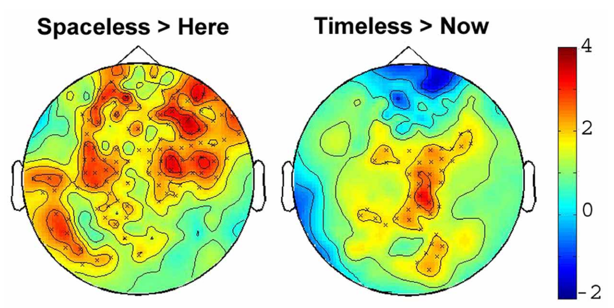

FIGURE 3 | 2D scalp maps of theta power SC contrasts. 2D topographic representations of significant sensor-level theta power (4–8 Hz) SC for the Timelessness vs. Now (**Right**), and Spacelessness vs. Here (**Left**). Crosses on the map represent significant clusters; color bar scale indicates t-values.

to "Now," and "Spacelessness" was compared to "Here." Although the sensor-level analyses guided our source localization toward the theta frequency, we validated these results by searching for an overlap between the time and space comparisons over all frequency bands. Overlapping clusters were found only within the theta band, indicating increased activity. While not being the main goal of this study, we nevertheless report the "Timelessness" and "Spacelessness" activity patterns, before focusing on their overlapping activity.

"Timelessness" vs. "Now" (**Figure 4**, **Table 2**) showed mostly right-lateralized (88%) theta activity spanning several regions, including right motor areas [postcentral gyrus and middle frontal gyrus (MFG)], parietal lobule, thalamus, basal ganglia, bilateral cerebellum, right temporal gyrus, right insula, right somatosensory and bilateral medial posterior cingulate cortices (PCC, including precuneus and cuneus). Spacelessness vs. Here showed theta activity which was bilaterally distributed (54% right hemisphere), over several regions (**Figure 4**, **Table 2**). It included bilateral PCC (with precuneus), bilateral cerebellum, bilateral parahippocampus, right basal ganglia, bilateral temporal gyrus, left thalamus, right postcentral gyrus, MFG right parietal lobule, and a small portion of the right insula. The "Timelessness" and "Spacelessness" conditions overlapped at the posterior part of the right superior temporal gyrus (STG), left cerebellum, and bilateral posterior cingulate cortex and adjacent precuneus (PCC/Prc) (**Figure 4**, **Table 3**).

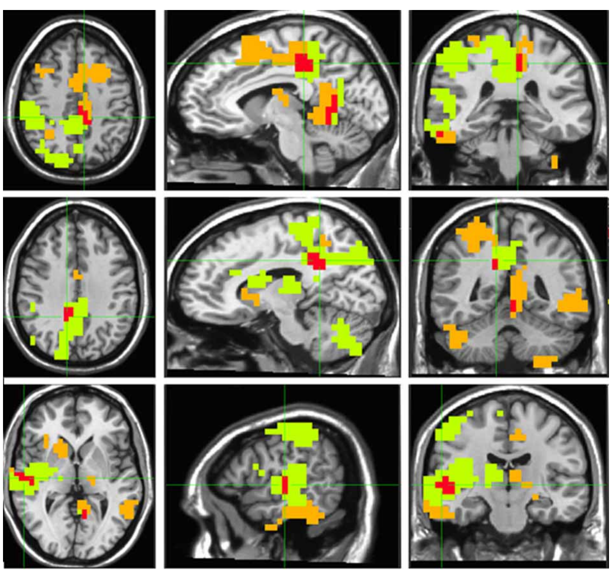

FIGURE 4 | Beamforming source estimates for the overlap between Timelessness vs. Now and Spacelessness vs. Here contrasts in the theta (4–8 Hz) frequency. Axial, sagittal and coronal views (left to right) of group (n = 11) SAM pseudo-*F* source estimates overlayed on the Colin template. Note that in all images right and left sides are crossed. Green, orange, and red indicate Timelessness, Spacelessness and overlap between conditions, respectively. **Top**: left cingulate/precuneus and culmen (clusters 2 and 4, respectively, **Table 3**); **Center**: right cingulate/precuneus (cluster 1, **Table 3**); **Bottom**: right superior temporal gyrus (cluster 3, **Table 3**).

In order to control for attention, memory or imagination processes, we contrasted, in source space, the "Then" vs. "Now" and "There" vs. "Here' conditions, and then looked for an overlap between them. As before, while focusing on the theta rhythm, we checked for overlapping regions over all frequency bands. Overlapping clusters were found mostly within the theta band, with the only exception being one alpha band cluster localized exactly (same 10 voxels) over theta cluster no. 1, on the right superior parietal lobule (**Figure 5**, **Table 3**). The two contrasts overlapped in three clusters, which included four main regions: Right posterior parietal lobule (PPL), right precentral and MFG, and bilateral precuneus (**Figure 5**, **Table 3**). Yet, there were regions which did not overlap between the two contrasts (**Table 4**). These included the right superior temporal gyrus (STG), which although activated in both contrasts, did not overlap. Additionally, only "Then" vs. "Now" activated the right insula, and only "There" vs. "Here" activated the right anterior cingulate and right lateral cerebellum.

NEUROPHENOMENOLOGICALLY-GUIDED MEG ANALYSIS

To study possible differences between the BTS and NTS groups, we derived for each participant the mean theta activity value within each of the four clusters of overlap between the "Timelessness" and "Spacelessness" conditions. On these values, we ran a Three-Way ANOVA with one grouping factor (BTS, NTS) and repeated measures on Condition (Timelessness, Spacelessness) × Cluster (R-PCC, L-PCC, R-STG, cerebellum). There was no main effect for Condition, Cluster or Group. However, we found a significant Group × Cluster interaction [$F_{(3, 27)} = 2.85$, $MSE = 0.001$, $p < 0.05$]. As can be seen in **Figure 6**, the BTS group exhibited lower R-STG and higher L-cerebellum theta activity compared to the NTS group.

While the insula showed theta activity during both "Timelessness" and "Spacelessness," the activity pattern was not overlapping. As a result, this region does not appear as an overlapping cluster. However, in order to test the hypothesis that group differences in bodily boundaries are related to insula activity, as the insula is a major interoceptive regions (Craig, 2002), we defined the insula anatomically as an ROI, and then calculated the theta activity value within the bilateral insula for the overlap between the "Timelessness" and "Spacelessness" conditions. On these values, we ran a Three-Way ANOVA on Group (BTS, NTS) × Condition (Timelessness, Spacelessness) × Hemisphere (L, R). Two outliers with very high values (above two standard deviations from the group mean) for the "Spacelessness" condition, one from each group, were excluded. We found a Condition × Hemisphere interaction [$F_{(1, 7)} = 5.52$, MSE = 0.002, $p < 0.05$], with "Spacelessness" being left-lateralized, and "Timelessness" being right-lateralized (the latter being significant [$p < 0.05$, Bonferroni-corrected, *post-hoc* *t*-test]) (**Figure 7A**). Importantly, we found a main effect for Group [$F_{(1, 7)} = 6.12$, MSE = 0.006, $p < 0.05$], with the BTS group showing lower overall insula theta activity compared to NTS (**Figures 7B,C**).

For comparison purposes, we show the mean theta activity value within each of the four clusters of overlap between the "Timelessness" and "Spacelessness" conditions for the one participant who reported an OBE (**Figure 8**). In comparison with

Table 2 | Beamforming solutions for the contrasts Timelessness vs. Now and Spacelessness vs. Here in the theta (4–8 Hz) frequency band ($n = 11$).

Overlapped conditions	Cluster (no. voxels)	TLRC coordinates (mm, RAI)			Hemisphere overlap		Regions included in cluster (atlas TT_Daemon)	
		x	*Y*	*z*	L (%)	R (%)	Name	Voxels
Timelessness vs. Now	1 (529)	−47.5	37.5	47.5	18	72	Precuneus	104
							Cingulate gyrus	63
							R. Postcentral gyrus	60
							R. Inferior parietal lobule	41
							R. Precentral gyrus	40
							Paracentral lobule	35
							R. Middle frontal gyrus	19
							Culmen	19
							Cuneus	15
							R. Superior parietal lobule	13
							Uvula	12
	2 (253)	−67.5	22.5	−7.5	0	97	R. Superior temporal gyrus	63
							R. Insula	61
							R. Middle temporal gyrus	38
							R. Thalamus	23
							R. Lentiform nucleus	12
							R. Transverse temporal gyrus	8
							R. Claustrum	6
	3 (22)	−17.5	−7.5	17.5	0	96.7	R. Caudate	9
							R. Anterior cingulate	4
Spacelessness vs. Here	1 (204)	17.5	−12.5	47.5	89	7	Superior frontal gyrus	45
							Medial frontal gyrus	42
							Cingulate gyrus	40
							Middle frontal gyrus	24
							Paracentral lobule	18
							Precuneus	3
	2 (149)	−37.5	−12.5	−22.5	0	99	R. Inferior frontal gyrus	24
							R. Superior temporal gyrus	23
							R. Uncus	19
							R. Lentiform nucleus	15
							R. Parahippocampal gyrus	13
							R. Subcollosal gyrus	4
							R. Caudate	3
							R. Insula	3
	3 (73)	−67.5	22.5	−12.5	0	97	R. Inferior temporal gyrus	21
							R. Fusiform gyrus	12
							R. Culmen	9
							R. Cerebellar tonsil	6
							R. Middle temporal gyrus	3

(Continued)

Table 2 | Continued

Overlapped conditions	Cluster (no. voxels)	TLRC coordinates (mm, RAI)			Hemisphere overlap		Regions included in cluster (atlas TT_Daemon)	
		x	*Y*	*z*	L (%)	R (%)	Name	Voxels
	4 (72)	−37.5	37.5	57.5	0	89	R. Postcentral gyrus	17
							R. Inferior parietal lobule	14
							R. Superior parietal lobule	11
							R. Precuneus	10
	5 (52)	2.5	42.5	−2.5	94	0	L. Posterior cingulate	24
							L. Culmen	13
							L. Cerebellar lingual	3
	6 (44)	52.5	47.5	−2.5	100	0	L. Middle temporal gyrus	28
							L. Inferior temporal gyrus	3
	7 (33)	32.5	42.5	−42.5	100	0	L. Cerebellar tonsil	5
	8 (33)	−42.5	−12.5	47.5	0	78	R. Middle frontal gyrus	22
							R. Superior frontal gyrus	8
	9 (22)	2.5	12.5	17.5	98	2	L. Thalamus	10
							L. Parahippocampal gyrus	3
	10 (15)	−67.5	7.5	2.5	0	88	R. Superior temporal gyrus	13
	11 (13)	−12.5	37.5	32.5	0	100	R. Cingulate gyrus	11

Information supplied includes number of voxels in each cluster, center of cluster characteristics, hemispheric overlap, brain regions, and number of voxels in the region. Only clusters >2 voxels are presented. The Afni-supplied TT Daemon atlas was used. Due to poor resolution and signal leakage to non-brain regions, overlap percentages do not always add up to 100%.

the BTS and NTS groups, the OBE participant exhibited much lower bilateral PCC and left cerebellar values. Right MTG and total insula values were slightly higher than the NTS group.

DISCUSSION

MEG SENSOR-LEVEL RESULTS

Significant differences in power between the "Spacelessness" vs. "Here" as well as the "Timelessness" vs. "Now" contrasts were found only within the theta frequency. Both contrasts showed maximal theta power over the right hemisphere. This result is in line with accumulating evidence from animal and human studies, showing that theta activity is tightly related to space and time processing, i.e., encoding and retrieval (recently reviewed by Hasselmo and Stern, 2013). This is also in agreement with the notion that there is a right-hemisphere specialization for space and time processing (Rao et al., 2001; Ellison et al., 2004; Oliveri et al., 2009a,b; reviewed by Walsh, 2003).

The production of theta with eyes closed is a well-known accompaniment of states of deep relaxation such as stage 1 sleep, meditation and hypnosis (Vaitl et al., 2005). Gruzelier (2009) reviews EEG-neurofeedback (NF) training studies for increasing theta activity, showing wide behavioral effects, including increased creativity, heightening psychological integration, relief from anxiety and depression and resolved post traumatic stress syndrome. Phenomenologically, participants in this EEG-NF protocol reported increased theta "to be associated with a deeply internalized state and with a quieting of the body, emotions, and thought" (Gruzelier, 2009, p. 102). Based on the findings that theta oscillations play a critical role in the coupling and integration of widely distributed neural circuits (Von Stein and Sarnthein, 2000), as well as the EEG-NF results, Gruzelier (2009) proposed that the wide ranging behavioral correlates of theta result from theta's role in mediating distributed circuitry in the brain, relating the concepts of psychological integration (integrative experiences leading to feelings of psychological well-being) and neural integration.

The "Timelessness" and "Spacelessness" conditions represent alterations in the sense of time and space, akin to those reported in various meditative practices, and can be compared to previously reported theta topography in studies of meditative states. The increased frontal-central theta power (**Figure 3**) is in accord with ample meditation studies, reporting increased theta activity, mostly over frontal-central sites (Hebert and Lehmann, 1977; Aftanas and Golocheikine, 2001; Kubota et al., 2001; Faber et al., 2004; Cahn and Polich, 2006; Slagter et al., 2009; Baijal and Srinivasan, 2010). Increased theta in meditation studies has been interpreted as reflecting internalized attention (Cahn and Polich, 2006), space and time processing (Baijal and Srinivasan, 2010), as well as being related, especially when manifesting as theta bursts, to deep meditative states, feelings of blissfulness and low

Table 3 | Beamforming solutions for the overlapping contrasts between Timelessness/Spacelessness and Then/There in the theta (4–8 Hz) frequency band ($n = 11$).

Overlapped conditions	Cluster (no. voxels)	TLRC coordinates (mm, RAI)			Hemisphere overlap		Regions included in cluster (atlas TT_Daemon)	
		x	*Y*	*z*	L (%)	R (%)	Name	Voxels
Timelessness vs. Now and Spacelessness vs. Here	1 (13)	−10.2	41.7	31.3	0	100	R. Cingulate gyrus	11
							R. Precuneus	1
							R. Posterior cingulate	1
	2 (13)	7.1	31.3	42.1	100	0	L. Cingulate gyrus	7
							L. Paracentral lobule	3
							L. Precuneus	1
	3 (11)	−54.3	16.1	3.0	0	100	R. Superior temporal gyrus	11
	4 (9)	5.8	51.9	0.3	100	0	L. Culmen	6
							l. Posterior cingulate	1
							L. Lingual gyrus	1
Then vs. Now and There vs. Here	1 (30)	−33.3	57.3	47.2	0	94	R. Superior parietal lobule	10
							R. Inferior parietal lobule	8
							R. Precuneus	5
	2 (14)	−43.9	7.5	49.6	0	86	R. Precentral gyrus	12
							R. Middle frontal gyrus	2
	3 (7)	7.5	42.5	56.1	100	0	L. Paracentral lobule	4
							L. Precuneus	2

Information supplied includes number of voxels in each overlapping cluster, center of cluster characteristics, hemispheric overlap, brain regions, and number of voxels in the region. Only clusters >1 voxels are presented. The Afni-supplied TT Daemon atlas was used. Due to poor resolution and signal leakage to non-brain regions, overlap percentages do not always add up to 100%.

thought content, and a sense of integration (Kasamatsu and Hirai, 1966; Hebert and Lehmann, 1977; Aftanas and Golocheikine, 2001).

The results are also in agreement with the junction-point-model hypothesis proposed by Travis (1994). Briefly, Travis proposes that bursts in the 7–9 Hz band underlie the state of transcendental consciousness (Travis, 1994), which is "the least excited state of mental activity," unbounded by a sense of time and space (Alexander et al., 1987). Travis suggests that transcendental consciousness underlies other forms of consciousness, and can be seen especially during transitions between different states of consciousness. He then provides support for his hypothesis by showing increased 7–9 Hz activity during the transition between waking, NREM-sleep, and REM-dreaming. Similar theta activity has also been reported during Transcendental Meditation (TM); and in TM practitioners, it also unusually accompanies sleep, a state called witnessing sleep (Travis, 1994). This state differs from lucid dreaming by increased "separateness" and reduced dream control (Alexander, 1988). The junction-point model ties all these states as windows to an underlying field of transcendental consciousness, related to alterations in the sense of time and space, and a sense of boundlessness.

Taken together, the literature on theta in neurofeedback and meditation suggests that this is the optimal bandwidth for integration and synthesis across neural regions. As Hunt (2007, p. 226) argues, "widespread EEG theta would appear to be the level of activation which affords a maximized coherence across the widest possible neural areas. . . ." This interpretation aptly fits the phenomenology of the "Timelessness" and "Spacelessness" states, which include many descriptions of integration (**Table 1**): "The purest form of the sensation was there, but un-restricted. There was relaxation and widening" and "There was a sense of open space without the bodily dimension" (participant no. 11); "It was a sense of spaciousness, boundlessness. . . there was no clarity where the center is and where is the periphery. There was no quality of border" (participant no. 12); "There was relaxation and letting-go, emptiness, experience of bliss, quiet, wide" and "The metaphor is an amoeba, everything spreads. A sense of nothingness, emptiness. A sense of expansion" (participant no. 5); "I lost discrimination between different body parts. It felt pleasant, like a huge hammock. A sense of expansion" (participant no. 14); "The center of space became endless, without a reference point in the middle. There was a sense of floating in a sea of being... Everything was a part of one conscious experience. The dichotomy between subject and object dissolved. . . Everything

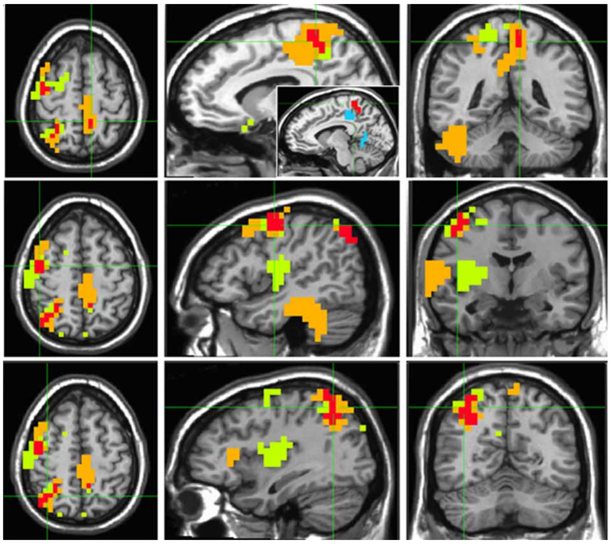

FIGURE 5 | Beamforming source estimates for the overlap between Then vs. Now and There vs. Here contrasts in the theta (4–8 Hz) frequency. Axial, sagittal, and coronal views (left to right) of group ($n = 11$) SAM pseudo-F source estimates overlayed on the Colin template. Note that in all images right and left sides are crossed. Green, orange and red indicate Then, There and overlap between conditions, respectively. **Top**: left paracentral lobule and precuneus (cluster 3, **Table 3**). In the sagittal view, the same cluster (red) is compared with left cingulate/precuneus activity (cyan) for the Timelesness/Spacelessness overlap (cluster 2, **Table 3**). Note the clear separation between the superior cluster found in the Then/There overlap, and the inferior cluster found for the Timelesness/Spacelessness overlap; **Center**: right precentral and middle frontal gyrus (cluster 2, **Table 3**); **Bottom**: posterior parietal lobule (cluster 1, **Table 3**).

was a part of a singular event. The experience of the body faded" (participant no. 4). Indeed, Faber et al. (2012) discuss the question, "Why are there so few systematic reports on subjective experience during meditation," and emphasize that "it could be very useful in sorting out brain states of different cogitations" (p. 262). In this study, we have shown how such reports can be utilized in a productive way, both to aid in interpreting brain activity during these unique states, but also to learn more about these states, from the systematic self observations of our meditators. One does not have to rely on the ingestion of a hallucinogen such as *ayahuasca*, to uncover what Bresnick and Levin (2006) term "profound alterations of temporal-spatial experiences including expansive space and slowed time." These experiences can be found in long-term meditators. Whether the meditators in this study are more aware of what Travis (1994) terms "an underlying, undifferentiated field," wherein presumably there is an alteration in the experience of both space and time, is a metaphysical issue—and not one that we can resolve using the present experimental protocol. Nevertheless, as Hunt (2007, p. 226) has suggested, "advanced meditation involves an attunement to a background field of consciousness, whose increased meditative access seems to be correlated with an unusually coherent EEG in the theta bandwidth." What might be considered to be the *psychedelic* effects invoked by systematically observing (or, becoming sensitized to) one's experience of both space and time—sometimes resulting in spacelessness and/or timelessness—might, in turn, be actually the externalization of this background field of consciousness (Hunt and Chefurka, 1976). We cannot make a conclusive case here for this; we can, however, provide a portal for future research, building on the protocol explored here.

MEG SOURCE LOCALIZATION ESTIMATES

"Then" and "There" (control) conditions, and their overlap

The "Then" vs. "Now" and "There" vs. "Here" contrasts served as control conditions for ruling out autobiographic memory and imagination processes, respectively, as well as attentional processes, which might have taken place during the "Timelessness" and "Spacelessness" target conditions. In both contrasts, only increased theta activity was detected, mostly right-lateralized (**Tables 3**, **4**). Within the context of the hypothesis that time can be represented along a left-to-right oriented mental time-line, and based on psychophysical and neuroimaging studies, it has been suggested that the right hemisphere entails the representation of the past and the left hemisphere the representation of the future (Szpunar et al., 2007; Oliveri et al., 2009a). The right hemisphere dominance in the "Then" vs. "Now" contrast is in line with this, as participants were recalling past events.

The two contrasts overlapped in three clusters, which included four main regions: Right PPL, right precentral and MFG, and bilateral precuneus (**Figure 5**, **Table 3**). These results are in line with fMRI studies of mental traveling to the past, reporting bilateral PPL activation (Arzy et al., 2009) and left precuneus and MFG activation (Szpunar et al., 2007). Moreover, the results support our hypothesis of episodic memory network activation in the control conditions, as the right PPL and MPG were shown to be involved in episodic memory performance (Rajah et al., 2011). Similarly, the precuneus is a region involved with autobiographic memory (Cabeza and Nyberg, 2000; Rugg et al., 2003), as well as mental imagery (Lundstrom et al., 2003). Altogether, the overlapping pattern of the "Then" vs. "Now" and "There" vs. "Here" conditions reveals a largely right-lateralized network specialized in episodic memory, as well as mental imagery of one's body.

Alteration in the experience of time

The "Timelessness" vs. "Now" (**Figure 4**, **Table 2**) contrast revealed theta activity in a right-lateralized network of parietal, temporal and insular cortical regions, as well as the basal ganglia, thalamus and cerebellum. Specifically, these regions included the motor areas (postcentral gyrus) spreading into supplementary motor area—SMA (MFG), parietal lobule, thalamus, and basal ganglia. This is consistent with previous prospective timing studies suggesting that fronto-striatal circuits consisting of recurrent loops between SMA, basal ganglia and thalamus are critical for the processing of duration (Coull and Nobre, 1998; Ferrandez et al., 2003; Coull, 2004; Wittmann, 2009), as well as with neuroimaging of temporal task performance documenting recruitment of the right posterior parietal cortex (Coull and Nobre, 1998; Walsh, 2003; Oliveri et al., 2009a). Theta activity was also found in the bilateral cerebellum, in accord with TMS (Tomlinson et al., 2013) and PET (Coull and Nobre, 1998) studies showing a cerebellar role in time perception and representation (Salman, 2002), as well as over the right temporal gyrus, a region shown previously

Table 4 | Beamforming solutions for contrasts Then vs. Now and There vs. Here in the theta (4–8 Hz) frequency band.

Overlapped conditions	Cluster (no. voxels)	TLRC coordinates (mm, RAI)			Hemisphere overlap		Regions included in cluster (atlas TT_Daemon)	
		x	y	z	L (%)	R (%)	Name	Voxels
Then vs. Now	1 (87)	−27.5	52.5	57.5	0	93	R. Superior parietal lobule	22
							R. Postcentral gyrus	13
							R. Inferior parietal lobule	7
	2 (78)	−42.5	7.5	52.5	0	70	R. Precentral gyrus	26
							R. Postcentral gyrus	26
							R. Middle frontal gyrus	11
	3 (66)	−32.5	17.5	17.5	0	100	R. Insula	34
							R. Lentiform nucleus	11
	4 (53)	−12.5	67.5	32.5	1	92	R. Precuneus	36
							R. Cuneus	14
	5 (15)	7.5	42.5	62.5	94	0	L. Precuneus	6
							L. Paracentral lobule	4
	6 (14)	−67.5	32.5	7.5	0	55	R. Superior temporal gyrus	10
							R. Middle temporal gyrus	2
There vs. Here	1 (201)	−62.5	7.5	12.5	0	90	R. Middle temporal gyrus	36
							R. Superior temporal gyrus	27
							R. Inferior temporal gyrus	20
							R. Fusiform gyrus	18
							R. Culmen	16
							R. Postcentral gyrus	9
							R. Cerebellar tonsil	6
							R. Precentral gyrus	5
							R. Parahippocampal gyrus	3
	2 (129)	2.5	47.5	57.5	74	23	Cingulate gyrus	39
							Paracentral lobule	34
							Precuneus	29
							Postcentral gyrus	7
							Medial frontal gyrus	5
	3 (66)	−32.5	42.5	57.5	0	92	R. Superior parietal lobule	21
							R. Precuneus	14
							R. Inferior parietal lobule	11
	4 (38)	−37.5	12.5	52.5	0	74	R. Precentral gyrus	21
							R. Middle frontal gyrus	15
	5 (36)	−12.5	−32.5	7.5	0	100	R. Anterior cingulate	20
							R. Caudate	8

Information supplied includes number of voxels in each cluster, center of cluster characteristics, hemispheric overlap, brain regions, and number of voxels in the region. Only clusters >2 voxels are presented. The Afni-supplied TT Daemon atlas was used. Due to poor resolution and signal leakage to non-brain regions, overlap percentages do not always add up to 100%.

to be involved in time production in lesion (Noulhiane et al., 2007) and TMS (Bueti et al., 2008) studies. Finally, theta activity was seen in the right insula, right somatosensory and bilateral medial posterior cingulate cortices, a network involved in somatic information processing. The interoceptive insula has been previously suggested to be responsible for the perception of duration (Craig, 2009a,b; Wittmann, 2009; Wittmann et al., 2010). Indeed, an fMRI study of MM practitioners showed that attending to

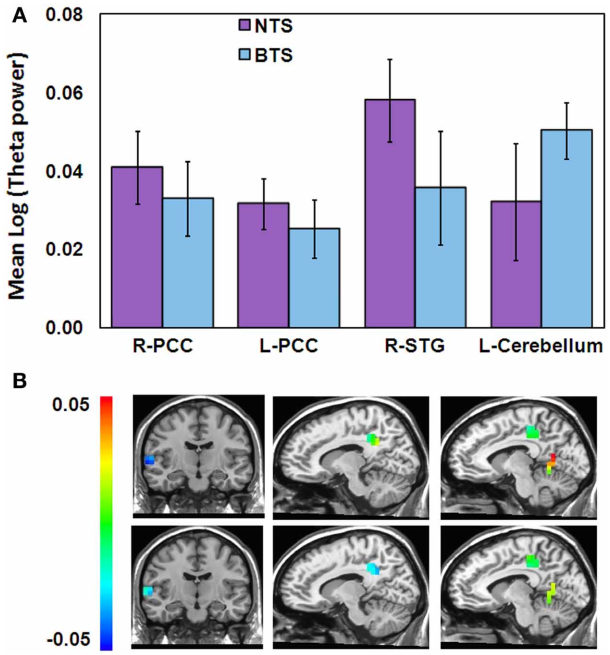

FIGURE 6 | Differences in theta activity between the BTS ($n = 5$) and NTS ($n = 6$) groups over 4 overlapping ROIs. (A) Group × Cluster interaction. BTS, both time and space; NTS, Not both Time and Space; **(B)** Spacelessness (top) and Timelessness (bottom) group theta differences within the 4 clusters, calculated as BTS minus NTS. Color scale denotes log(theta power) values. Left column—right superior temporal gyrus (STG); Middle column—right posterior cingulated cortex (PCC); Right column—left PCC and cerebellum clusters.

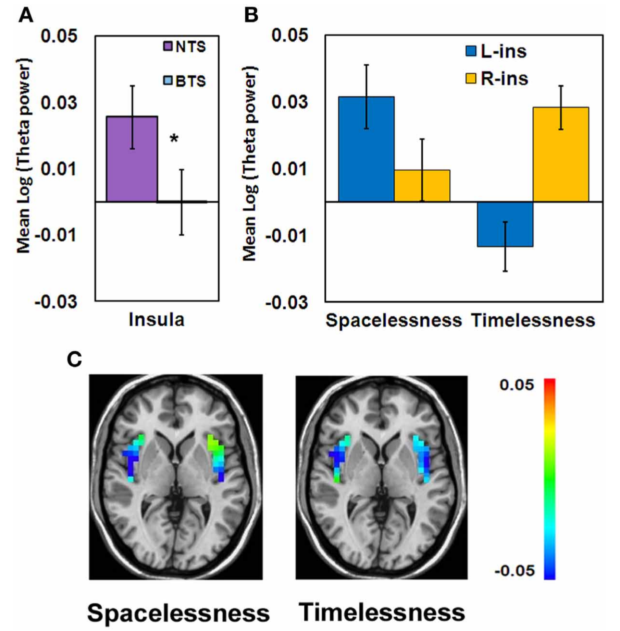

FIGURE 7 | Theta activity differences between the BTS ($n = 4$) and NTS ($n = 5$) groups over insula. (A) Group main effect. $*p < 0.05$. BTS, both time and space; NTS, Not both Time and Space. **(B)** Condition × Hemisphere interaction. R, right; L, left. **(C)** Group differences in theta activity, calculated as BTS minus NTS. Color scale denotes log(theta power) values.

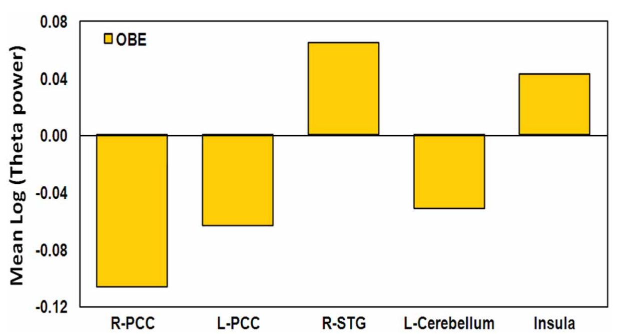

FIGURE 8 | OBE participant activity in the ROIs. Mean log theta power during the Timelessness and Spacelessness conditions, in the selected ROIs.

the present moment was accompanied by activation in the right insula as well as the somatosensory cortex (Farb et al., 2007).

Altogether, the regions recruited during the "Timelessness" condition were previously related to either momentary processing of time, or interoception. This is in accord with our hypothesis that alteration in the expereince of time is related to an altered sense of body.

Alteration in the experience of space

"Spacelessness" vs. "Here" showed theta activity which was largely bilaterally distributed, over several regions (**Figure 4**, **Table 2**). Activated regions included bilateral cerebellum—known to regulate balance via processing of vestibular information (Timmann et al., 2010); bilateral parahippocampus, known to subserve spatial computation and learning (Aguirre et al., 1996); and right basal ganglia, sensitive to spatially-related behavioral conditions (Lavoie and Mizumori, 1994). Additionally, bilateral temporal gyrus, left thalamus, right postcentral gyrus, MFG, bilateral frontal cortices and right parietal lobule (IPL) were activated, all related to space processing (Halligan et al., 2003; Hagler and Sereno, 2006; Silver and Kastner, 2009). Additionally, the bilateral PCC and a small portion of the right insula, both related to interoception (Damasio and Meyer, 2009), were activated. Moreover, the PCC is involved in processing vestibular information (Wiest et al., 2004) supporting its major role in navigation of the body in space (Vogeley et al., 2004; Vogt and Laureys, 2005).

Altogether, the regions showing theta activity during the "Spacelessness" condition were previously related with some form of spatial processing (summarized by Iacoboni et al., 1997), or with interoceptive processing. This, again, is in line with our hypothesis that the alteration in the experience of space is related to an altered sense of body.

Shared alterations in the experience of time, space, and body

The "Timelessness" and "Spacelessness" conditions overlapped in four clusters (**Figure 4**, **Table 3**): bilateral cingulate cortex/precuneus (PCC/Prc), right temporoparietal junction (TPJ) and left cerebellum. In line with our hypothesis, this pattern of theta activity was different from the overlap pattern between the control conditions of "There" and "Then," which showed activity in regions related to mental imagery and episodic memory. We argue that this overlap pattern is predominantly related to alterations in the experience of the body. Subsequently, we provide support for this argument, relating the overlapping regions with bodily processing.

The PCC/Prc plays a central role in consciousness (Cavanna and Trimble, 2006) as these regions differentiate patients in minimally conscious states from those in vegetative states (Laureys, 2005; Vogt and Laureys, 2005; Vanhaudenhuyse et al., 2010), and are deactivated during REM sleep, when participants experience vivid dreams (Alkire et al., 2008). In addition, these are key regions for bodily representation (Damasio, 1998, 1999; Damasio and Meyer, 2009) and vestibular processing (Wiest et al., 2004). Importantly, the PCC/Prc overlap for the "Timelessness" and "Spacelessness" conditions clearly differs from the left precuneus cluster found in the "There" and "Then" overlap (see relative activity in **Figure 5**), by being relatively inferior, anatomically. A recent fMRI study of emotional processing (Immordino-Yang et al., 2009) proposes a different role for inferior and superior parietal medial cortex, suggesting the first to be related to interoceptive processing, and the second to musculoskeletal processing. Consistent with that emotional processing study, our data suggest a functional subdivision in the parietal medial cortex regarding spatio-temporal processing. While the "There" and "Then" conditions overlapped in a more superior position, strongly related anatomically with the lateral parietal cortex (Parvizi et al., 2006), which is activated in episodic memory and imagination, the "Timelessness" and "Spacelessness" conditions overlapped at an inferior position, strongly related with interoception (Damasio and Meyer, 2009).

The caudate part of the STG is encompassed within the temporo-parietal junction (TPJ). The TPJ is a multimodal association cortex, integrating thalamic, visual, auditory, somatic, and limbic areas (Decety and Lamm, 2007). It is also a key region for multisensory body-related self-processing, related to a first-person perspective; damage to this area can produce a variety of disorders associated with bodily awareness (Blanke and Arzy, 2005). Recent findings emphasize the role of the right TPJ in abnormal vestibular processing, as during OBEs (Blanke et al., 2004), and Near-Death Experience (NDE) characterized by an altered sense of time, and sensations of lightness and void (Blanke and Dieguez, 2009).

The observed cerebellar activity is within the midline culmen. This area is the vestibulo-cerebellum (Barmack, 2003). Several studies point to the role of the cerebellum in altered sense of body. In a PET study where OBEs were repeatedly elicited during stimulation of the right TPJ in a patient in whom electrodes had been implanted to suppress tinnitus (De Ridder et al., 2007), a strikingly similar pattern of activity to our overlapping pattern was found. Activity during OBE was seen at the right TPJ, right precuneus and superior vermis of the cerebellum. In another single-subject study (Schutter et al., 2006), the participant reported that after cerebellum rTMS, but not after sham and occipital stimulations, she experienced her body falling/drifting sidewards and even out of the chair.

To summarize, we show that an altered experience of time and space involves theta activity in regions related to a sense of the body. These findings support the phenomenologically reported spaciousness, a sense of alteration in the regular bodily boundaries. The type of altered sense of body found in this study include states where the sense of self becomes diffused and "spills out" of the body boundaries (participants no. 1, 2, 4, and 5), or simply disappears (participants no. 12, 13, and 14), and not just cases where the self simply changes its location, as in an OBE (participant no. 8).

Neurophenomenologically-guided analyses

The participants were split into two groups based on the phenomenology of their reported experience of time and space. Interestingly, the both-time-and-space (BTS) group showed lower right TPJ and insula theta activity, accompanied by higher cerebellar theta activity, compared to the not-both-time-and-space (NTS) group. As all these regions are related to bodily processing and body schema, this shows that the BTS group activates regions involved in bodily processing differently than the NTS group. This might lead to their heightened alteration in sense of bodily boundaries, which is in turn related to their heightened alterations in the experience of time and space.

In comparison, the OBE participant manifested a markedly different pattern of theta activity compared to both the NTS and BTS groups (**Figure 8**). This might explain the preserved sense of body (though perceived as floating in space), "I was with my body, just floating in outer space. The body was identical, I wasn't floating as consciousness, but as a body" (**Table 1**). Here we see a different form of an altered sense of body—without loss of boundaries (not along the body—boundary continuum). This was expressed in this participant's very different bilateral PCC theta power values, which evidenced a reduction in theta activation, rather than an increase (as with the other participants). These distinctions highlight the utility of phenomenology in guiding neuroscientific analyses.

Summary of the MEG source localization estimates

The results obtained from the MEG source localization estimates provide evidence that alterations in the sense of time and space: (1) do not rely on memory and mental imagery; and (2) are related to an altered sense of body.

In relation to the sensor level results (section MEG Sensor-Level Results) pointing to the critical role of the theta band in such experiences, we suggest that theta activity in cortical regions related to bodily processing results in experiences of an altered sense of the body, of time and of space, where the different sensory modalities integrate, and sensorial boundaries decrease. The neurophenomenologically-guided analyses (section Neurophenomenologically-Guided Analyses) provide further evidence that different phenomenological experiences result in significantly different levels of theta activity within these cortical regions, which are related to bodily processing.

LIMITATIONS OF THE STUDY

This study has a number of limitations that should be taken into consideration. First, sample size was rather small after exclusion of five of the participants. The 11 remaining participants were further divided into two sub-groups, resulting in very small group sizes. Second, the study design was fixed, as opposed to counterbalanced, between the Time and Space sessions. The verbal ratings of success of the participants were lower for "Timelessness" compared to "Spacelessness." This might be due to the study design, as the two conditions were studied in that order, which makes it impossible to dissociate perceived task difficulty from increasing depth of state due to the previous session, or due to increasing acquaintance with the experimental setup. Thus, all results reported here should be considered preliminary, and warrant replication.

CONCLUSIONS

This study illustrates the utility of employing experienced contemplative practitioners within a neurophenomenological setup for scientifically characterizing self-induced altered spatio-temporal experiences. The results reported here support our hypotheses that an altered experience of time and space is related to an altered sense of body, by showing that: (1) "Timelessness" and "Spacelessness" conditions overlap in a neural network related to alterations in bodily processing. This was shown to be distinct from mere memory and imagination processes; and (2) phenomenologically-guided neural analyses yielded further insight, by enabling us to dissociate different levels of an altered sense of the body. Additionally, our results underscored the specificity of theta activity, and emphasize theta's unique role in altered experience of time, space and the body. Taken together, the results reported here support previous suggestions of the psychological integrative role of the theta band (Hunt, 2007; Gruzelier, 2009), and provide further understanding of deep meditative states, reported frequently to invoke enhanced theta activity.

AUTHOR CONTRIBUTION

Joseph Glicksohn, Aviva Berkovich-Ohana, and Abraham Goldstein sponsored the study; Abraham Goldstein provided research facilities; Aviva Berkovich-Ohana and Joseph Glicksohn designed, while Yair Dor-Ziderman and Aviva Berkovich-Ohana ran the experiment; Yair Dor-Ziderman analyzed MEG data; Aviva Berkovich-Ohana analyzed phenomenological data and Aviva Berkovich-Ohana, Joseph Glicksohn, and Yair Dor-Ziderman wrote the paper.

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A scientific approach to silent consciousness

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INTRODUCTION

All mammals show the physiological correlates of waking, dreaming and deep sleep. Many contemplative traditions propose a fourth state of consciousness, "silent consciousness," defined as consciousness without reportable contents. For example, the *Mandukya Upanishad*, one of the root texts of Vedanta philosophy, explicitly claims a fourth state of "consciousness without content." (Sharma, 1997) The classical summary of yogic thought, Patanjali's *Yoga Sutras*, recommends "Let there be soundless repetition of (the inner mantra) OM and meditation thereon." (Feuerstein, 1989). The classical texts of Zen Buddhism also cite consciousness without reportable contents many times (Reps and Senzaki, 1998; Hori, 2000). About a fifth of the world population is Hindu or Buddhist.

"Silent consciousness" may sound paradoxical to Western ears, but such reports are widespread in Asian, Western, Middle Eastern, and shamanic traditions. While contemplative practices are very diverse, "inner silence" is often taken to be a goal.

One common rationale is that silent consciousness exists continuously in the background of the three standard states, and that contemplative practices aim to make that background more easily accessible to the practitioner. Thus, various practice aim to "uncover" what already exists in the mind.

The resulting access to silent consciousness is often interpreted in ontological terms as a direct knowledge of metaphysical reality. However, such claims are not considered in this article, which is focused on empirical evidence.

Benson (1984) reported such experiences in naive subjects who mentally repeated an arbitrary mantra, the word "one." Follow-up studies show a host of non-voluntary physiological effects, including changes in stress-related gene expression, alteration in O2/CO2 exchange, and changes in energy metabolism, insulin secretion and inflammatory pathways (Dusek et al., 2008; Bhasin et al., 2013).

These findings support Benson's proposal that mantra meditation evokes a neurohormonal "relaxation response," able to counteract the HPA stress reaction homeostatically.

The exact relationship between silent consciousness and the relaxation response is not known. An empirical probe for silent consciousness is therefore described below.

REDUNDANCY: FADING OF REPEATED SIGHTS, WORDS, AND ACTIONS

Contemplative practices use high numbers of repetitions: An inner syllable, a vocalized chant, a repeated breathing technique, a precise body posture, a highly practiced skill like archery, a hand gesture, a whirling dance, or a martial arts movement. Advanced practitioners spend thousands of hours in repeated actions. Nevertheless, reports of boredom are rare.

Conventional science has also studied the effects of high redundancy. Gestalt psychologists explored both the ganzfeld (a featureless visual field, like a dense, bright mist) and semantic satiation (the fading of meaning after word repetition). Both are repetition effects, and require no special apparatus. They are therefore a plausible part of ancient human practices.

The ganzfeld is defined as any visual field that lacks spatial or temporal contrast. Many neurons in the visual system are contrast-sensitive, and these cells may drop down to baseline rates of firing. Visual brightness and hue therefore tend to disappear during ganzfeld "blank-outs," while consciousness continues (Gur, 1991).

Here are some ganzfeld examples from a Kashmiri tradition called "*112 Centering Practices*." (Reps and Senzaki, 1998).

1. In summer when you see the entire sky endlessly clear, *enter such clarity*.
2. Simply by looking into the blue sky beyond clouds, *the serenity*.

Because an unclouded sky has no spatial or temporal contrast these could be regarded as ganzfeld conditions.

Word repetition has similar effects. Children often discover that repeating a word causes its meaning to fade. Word repetition is a near-universal practice in contemplative traditions. When subjects passively perceive repeated words, they quickly perceive word transformations (Warren, 1968). Semantic satiation (fading of meaning) tends to be noticed when subjects actively repeat words.

In vision, stabilized retinal images also fade as a function of redundancy (Rucci et al., 2007).

AUTOMATICITY OF OVERPRACTICED ACTIONS

Mantra repetition has both sensory and motor components, and highly practiced sensorimotor tasks quickly become automatic and minimally conscious. fMRI studies of automatic skills show that BOLD hot spots fade from cortex after practice (Schneider et al., 1994). Nevertheless, these tasks continue to be performed with minimal conscious involvement. Thus, the neural activities supporting the action continue after subjective fading. Since synaptic efficiency has increased with learning, networks for the skill can operate with less energy. BOLD activity therefore fades along with subjective information about the overpracticed skill.

When an automatic task is changed, cortical fMRI reappears, and task details become more consciously available. Thus, renewing a mantra after fading may reinstate conscious access for some time.

In sum, repetition may fade redundant elements from consciousness.

NEAR-THRESHOLD ATTENDING

Some practices focus on barely perceivable events. Some examples from Reps and Senzaki (1998):

1. (Look at) at any point in space or on a wall—until the point *dissolves*.
2. Stop the doors of senses when feeling the creeping of an ant. *Then*.
3. Or, as breath comes in, feel the sound *hh*.
4. Intone a sound audibly, then less and less audibly as feeling deepens into this silent *harmony*.

Near-threshold attending may help subjects become more attuned to silent consciousness.

FEELINGS OF KNOWING AND SURPRISE

William James wrote the classic description of a "fringe" feeling of knowing (FOK), the tip-of–the-tongue state.

"Suppose we try to recall a forgotten name. The state of our consciousness is peculiar. ...It is a gap that is intensely active. A sort of a wraith of the name is in it, beckoning us in a given direction, making us at moments tingle with the sense of our closeness, and then letting us sink back without the longed-for term. If wrong names are proposed to us, this singularly definite gap acts immediately so as to negate them. They do not fit into its mold." (James, 1890).

Feeling of knowing are very common (Mangan, 1993). Active FOK's like the tip-of-the–tongue state evoke fMRI activity in the prefrontal cortex (Maril et al., 2001).

Baars (1988) provides an extended discussion, concluding that

1. The tip-of-the-tongue (TOT) state involves a complex representation of the expected word.
2. It occupies central limited capacity, since the state is disrupted by incompatible conscious contents.
3. Yet the TOT lacks experiential qualities like color, warmth, flavor, location, texture, intensity, etc. More broadly, feelings of knowing lack figure-ground contrast, internal structure, and clear temporal boundaries.

And yet, as James (1890) emphasized, such feelings of knowing pervade our lives.

FOKs AND SURPRISE

FOK's may become more consciously available when they are mismatched by unexpected input. If we mentally search for the word "brontosaurus" and hear "pterodactyl" instead, we quickly recognize a mismatch, even before the correct word comes to mind. Likewise, if we see a blank space for an expected_________, we can often fill in the expected content in some detail. Surprising events often seem to draw attention to our own expectations. Zen Buddhism uses surprise as a mind-changing practice.

Here is a typical report from a Zen Buddhist magazine:

> "A long, thin, flat hardwood stick, the kyosaku was marched up and down the aisles .... If anyone fell asleep during zazen (as happened more than occasionally) the monitor would pounce. Whack!... whack! One good hit on each shoulder and the wary offender was awake." (Fischer, 1998).

Sudden shocking events can induce a sense of dissociation, a drastic change in one's normal feelings of knowing. The sudden physical blow also violates one's personal space, with consequent feelings of confusion, shock, disorientation, impulsive urges to hit back, and tensing for another shock.

Zen koans also challenge expectations. A famous example is the koan "What is your original face before your mother and father were born?" Students are told to ponder such questions over and over again. Setttled answers are discouraged. Zen koans are not supposed to be resolved; the sense of paradox is itself an object of contemplation.

A somewhat different view is that long contemplation on koans is designed to interfere with the flow of ordinary conscious contents—inner speech, sensory perception, imagery and the like—so that the silent background of consciousness becomes more accessible.

For example,

A student asked Master Yun-Men (A.D. 949)

"Not even a thought has arisen (in consciousness); is there still a fault or not?"

Master replied, "*Mount Sumeru!*"

"Buddha preached for forty-nine years, but his tongue never moved," the master Gensha said.

A monk asked Ummon, "What is the kind of talk that transcends Buddhas and Patriarchs?"

Ummon replied: "*Rice cake!*"

Notice that Zen masters do not give answers but perform interventions, constantly mismatching the student's expectations. According to Hori (2000) "*koans* are also understood as pointers to an unmediated "pure consciousness," devoid of cognitive activity."

GAP MATCHING AS A PROBE FOR SILENT CONSCIOUSNESS

In novices, silent moments are said to be experienced separately from the normal flow of conscious contents, like a gap in the flow of conscious sensations, images, feelings and inner speech. Silent moments might therefore be tested experimentally with a gap-detection task.

Endogenous silences may inhibit external sounds for a brief time, as is known to occur during sleep and after some hypnotic suggestions. If meditating subjects report silent gaps when there are none, they might be reporting a moment of endogenous silence. False positives in gap detection could therefore pinpoint a time window for recording neural correlates of silent consciousness (He et al., 2013). These effects could be enhanced with binaurally fused sound, commonly experienced in the center of the head.

Scalp EEG can rule out microsleeps, which have a distinctive EEG, MEG and BOLD signature (Poudel et al., 2012; Garcés Correa et al., 2013; etc.).

ABSORPTION AND PLEASURE

Absorption and pleasure are often reported during silent states. Absorption is exclusive conscious engagement with one stream of thought. Silences are also described as "blissful," adding a hedonic dimension (e.g., Reps and Senzaki, 1998). The closest analogue seems to be the notion of delight in mathematical beauty (Strogatz, 2012). These aspects deserve more study.

A BRAIN HYPOTHESIS

Conscious experience is believed to involve widespread cortico-thalamic oscillations in the 4–12 Hz range, modulated by higher frequency waveforms up to 200 Hz (Baars et al., 2013).

Silent consciousness may therefore correspond to increased theta-alpha power, spreading in cortex with minimal higher "content" frequencies, as has been reported during contemplative techniques.

SUMMARY AND CONCLUSIONS

Contemplative practices have been known for centuries. Western skeptics may attribute such practices to supernatural beliefs, but a better analogy may be to music training, where generations of adepts pass on a high-level skill. Music training is not arbitrary, but aims to produce precise sounds for emotional effect. Contemplative training may not be arbitrary either. They seem designed to evoke certain conscious experiences, particularly "consciousness without content." We suggest a principled method to study the psychophysics of momentary silent consciousness.

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Decreased electrophysiological activity represents the conscious state of emptiness in meditation

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Many neuroscientific theories explain consciousness with higher order information processing corresponding to an activation of specific brain areas and processes. In contrast, most forms of meditation ask for a down-regulation of certain mental processing activities while remaining fully conscious. To identify the physiological properties of conscious states with decreased mental and cognitive processing, the electrical brain activity (64 channels of EEG) of 50 participants of various meditation proficiencies was measured during distinct and idiosyncratic meditative tasks. The tasks comprised a wakeful "thoughtless emptiness (TE)," a "focused attention," and an "open monitoring" task asking for mindful presence in the moment and in the environment without attachment to distracting thoughts. Our analysis mainly focused on 30 highly experienced meditators with at least 5 years and 1000 h of meditation experience. Spectral EEG power comparisons of the TE state with the resting state or other forms of meditation showed decreased activities in specific frequency bands. In contrast to a focused attention task the TE task showed significant central and parietal gamma decreases ($p < 0.05$). Compared to open monitoring TE expressed decreased alpha and beta amplitudes, mainly in parietal areas ($p < 0.01$). TE presented significantly less delta ($p < 0.001$) and theta ($p < 0.05$) waves than a wakeful closed eyes resting condition. A group of participants with none or little meditation practice did not present those differences significantly. Our findings indicate that a conscious state of TE reached by experienced meditators is characterized by reduced high-frequency brain processing with simultaneous reduction of the low frequencies. This suggests that such a state of meditative conscious awareness might be different from higher cognitive and mentally focused states but also from states of sleep and drowsiness.

Keywords: EEG, meditation, consciousness, thoughtless emptiness, decreased neural processing

INTRODUCTION

Meditation practices include a variety of different mental states or states of consciousness which are expressed through diverse EEG (electroencephalography) patterns, largely influenced by individual situational factors, observed meditation style and previous meditation experience. To enhance accuracy and comparability of meditation studies with respect to various meditative practices it is useful to discriminate between mental properties instead of meditation method or tradition. For example, Lutz et al. distinguished between two modes of meditation, the focused attention, and open monitoring (Lutz et al., 2008). They later described the practice of non-referential compassion as related to open monitoring but different with regard to the mental content, possibly representing a third category (Lutz et al., 2007).

All those concepts regard meditation as an engaged process requiring specific mental processes to be highly active. However, a consequent practice of meditation also asks for a quiet and effortless but fully conscious state which goes beyond the mentioned meditation types. Taking a look at common instructions for entering meditation we find that

- the mindfulness aspect of non-judgmental awareness asks for refraining from specific mental and conceptual elaboration of perceptions while staying fully conscious
- the mindfulness aspect of being present in the moment asks for refraining from planning and the mental construction of time
- an advanced state of thoughtlessness, sometimes experienced as "pure being" or a state close to so called "non-duality" is characterized by being conscious however without apparent categorical thinking or episodic memories.

These aspects of meditation ask for the ability to down-regulate certain mental processing activities. This would constitute a unique mode of meditation which is expected to present different neuronal patterns compared to focused attention or open monitoring (including compassion). It would suggest a reduction of brain processing functions, an assumption born out of an imaging study of Zen meditators that documented less default-mode-network (DMN) activity in meditators compared to controls and a quicker return to a lower baseline-activity after a task dependent activation (Pagnoni et al., 2008). Travis and Shear classified meditation techniques into three categories namely focused attention, open monitoring, and automatic self-transcending (Travis and Shear, 2010). They state: "Focus and monitoring experience are active mental processes, which keep the brain engaged in specific processing—individual activity keeps the mind from transcending."

In the present study we focus on an aspect of meditation that connects to automatic self-transcending which we refer to as a state of "thoughtless emptiness" (TE) or "thoughtless void." TE might be close to the conception of the Vedic form of "advaita" or what some call "non-duality." It requires refraining from using thoughts, memories, emotions, associations, perceptions while consciousness is maintained. Thus, this state is supposed to express reduced mental processing as described above. We were interested in identifying the neurophysiological properties of such "pure" consciousness. Therefore, TE not only had to be distinguished from meditative states of consciousness associated with higher order processing but also from (a) idling brain states which are present in resting conditions and (b) those states that lead to a loss of consciousness (LOC) such as sleep onset.

Before presenting own results a short overview about the expected brain dynamics of various states measured by the EEG is given.

THE RESTING STATE NETWORK

Resting task conditions were described by the activation of resting state networks (RSN) which represent mental functions of memorization, planning, evaluation of potentially survival-salient information from the body and the world, and self-referential functions. One of the RSNs is called the default mode network (DMN). DMN activity is reduced during attention-demanding cognitive processing (Raichle et al., 2001). Jann et al. (2010) found 10 different RSNs one of which is the DMN. Its activity was associated with increased alpha1 activity in the central areas and partly frontal areas, increased alpha2 in the posterior occipital region, increased beta1 over parietal electrodes, decreased delta at fronto-central and decreased theta in parieto-occipital areas.

SLEEPINESS AND SLEEP

Feelings of sleepiness during prolonged wakefulness are related to increased theta power, mainly frontally, and a decrease in alpha power (Strijkstra et al., 2003). A shift from dominant alpha to theta activity (3–7 Hz) indicates the transition from wakefulness to sleep stage 1. Stage 2 shows a distinct EEG pattern consisting of so-called sleep spindles (12–14 Hz) and K-complexes. During stage 3, or slow-wave sleep, delta activity (0.5–2 Hz) increases (Iber et al., 2007). Whereas these first three sleep stages are typically classified as unconscious non-REM (rapid eye movement) sleep, REM sleep is conscious and characterized by a predominance of theta activity (Rechtschaffen and Kales, 1968). Fronto-medial theta is thought to be related to the occurrence of dream images (Inanaga, 1998). Ogilvie et al. found significant increases over all standard EEG frequencies at the time of sleep onset (Ogilvie et al., 1991; Klimesch, 1999).

VARIOUS MEDITATION MODES

Mindfulness meditation emphasizes enhanced awareness and mindfulness, thus it is often thought to be a state of heightened wakefulness and attentiveness. One facet of mindfulness is the state of being present; another is the state of enhanced acceptance (Kohls et al., 2009). Mindfulness thus falls into the category of open monitoring and is related to our experimental condition of presence. Activations of brain regions involved in attentional control (e.g., prefrontal cortex), conflict resolution (e.g., dorsal anterior cingulate cortex), and emotional processing (e.g., medial/orbitofrontal cortices) support these aspects of meditation (Hölzel et al., 2007; Baron Short et al., 2010). Attention correlates positively with frontal midline theta band power (Gevins et al., 1997; Aftanas and Golosheikine, 2001; Başar et al., 2001). In contrast to sleep related theta activity, the task-related increases occur within a small frequency range (Klimesch, 1999). Klimesch suggested that broad band theta synchronization as observed during sleep lowers or blocks the ability of information encoding, whereas narrow band synchronization is closely linked to the encoding of information.

Lehmann and colleagues observed that a highly experienced Tibetan lama exhibited strong 40 Hz gamma oscillations arising from different oscillators depending on the type of meditation practiced, with the "dissolution of self" meditation activating right prefrontal anterior centers (Lehmann et al., 2001). Increased gamma power was also reported for meditators during focused concentration on an object (Lutz et al., 2003) as well as unconditional loving kindness and compassion compared to the resting state (Lutz et al., 2004). Generally, gamma oscillations around 40 Hz have been associated with cognitive processing and the temporal binding of perceptual stimuli (Llinás and Ribary, 1993; Joliot et al., 1994; Lutzenberger et al., 1995; Elliott, 1998; Kaiser and Lutzenberger, 2005). For a review of various studies related to meditation also see (Cahn and Polich, 2006).

Travis and Shear's analysis of EEG correlates of their three proposed meditation states suggests that focused attention was characterized by beta and gamma activity, open monitoring by theta activity and automatic self-transcending by lower alpha activity (Travis and Shear, 2010).

The aim of our study was to characterize the electrophysiological correlates related to various meditative states of consciousness. For this purpose, we have asked meditators from different traditions and with varying proficiency to meditate while measuring 64 channels of EEG and to enter a variety of intended states: a state of *resting* wakefulness, an open-monitoring-like state of highest possible presence (*presence/monitoring*), a state of *focused attention*, the state of *TE*, and finally an attunement to a first visualized and then generally perceived *spatial connectedness*. The basic question in this study was to identify those brain processes which remain active even in a state of *TE* with reduced mental processing and are required for staying awake without falling asleep. Besides contrasting the EEG spectra of the measured states against each other we additionally compared the results from participants with high and low meditation proficiency.

MATERIALS AND METHODS

PARTICIPANTS

Sociodemography

Altogether, we collected data from 50 participants aged from 22 to 68 years (mean age 45 years, 17 females/33 males). All participants were subjected to the same experimental procedure described above. The meditating participants were eligible for inclusion in the study if they had been carrying out a meditative spiritual practice on a regular basis for at least 2 years. To extend the range of meditation experience to the lower end, eight age-matched participants without meditation experience were included.

The meditator participants were associated with different kinds of spiritual traditions such as Zen-Buddhism (11), Qi-Gong (4), Tibetan Buddhism (4), Sahaja Yoga (8), Western contemplative methods (7), spiritists or mediumistic practice (5), or were spiritual healers or shamans (3). Six participants were Zen Buddhist monks in Japan. Most of the Buddhist and Qi-Gong practitioners were Japanese or Chinese and were measured in Japan. Based on these techniques, the subjects developed their individual "idiosyncratic" meditation style. All participants participated voluntarily and received no remuneration. The study was approved by the ethics committee of the University of Northampton/UK and the ethics committee of the University Medical Center Freiburg i.Br./Germany.

Meditation experience

The total meditation experience was the criterion for grouping of participants. It was calculated by multiplying the years of experience with their weekly practice sessions and the time per session. The results for the 50 participants varied between 0 and 21,185 h. Meditation experience averaged 3357 h and 14 years of meditation practice. While 8/50 participants had no meditation experience. 4/50 meditating participants had less than 50 h of experience, 7/50 had between 100 and 1000 h, 18/50 between 1000 and 5000 h, 6 between 5000 and 10,000 h and 7 participants had more than 10,000 h of meditation experience in their life.

Grouping

For the analysis of meditation-specific states we intended to use only experienced meditators. Thus, we included all participants with at least 5 years practice or more than 1000 h of total meditation time, which applied to 30 subjects (11 females/ 19 males, mean age 47 years). On average, participants in this group had meditated for 20 years and 6498 h.

The influence of meditation experience on the findings was researched by a between-group comparison. Based on total meditation practice hours, the group of all 50 available participants was divided into three subgroups of equal size. For the between-group analyses, the group of 17 most experienced meditators (MEM) was compared to the group of 17 least experienced meditators (LEM), the intermediate group was omitted. The 17 LEM (4 females/13 males, mean age 42 years) had less than 500 h of meditation practice (mean practice of 111 h and 3.4 years); the 17 MEM (5 females/ 12 males, mean age 48 years) had at least 3800 h of meditation practice (mean practice of 9716 h and 27 years).

EXPERIMENTAL PROCEDURE

All participants were informed about the aims of the study and gave their consent before their participation. A brief initial questionnaire asking questions about meditative experience in terms of duration and type of practice was administered. In addition, they were asked to describe the posture and method of their meditative practice as precisely as possible. Three recording sessions were carried out with each participant:

1. The recording started with an initial 15 min baseline session in which participants should *rest* but not meditate while sitting in their usual meditation posture for 5 min with eyes opened, 5 min with eyes closed, and spend 5 min silently *reading* a text from a book or a computer screen.
2. After a short break, a meditation session of 20–30 min duration was carried out in which they were asked to meditate in their own usual way, from now on referred to as "*idiosyncratic meditation*." The idiosyncratic meditation is the only state in which subjects were not instructed to aim for a specific mental state, but could choose their own specification. The subjects' reports of commonly used meditation techniques include mindfulness/presence/awareness (10), thoughtlessness/emptiness (10), visualization/Chakra (10), connectedness/unity (4), Kundalini Yoga (6). Their meditation practice also included mediumship, Mantras, concentration, connecting with god or an energy source. Participants without prior meditation experience received a short introduction into meditation. They were instructed to sit as relaxed as possible in an upright position while focusing on their breath and letting their thoughts come and go with a non-judgmental attitude. Special events, feelings, or states of consciousness occurring during the meditation could be signaled by the participants by pressing a button.
3. Subsequently, an additional guided short meditation session of 10 min duration was performed, comprising another four tasks, each lasting 2 min. All subjects had their eyes closed. The denotations are listed together with the corresponding instructions as follows:

   a. *Presence/Monitoring*: "Try to be in a state of high presence at the place you are in this room at each moment of time."
   b. *Thoughtless emptiness (TE)*: "Try to maintain the state of emptiness from all thought as well as possible."
   c. *Focused attention*: "Direct your attention on a spot in the middle of the forehead above your eyes. This spot is sometimes called 'the 3rd eye' if you are familiar with this term."
   d. *Spatial connectedness*: "Sit in an upright position. First visualize and then just perceive an interconnecting 'energy stream' going through the body axis, and its projection down to earth and up to the sky."

Instructions were spoken by the same experimenter for all participants to initiate the task during the recording. Before the recording the instructions were explained by the experimenter and participant had the chance to ask questions. All participants reported that they could follow or were familiar with the meditative tasks requested in this study.

By offering these different tasks we intended to operationalize four supposedly different mental states operative in meditation, also requiring concentration and mindfulness, which might be related to the executive and the monitoring function of attention-networks (Austin, 2014). Events, feelings, emotions, thoughts and properties of the session were summarized in a written report after the sessions. For the analysis of instructed meditation tasks it was important to verify that the meditators were able to reach and maintain the requested mental states. This was accomplished by asking them after completion how well they were able to fulfill the task. All meditators reported successful implementation. An entire session lasted about 2.5–3 h.

EXPERIMENTAL SETUP

All participants were measured with the same equipment. During all sessions, physiological data were recorded with a 72 channels QuickAmp amplifier system (BrainProducts GmbH, Munich, Germany). EEG was measured using a 64 channels ANT electrode cap with active shielding and Ag/AgCl electrodes which were arranged according to the international 10/10 system. The system was grounded at the participants' shoulder. Data were recorded at a sampling rate of 250 Hz and 22 bit resolution with a common average reference and filtered in a range from DC to 70 Hz. For correction of eye movement and blink artifacts, the vertical electrooculogram (EOG) was measured by placing two electrodes above and below one eye. Respiration was measured with a respiration belt and skin conductance at the second and third finger of the non-dominant hand. Additionally, for measuring heart rate variability, the electrocardiogram (ECG) was assessed with two more electrodes. The experimenter was monitoring the raw data during the recording. Due to meditators residing in different countries, the measurements were carried out at various locations, predominantly in rooms normally used for meditation or in the participants' homes.

PROCESSING OF PHYSIOLOGICAL DATA

Preprocessing

The whole data analysis was done using Matlab version 7.3. After detrending the DC recorded EEG data sets all EEG channels were corrected for eye movements using a linear correction algorithm as described in Hinterberger et al. (2003). This algorithm detects eye blinks and movement events and uses those periods for determining a correction factor for each channel. The EOG was multiplied with this factor and then subtracted from the EEG according to Gratton et al. (1983). This algorithm was tested to work sufficiently well in normal non-moving EEG and can also be applied in real-time online analysis (Hinterberger et al., 2003). The time-series of the raw data and also spectral data was visually inspected for continuous artifacts by means of the visualization scheme used in the state monitoring approach (Hinterberger, 2014). Periods with non-local artifacts involving many electrodes were eliminated. Local artifacts such as bad electrodes were eliminated by replacing the signal with an interpolation of the surrounding electrodes. This was the case in two participants. The remaining possible short-term high-amplitude artifacts were handled in the temporal averaging procedure, e.g., by using the median instead of the mean as described below.

Power spectral density (PSD)

A power spectrum time series was calculated using the Fast Fourier Transform (FFT). FFT was applied to the windowed EEG time series which was convolved using a Nutall window and shifted in steps of 0.5 s. A window size of 2 s was chosen for calculation of the FFT frequency coefficients up to 10 Hz while all higher frequencies were calculated using a 1 s window. The Fourier amplitudes of the 1 s windows had to be multiplied by the square root of 2 to make them comparable with the 2 s windowed frequency coefficients. To limit the influence of high amplitude artifacts the spectral amplitudes were limited to five standard deviations.

It has been shown that the selection of standard frequency bands does not result in an optimal independency of the bands (Doppelmayr et al., 1998). Since the rhythms slow down with age, it would make sense to define the frequency band limits individually for each subject (Köpruner et al., 1984). Therefore, in our approach an algorithm was developed that allowed for determining the individual alpha peak frequency (IAF) using the resting EEG data stream stemming from the eyes closed condition because alpha is most dominant in an *eyes closed resting* state. For calculation of the IAF the algorithm carried out the following steps:

1. Searching for the 1 min epoch in the eyes closed data with the highest standard alpha band activity (8–12 Hz) in parietal-occipital areas. This epoch served as analysis epoch for the IAF.
2. Extracting this epoch from unfiltered pre-processed raw data (corrected for EOG artifacts).
3. Calculating a high-resolution FFT over the 1 min epoch in the full frequency range from 0 to 70 Hz.
4. Averaging of all spectra from parietal and occipital regions.
5. Determining the individual expected age-dependent peak frequency as $IAFexp = 10.89 - (age - 20)/50 * 2.65$). According to Doppelmayr et al. (1998) the actual IAF can vary, influencing also the range of the theta band and consequently the upper limit of the delta band. Thus, the IAF was determined using the high-resolution spectra and searching for a peak in the range of $IAFexp \pm 2$ Hz.

Using the IAF as an anchor, the frequency bands were determined as follows:

Delta: 1.5 Hz to $0.6 * IAF$
Theta: $0.6–0.8 * IAF$
Alpha: $0.8–1.2 * IAF$
Beta1: 12.5–16 Hz
Beta2: 16.5–24 Hz
Gamma1: 24.5–47 Hz
Gamma2: 54.0–70 Hz

To obtain a measure of the power spectral density (PSD) FFT values were squared and all FFT bins within a frequency band range were averaged. EEG PSD was calculated for each participant, recording session, electrode, and frequency band.

The subsequent statistical comparisons of EEG PSD measures using *t*-tests require the assumption of having normally distributed data. To ensure statistical validity, it was necessary to take a closer look at the distribution of the data sets. Therefore, a distribution analysis of the EEG measures, especially the PSD measures was done. As a result, the log- transformed Fourier amplitude values (as used for PSD) could be fitted with a normal distribution function in a wide range so that more than 99% of the values were within the normal distribution. Therefore, all PSD values were log-transformed for further statistics.

Temporal averaging procedure

For further data analysis artifact-free epochs of the eight conditions (according to **Figure 1**) were selected and averaged. In order to be robust against rare but possible high amplitude artifacts the temporal median was used and the interquartile range served as a measure for the standard deviation which can be estimated by multiplication with 0.7413.

In order to compare the *idiosyncratic meditation* with normal *resting* state activity a further artificial reference condition was defined as either the eyes opened or eyes closed condition, or, when participants chose to have their eyes half open during the *idiosyncratic meditation*, the mean values between eyes opened and closed resting were used. This adjusted additional resting state is marked with an asterisk (*resting**). Those 8 + 1 conditions are now called task conditions. They were available for each participant and can therefore be compared with each other.

Spatial data reduction

To limit the number of coefficients in the statistical analysis and for providing a comprehensive visualization with spectral and topographical resolution, the 64 channels were merged into 13 topographic brain regions according to **Figure 2**.

The resulting PSD data set for each participant thus comprised the dimensionality of 8 + 1 conditions times 13 areas times 7 frequency bands. Further reduction levels were achieved by averaging over all electrodes resulting in the global band power (GBP) and further averaging the GBP measures over all bands leading to a global field power (GFP) measure.

Comparison between conditions

To limit the number of task comparisons to those relevant for answering our research questions, the following eight comparisons were selected:

1. Eyes opened resting vs. eyes closed resting.
2. Reading vs. eyes opened resting.
3. Idiosyncratic Meditation vs. resting*.
4. Presence/monitoring vs. resting (eyes closed).
5. TE vs. resting (eyes closed).
6. TE vs. presence/monitoring.
7. TE vs. focused attention.
8. TE vs. spatial connectedness.

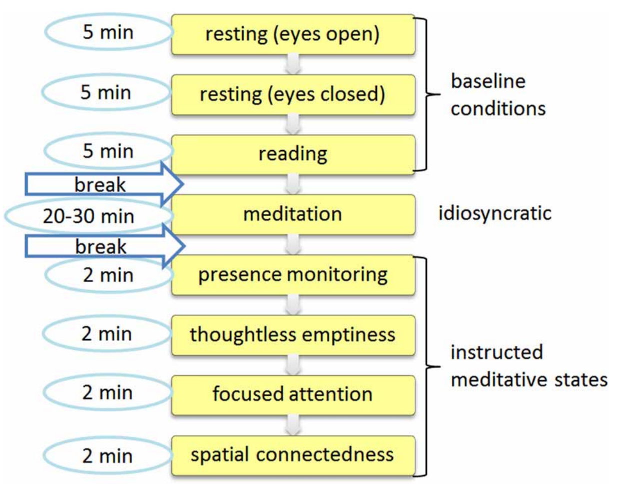

FIGURE 1 | Session protocol. The session consisted of an initial baseline recording that was followed by an idiosyncratic meditation task and a subsequent session with four specific meditative tasks.

The temporal medians of the power spectral estimates of the respective conditions are compared by calculation of effect sizes defined as standardized mean differences (Cohen's d)[1]. For calculation of the group effect, the effect sizes of all participants were submitted to a paired two-tailed *t*-test across participants for each location and frequency band.

False discovery rate adjustment

On the level of GBP there are seven frequency bands and eight comparisons resulting in 56 variables. On the level of spatially resolved data of 13 areas statistics provides 728 variables, meaning that 36 values should randomly reach significance on a 0.05 level. Correction for multiple comparisons is not trivial as such measures may be dependent on each other. Therefore, Bonferroni correction of significance levels would be far too conservative and wipe out most effects. The false discovery rate (FDR) gives the proportion of false discoveries among all discoveries. Based on the formulas by Benjamini and Hochberg (1995) and Yekutieli and Benjamini (1999), we applied FDR adjustment on all three dimensions, i.e., on the level of 7 frequency bands, 13 brain areas, and 8 task comparisons.

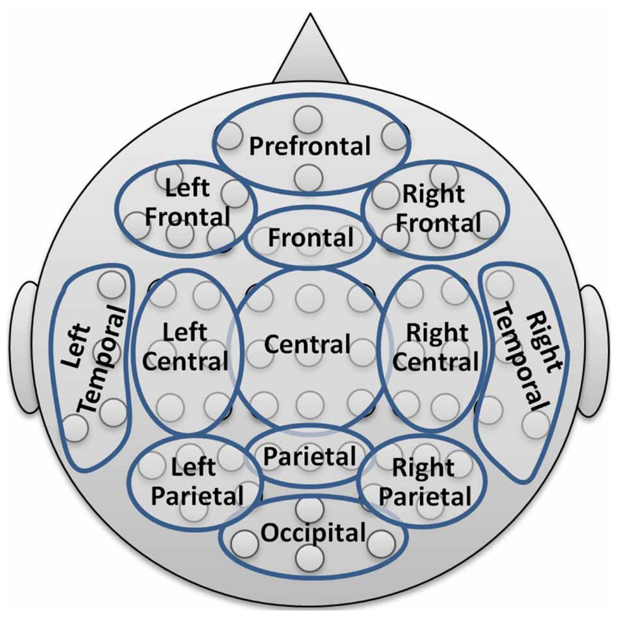

FIGURE 2 | Reduction scheme into 13 major topographic brain regions.

[1] $d = \frac{x_1 - x_2}{\sqrt{(s_1^2+s_2^2)/2}}$ with x_1 and x_2 being the mean PSD values and s_1 and s_2 the estimated variances, according to Cohen (1988).

Summary of data sets

In summary, the presented statistical results comprised the following PSD differences:

- The GFP as an average over all electrodes and all frequencies of the 8 comparisons ($N = 30$ experienced meditators).
- The global band power (GBP) as the average PSD over all electrodes of 8 comparisons and 7 frequency bands ($N = 30$ experienced meditators).
- Spatially resolved PSD from 8 comparisons, 7 frequency bands, and 13 topographic brain regions ($N = 30$ experienced meditators).
- The GBP as the average PSD over all electrodes, providing one data matrix of 8 comparisons × 7 frequency bands that includes 17 LEM and on including 17 MEM.

Table 1 | State comparisons on the level of the global field power have been calculated.

State comparisons	t ($n = 30$)	p-value^{+}
Eyes open vs. eyes closed resting	−2.93**	0.010
Reading vs. eyes open	−1.45	0.219
Idiosyncratic meditation vs. resting*	−3.40**	0.006
Presence/monitoring vs. resting (eyes closed)	−0.37	0.844
TE vs. resting (eyes closed)	−3.14**	0.001
TE vs. presence/monitoring	−3.91**	0.004
TE vs. narrow focusing	0.11	0.844
TE vs. spatial connectedness	−0.33	0.844

Resting condition depends on eyes open or closed in idiosyncratic meditation, **corrected $p \leq 0.01$. +The p-values were corrected for multiple comparisons.*

RESEARCH QUESTIONS

On the basis of this data and with respect to the introduced issues, we formulated the following exploratory research questions:

(Q1) Global PSD comparisons. What are the global differences in PSD between all comparisons of interest? This will give a first impression of the findings on a high reduction level.

(Q2) Detailed PSD comparisons. What are the spectral and topographical characteristics of the EEG PSD differences when comparing

(a) *resting conditions* with selected states?

(b) *thoughtless emptiness (TE)* with other standardized conditions?

(Q3) Idiosyncratic meditation compared. How do the idiosyncratic meditation styles correspond to the standardized instructed conditions?

(Q4) Impact of experience. How does meditation experience influence PSD differences?

(a) In *group comparisons*, the 17 least and 17 MEM were compared.

(b) A *regression analysis* over all 50 participants could uncover the dependency of experience and state differences.

RESULTS

The first section presents the brain activities related to different mental states in the group of 30 experienced meditators. The second section illustrates the comparisons between the LEM and MEM.

GLOBAL PSD COMPARISONS (Q1)

First, a general description of the characteristics of all eight state comparisons is provided. On the highest reduction level, the GFP includes all frequencies between 1 and 70 Hz and an average over all electrodes. t-test comparisons between task conditions were calculated and displayed in **Table 1**. To correct for multiple testing in 8 different comparisons and 7 frequency bands, an FDR adjustment was applied to the resulting p-values. The corrected p-values are shown in **Table 1** and p-values in the text refer to the corrected p-values.

There was a significant overall EEG power decrease during the *idiosyncratic meditation* condition as compared to the *resting* state ($t = -3.4$, $p < 0.01$). GFP also decreased significantly during *TE*, compared to *resting* ($t = -3.14$, $p < 0.01$) and compared to *presence/monitoring* ($t = -3.91$, $p < 0.01$). In other words, the state of *presence/monitoring* has significantly greater overall EEG power than *TE*.

A spectrally resolved view on these results is illustrated in **Figure 3** presenting the GBP. The alpha and gamma differences between *eyes open* and *eyes closed resting* are a highly significant but also trivial result. All three comparisons against the *resting* condition (*idiosyncratic meditation, presence/monitoring*, and *TE*) show that normal *resting* is associated with increased delta and theta waves compared to meditative states. The GBP during *idiosyncratic meditation* related to *resting* is very similar to the contrast between *TE* and *eyes closed resting*. While the beta1 band offers a reduction during *idiosyncratic meditation* ($t = -2.8$, $p < 0.05$) and *TE* ($t = -2.7$, $p < 0.05$), the state of *presence/monitoring* is associated with an increased alpha ($t = 2.7$, $p < 0.05$). The comparison of *TE* with each of four conditions shows quite characteristic differences: while the *resting* state expresses higher delta ($t = 6.0$, $p < 0.001$), theta ($t = 3.3$, $p < 0.05$), and beta1 ($t = 2.7$, $p < 0.05$) activations, the state of *presence/monitoring* strongly differs in the alpha ($p < 0.01$) and beta ($p < 0.01$) range and less in the gamma range ($p < 0.05$). A narrow, but not visual focus (*focused attention* condition) only affects gamma activity ($p < 0.05$). The *spatial connectedness* exercise is not significantly different from the state of *TE*.

DETAILED PSD COMPARISONS (Q2)

Differences to resting states (Q2a)

Besides the global alpha blocking in the *eyes open* vs. *eyes closed* condition $p < 0.001$), **Figure 4A**) shows a reduction in parietal-occipital PSD in the alpha ($p < 0.001$), beta1 ($p < 0.01$), and beta2 ($p < 0.05$) bands, while frontal and temporal beta2 power increased ($p < 0.05$). Large gamma increases with opened eyes predominantly show up in lateralized frontal ($p < 0.001$), central ($p < 0.01$), and temporal ($p < 0.01$) areas. The cognitive load induced through reading further decreased the alpha rhythms ($p < 0.05$) while parietal and occipital theta ($p < 0.05$) and occipital gamma ($p < 0.05$) increased significantly (**Figure 4B**).

Contrasting the *resting* condition with meditative states as shown in **Figures 4C–E** all those comparisons present

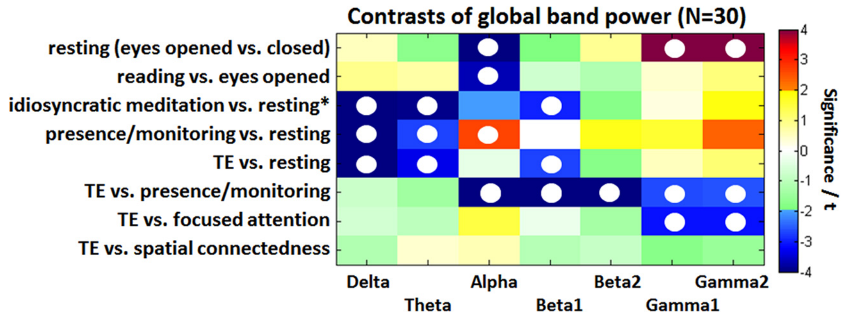

FIGURE 3 | Color-coded PSD differences shown as *t*-values resulting from the eight standard comparisons between psychophysiological states during the recording sessions for seven distinct frequency bands, averaged over 30 experienced meditators. The colors are coding *t*-values. All orange-red fields are positively significant on a 5% level and all bluish values are negatively significant. White, yellow, and green fields are non-significant. Fields marked with a white circle were significant on the 0.05 level after FDR adjustment.

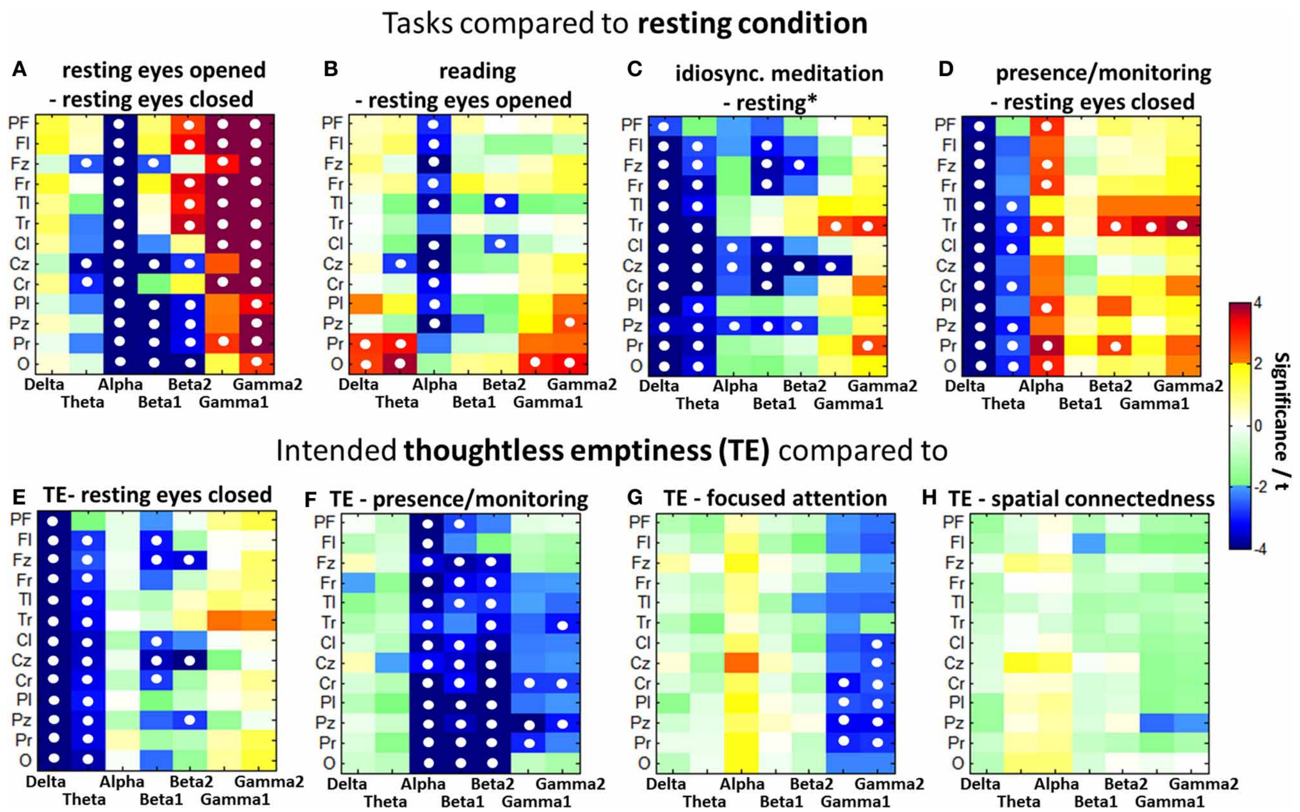

FIGURE 4 | Color-coded PSD differences shown as *t*-values resulting from eight selected task comparisons (A–H). (A) *t*-test of 30 experienced participants was calculated from the effect sizes (Cohen's d) from each participant for each location and frequency band. Fields marked with a white circle reached significance on the 0.05 level after FDR adjustment over all three dimensions, i.e., brain regions, frequency bands, and task comparisons.

almost globally lowered delta and theta band PSD. While the *idiosyncratic meditation* offers tendencies toward decreased alpha (central and parieto-central $p < 0.05$), the eyes closed *presence/monitoring* condition presents clearly increased alpha power ($p < 0.05$) predominantly on the right side. All meditative styles present more or less increased temporal gamma power.

Differences of thoughtless emptiness (TE) (Q2b)

Figures 4E–H show the comparisons between *TE* and the *resting* condition as well as the other three investigated meditative states. For all comparisons, the differences within one frequency band tend to occur globally over all brain areas in the same direction.

Compared to the *resting* state, *TE* is related to a significant decrease in the delta frequencies for all brain areas

($p < 0.001$) and in the theta frequencies for all but the prefrontal area ($p < 0.05$). Beta1 is decreased mainly in the frontal ($p < 0.05$) and central ($p < 0.05$) areas and beta2 in the frontal midline ($p < 0.05$), central midline ($p < 0.001$) and parietal midline ($p < 0.05$) regions. The state of *TE* has globally decreased delta and theta only in comparison to the *resting* state, but not compared to the other meditative states.

Compared to the state of *presence/monitoring*, *TE* shows significantly decreased activation in all brain areas for alpha ($p < 0.01$) and in most areas for beta1 ($p < 0.01$) frequencies, as well as in all but the prefrontal and left frontal areas for beta2 ($p < 0.01$) and the right temporal ($p < 0.05$), right central ($p < 0.05$) and mid-parietal ($p < 0.05$) areas for the gamma band. The *presence/monitoring* state is the only state to have higher alpha power than TE.

In comparison with the *focused attention* condition, *TE* shows significant central and parietal gamma decreases ($p < 0.05$) even after FDR adjustment.

The *spatial connectedness* has the greatest similarity in brain activity to the state of *TE*. No significant differences are expressed after FDR adjustment. Without this correction *spatial connectedness* offers a higher gamma activity in the central parietal area compared to *TE*.

THOUGHTLESS EMPTINESS AND IDIOSYNCRATIC MEDITATION (Q3)

When assessing individual meditation styles which built the base for the *idiosyncratic meditation*, 10/30 mentioned a kind of TE as their primary aim. Another 10/30 used mindfulness techniques, 4/10 visualizations, and again 10/30 reported of the experience of connectedness or unity. As most meditators reported several contents within their meditation session and the experiences could hardly be addressed to only one specific state we decided to treat all *idiosyncratic meditation* sessions of all 30 meditators as an undefined and pluralistic condition.

A comparison of the power spectral patterns of the 20–30 min *idiosyncratic meditation* and the intended *TE*, both contrasted against a resting task as visible in **Figures 4C,E**, presents large similarities. *TE* shares many features with the *idiosyncratic meditation*. Both conditions offer globally decreased delta and theta band activities as well as frontal and central beta-band reductions. In both conditions, also right temporal gamma increases significantly. The central alpha desynchronization during *idiosyncratic meditation* is not visible in the *TE* condition.

PROFICIENCY DEPENDENT PSD DIFFERENCES (Q4)

Analysis of IAF

Aftanas et al. reported a lower IAF for long-term meditators (3–7 years) relative to short-term meditators (Aftanas and Golosheikin, 2003). Our data do not support these findings. The group of 17 LEM had a mean IAF of 9.87 (*SD* 0.91) and the 17 MEM had a mean IAF of 10.17 (*SD* 1.37). The difference between these subgroups is small and not significant ($t = 0.76$). The similarity of the mean IAF between both groups also indicates that the *resting* condition in meditators was appropriate for determining the individual frequency bands and likely not impaired by a possible inability of resting without meditating.

Resting state contrasts

Figure 5 illustrates the contrast between states for comparison of the two groups of the 17 MEM compared with the 17 individuals with the least experience. After FDR adjustment, none of the differences in the LEM, but several differences in the MEM group remained significant. In the experienced participants the contrast between *eyes open* and *eyes closed resting* (less alpha, more gamma activity) is much more pronounced, showing significant differences in alpha ($p < 0.001$), beta1 ($p < 0.05$), and gamma ($p < 0.05$). A similar, but less pronounced difference can be observed in the *reading* vs. *eyes open condition*: MEM show a significant decrease in alpha ($p < 0.05$).

Meditative state contrasts

Only the MEM show significant delta ($p < 0.05$) and theta ($p < 0.05$) power during *idiosyncratic meditation* compared to *resting** (**Figure 5**). The MEM also have decreased power in beta1 ($p < 0.05$).

Whereas for the MEM, there are significant differences between the *resting (eyes closed)* state and the distinct meditative conditions, this is not true for the LEM, who show no significant differences between *resting*, *presence/monitoring* and the state of *TE*.

Experienced meditators exhibit a stronger deactivation in the lower bands than non-experienced individuals, when instantiating the state of *TE*. We can see a more pronounced acitivity in the alpha to beta2 bands in the state of *presence/monitoring*, and a stronger activation in the gamma bands in *focused attention*. Only *TE* and *spatial connectedness* are almost identical states for the MEM, but distinct from all other meditative conditions or the *resting* state. This finding is in consonance with the one seen in the group of 30 experienced meditators.

Regression analysis (Q4b)

A regression analysis across all 50 participants using Spearman rank partial correlations of band power with meditation experience in hours, controlled for age, yielded r-values below 0.3 in most regions and frequencies; most of them were negative in all comparisons. Mainly in the delta band greater values were reached. Correction of p-values using the FDR adjustment eliminated almost all significant differences. Negative correlations larger -0.3 which remained significant could be observed in the *TE* vs. *focused attention* task comparison prodominantly in temporal, right parietal and occipital regions.

DISCUSSION

GLOBAL PSD COMPARISONS (Q1)

The first two comparisons present generally well known results. Opened eyes are associated with an alpha blocking, i.e., a decrease in alpha compared to closed eyes as well as an increase in gamma activities to be explained with increased visual and structural processing.

We have explicitly contrasted three meditative conditions to the normal *resting* state: the *idiosyncratic meditation*, the state of *presence/monitoring* and the task of *TE*. Even on the highest reduction level GFP comparisons reached significance in three of those comparisons. As the GFP could be strongly dominated by

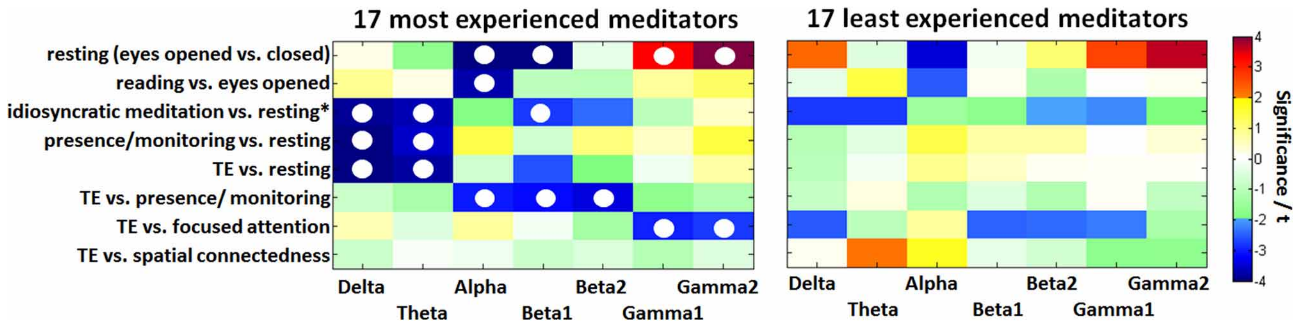

FIGURE 5 | Color-coded PSD differences shown as *t*-values resulting from the eight standard comparisons between psychophysiological states during the recording sessions for seven distinct frequency bands, averaged over the 17 most-experienced and the 17 least-experienced meditators. The colors are coding *t*-values while all orange-red boxes are positively significant on a 5% level and all bluish values are negatively significant. White, yellow, and green boxes are non-significant. Fields marked with a white circle were significant after FDR adjustment on the 0.05 level.

the delta band often showing high amplitudes we only discuss the spectrally resolved results. On that level of analysis our study showed that *resting* expressed higher delta and theta activity than any other meditative state. This contradicts the often reported theta increase during meditation in experienced meditators. However, theta increases were also associated with arousal and attention (O'Keefe, 1993; Klimesch, 1999), decreases in theta power have been found in motor tasks or imagined motor tasks, or more generally tasks requiring no input from the environment (Autret et al., 1985; Hansen et al., 1993; Weiss et al., 1995). Interpretations about the *TE* state that is characterized by less alpha and beta power in contrast to *presence/monitoring* and less gamma power in contrast to a *focused attention* task will be made in the discussion of spatially detailed activities [section Differences of Thoughtless Emptiness (TE) (Q2b)]. Additionally, it seems to be important to discuss possible artifacts which might lead to misinterpretations of our results.

CONSIDERATIONS ABOUT ARTIFACTS

High frequency muscle artifacts would be expected to show up in the beta and gamma frequencies, mainly in areas closer to the face or neck. Also, these artifacts usually exceed the narrow band of neural activity and spread into higher frequencies. Facial muscle tensions especially show up in prefrontal, temporal and occipital areas but much less in frontal, central and parietal areas. In contrast, movements of head, eyes, etc. could produce an increase in delta power. As participants were sitting still, possible movement artifacts were limited to small time frames which do hardly influence our results through the calculation of the median.

When evaluating the results from the four meditative tasks (recording session 3) following the *idiosyncratic meditation* (recording session 2) we need to remember that there was only a short break of a few minutes after a 20–30 min *idiosyncratic meditation* and we cannot guarantee a return to a baseline activity during this break. Therefore, comparisons of the instructed meditative tasks from the third session with *resting* from the first recording session have to be handled with caution. However, the obvious differences between tasks also indicate that meditators were able to switch quickly between these mental states. Subjective reports also state that. This issue could have been avoided by introducing a final *resting* task at the end and compare this with the initial resting conditions or by introducing another *resting* task between recording sessions 2 and 3.

DETAILED PSD COMPARISONS (Q2)

Differences to resting states (Q2a)

States within baseline recording. Decreased beta 1 during *resting with opened eyes* compared to *closed eyes* was predominantly found in highly experienced meditators related to frontal midline, mid-central, parietal, and occipital areas. High beta was also reduced in parietal and occipital areas. This is in line with Wróbel (1998) who found occipital beta to decrease in amplitude with increased visual attention. The increased frontal and temporal beta bands as well as global gamma increases during *opened eyes* reflect the higher cognitive load. This might also be responsible for further alpha blocking in the *reading* condition.

Meditative states compared to resting. All comparisons of *meditative states* with *resting* (*eyes closed* or *resting**) showed almost globally significant decreases in delta and theta power which could also be observed in the not displayed comparisons to *focused attention* and *spatial connectedness*. This finding is in line with the results from Dunn et al. on mindfulness meditation (Dunn et al., 1999). Delta effects have not been reported in most studies on meditation, and it is unclear whether it has been systematically analyzed (Cahn et al., 2010). Delta occurs usually during slow wave sleep, and the restorative value of sleep is linked to the periods of delta waves when human growth hormone is secreted (Feinberg, 2000). Synaptic plasticity in the cortex is supported by delta waves as well (Steriade and Timofeev, 2003). LOC due to general anesthesia is also associated with a predominance of slow-frequency oscillations (Gugino et al., 2001; John et al., 2001). However, delta increases also during mental tasks (Dolce and Waldeier, 1974; Valentino et al., 1993; Fernández et al., 1995) and correlates with performance (Vogel et al., 1968). It has been suggested that delta activity is related to attention and internal processing (Harmony et al., 1996). Generally, decreases in slow frequencies and increases in fast frequencies characterize EEG profiles under influence of psychostimulants (Hermann, 1982), which usually enhance alertness, wakefulness, concentration or mood (Nehlig et al., 1992; Koelega, 1993; Seidl et al., 2000). A decrease of these frequencies in our participants might indicate that they were indeed fully conscious during the meditative states.

Considering these findings, the decreased low frequency activity during *TE*, *presence/monitoring* and *idiosyncratic meditation* might be related to increased calmness and possibly also enhanced mood and concentration associated with consistent meditation practice. This tallies nicely with recent findings that mindfulness and transcendental meditation (TM) practice improves ADHD symptomatology in children (Grosswald et al., 2008; Zylowska et al., 2008; Van der Oord et al., 2012). Interestingly, a study analyzing the EEG changes evoked by the smoking of a cigarette reported decreased delta and theta power and increased alpha power compared to a sham smoking condition (Knott, 1988; Knott et al., 1998). This correlates to the picture of *presence/monitoring* vs. *resting*. Theta and alpha rhythms have been proposed to reflect top-down information processing involving attention and working memory retention (Razumnikova, 2007). Consistently, the task *presence/monitoring* falls into the category of open monitoring meditation and is characterized by spatial awareness and attentiveness. It is supposed to reflect a reduction in episodic memorization, planning and problem solving. Our results confirm that the state of *presence/monitoring* can be clearly opposed to drowsiness, sleepiness, sleep and other non-conscious states as described in the introduction.

In contrast, *resting with eyes closed* can be regarded as a wakeful and alert state which is associated with so-called mind-wandering activities which might keep the sensorimotor system alert. We therefore will focus more on the default mode processes active in *resting* conditions. According to the introduction, the condition of *presence/monitoring* should then move the RSN toward the DMN, and probably an increased attentiveness. The contrast of *presence/monitoring* and *resting* nicely reflects the typical DMN activations by showing decreased theta and delta and increased alpha and gamma corresponding to the DMN according to Jann et al. (2010), the default mode RSN1 and the self-referential RSN6 but not the RSN2. The loss of memorization might be the reason for the theta decrease. Dunn et al. (1999) also reported an increase in alpha power as observed during the *presence/monitoring* condition. The increased right temporal gamma power is discussed in the section Thoughtless Emptiness and Idiosyncratic Meditation (Q3).

For all comparisons of meditative states with the resting state it should be noted that some meditators might automatically have been in a meditation state during the *resting* task even if they were instructed not to do so. This effect decreases the effects on one hand but on the other hand gives rise to the question how resting states are different in meditators and non-meditators.

Differences of thoughtless emptiness (TE) (Q2b)

TE vs. resting (eyes closed). Similarly to the *presence/monitoring* task the theta and delta waves were globally and highly significantly reduced in intended *TE*. The pattern presents no alpha increase but a decrease in beta frequencies (predominantly frontal to occipital midline) as illustrated in **Figure 4E**. According to the discussion above this suggests that *TE* is neither an attentive state, nor is it related with sleep. Frontal beta power is decreased during *idiosyncratic meditation* and *TE*. Frontal beta synchronization is associated with stimulus assessment and decision making (Kropotov, 2008). A decrease might thus be related to an absence of these processes, indicating a non-judgmental attitude as aimed for during meditation. *TE* seems not to activate the DMN considering the highly significant decreases in alpha and beta waves.

TE vs. presence/monitoring. Desynchronizations in central areas in the alpha (or mu-rhythm band) and in the beta1 band have been associated with activation of the sensorimotor cortex and reported during preparation and execution of voluntary movement (Pfurtscheller, 1981; Pfurtscheller and Berghold, 1989; Toro et al., 1994; Pfurtscheller et al., 1996; Leocani et al., 1997) as well as during imagined movements (Pfurtscheller and Neuper, 1997; McFarland et al., 2000) and also attention to body parts (Jones et al., 2010). Alpha desynchronization has also been associated with improved information transfer through sensorimotor pathways (Klimesch, 1999; Pfurtscheller and Lopes da Silva, 1999). This suggests that the highest synchronization of the resting rhythms in motor and premotor areas observed in the *presence/monitoring* state (**Figures 4D,F**) suggest the largest quieting and possibly a decoupling of sensorimotor areas, movement-related areas, and parietal spatial processing areas from those processes still required for a wakeful consciousness. Those resting rhythms were not predominant in *TE*. However, the strongly decreased wide-spread beta frequencies also suggest a clearly reduced processing in areas attributed to motor-tasks, vision and cognition, since increasing beta2 activity is usually observed in cognitive tasks requiring greater attention (Razumnikova, 2007). Beta1 activity has been associated with the integration of different sensory qualities into a unified perception (Von Stein and Sarnthein, 2000; Hanslmayr et al., 2007), and has been proposed to be part of the experience of unity during meditation (Travis and Shear, 2010). The findings of significant beta1 decreases in *TE* suggest that *TE* does not involve such integration processes.

TE vs. focused attention. Lower gamma in *TE* can also be interpreted as an increase of gamma during *focused attention* which is in line with a recent study of mindfulness meditation (Cahn et al., 2010). It also has been hypothesized by Travis and Shear (2010) that *focused attention* during meditation might lead to higher beta2 and gamma activity. Our findings support this hypothesis at least for the gamma band by showing that *TE* contrasts with *focused attention* in a wide-spread deactivation of gamma and in the left temporal area with beta2. In the states of *presence/monitoring* and *focused attention*, posterior gamma activity was increased, which has also been reported during meditation of mindfulness practitioners. This is supposedly associated with changes in self-referential and attentional networks and may be related to momentary sensory awareness, or to conscious representation of mental content (Cahn et al., 2010; Berkovich-Ohana et al., 2012). In other words, these functions were possibly reduced in the state of *TE*.

TE vs. spatial connectedness. TE showed very similar brain activation to the spatial connectedness task, indicating a mental similarity between the sensations of nothingness and multidirectional infinite extension, thus a feeling of oneness.

General finding. Generally, the state of intended TE offered the lowest spectral activities across all frequency bands. One study using a clustering analysis of wavelet features identified five patterns involved in meditation, one of which they identified as particularly outstanding, showing a decrease in EEG power over 8 channels (F3, F4, C3, C4, P3, P4, O1, O2), and being associated with the subjective feeling of a unified, egoless and blessed state (Chang and Lo, 2005).

To summarize, *TE* constitutes a conscious and wakeful state of reduced resting rhythms, but also reduced higher frequencies suggesting diminished conscious representations of mental contents as well as reduced self-referential and attentional networks and maybe sensory awareness. Absence of activations related to decision making suggest a non-judgmental attitude. Physiologically, it represents itself similar to an instructed *spatial connectedness*.

THOUGHTLESS EMPTINESS AND IDIOSYNCRATIC MEDITATION (Q3)

The *idiosyncratic meditative* mental states of 30 long-term meditators were characterized by a decrease of power in the slow frequency bands and partially also in the faster frequencies. This result is similar to the reported decrease in power over all frequency bands during a state of "sacred, unified, egoless, and blessed meditation" (Chang and Lo, 2005), and also consistent with an early suggestion, that during advanced stages of meditation, cognitive functions are automatized or inhibited, leading to a reduction in cortical activity (Earle, 1981). Looking at the contents and strategies the meditators reported for their idiosyncratic meditation style 10/30 mentioned a kind of TE as aim. Another 10/30 used mindfulness techniques, 4/10 visualizations, and again 10/30 reported of the experience of connectedness or unity. Probably, the similarity between the *idiosyncratic meditations* with *TE* and the *spatial connectedness* can be explained by the fact that 20/30 meditators had similar meditation habits which physiologically differed from a state of *presence/monitoring*.

Overall, the brain activity during *idiosyncratic meditation* was similar to that during the intended *TE* condition. A remarkable difference is the reduction of alpha power during *idiosyncratic meditation* in the prefrontal, central and mid-parietal regions. This might be due to attention directed differently toward the body or the environment. The central alpha desynchronization during *idiosyncratic meditation* suggests that the *idiosyncratic meditations* are stronger loaded with imagery.

A specific characteristic of *TE* and the *idiosyncratic meditations* seems to be the right temporal gamma increase compared to the resting state. The right anterior temporal lobe has been associated with the solution of insight problems, with gamma frequencies indicating the event of the insight (Jung-Beeman et al., 2004). Maybe during meditation the meditators reached a state comparable to prolonged insight. In *TE*, the right temporal gamma effect is smaller and as we do not know about thoughtless insights, we cannot explain this effect in the *TE*. Similarly, a decrease of beta power in the parieto-occipital and centro-temporal regions was found during the solution of insight problems (Sheth et al., 2009). This would probably support the findings in *idiosyncratic meditation* but not in the *TE* task.

PROFICIENCY OF MEDITATORS (Q4)

Meditation experience seemed to have a noticeable influence on brain activity. The observed contrasts we discussed above were much more prominent in the 17 highly experienced meditators than in the 17 least experienced ones. The less experienced meditators showed no significant differences between the states of *presence/monitoring* or *TE* and the *resting* condition, indicating that they could not reach or maintain the desired mental state and still might have been cognitively active. The great similarity between *resting* state, *presence/monitoring* and *TE* in the LEM may indicate that they were generally less able to distinguish or maintain different mental states. Differences between baseline conditions are also considerably more pronounced in MEM, further supporting the theory of their enhanced ability to switch between mental states. Also taking into account that none of the differences in the LEM were significant after FDR adjustment, practicing meditation seems to be a tool for enhancing the ability to modulate brain activities and thereby to enable oneself to enter a larger variety of states of consciousness. The observation that the long idiosyncratic meditation corresponds to similar albeit not significant EEG activity in the LEM as in the MEM, might indicate that some LEM were able to reach the desired state or maintain it at least some of the time.

These proficiency related differences did not become visible in a regression analysis between meditation experience and PSD data. While the correlation between meditation experience and the significantly observed differences between states was only weak, it becomes visible in a two-group comparison according to **Figure 5**.

Our results do not support the findings by previous studies that associated increased meditation experience with increased theta power (Kasamatsu and Hirai, 1966; Wallace, 1970; Wallace et al., 1971; Corby et al., 1978), or an increase of theta power and a decrease of alpha power (Pagano and Warrenburg, 1983; Jacobs and Lubar, 1989; Milz et al., 2011). Inanaga (1998) suggested a negative correlation between frontal midline theta and anxious or frustrated experience which might arise due to inability of subjects to reach or maintain the desired states; this is also in contradiction to our data, which suggests decreased theta power in most brain areas in the MEM but no changes in the LEM compared to the *resting* state.

Treatment of Alzheimer's patients with acetylcholinesterase inhibitor to enhance cholinergic neurotransmission resulted in globally decreased theta power (Brassen and Adler, 2003). The reduced theta power in our MEM during *idiosyncratic meditation*, *presence/monitoring*, and *TE* might, speculatively, be taken in support of the finding that long-term meditators show increased cortical thickness in the putamen and no cognitive decline compared to age matched controls (Pagnoni and Cekic, 2007). The putamen is part of the basal ganglia. Acetylcholinergic activity is mainly derived from the nucleus basalis Meynert and its failure to provide adequate cholinergic activation is taken to be one of the starting points of Alzheimer's dementia (Hasselmo and McGaughy, 2004). It might well be the case that what we see in our data is a heightened efficiency of attentional networks that are vital for all other cognitive processes.

Data associating meditation experience with increased theta-power is thus not reliable to identify the neural correlates underlying the state of *TE*. These results confirm that research on distinct mental states should focus on analysis of experienced meditators, as we did in the previous sections of the results. The activity patterns observed in the larger group of 30 experienced meditators are very similar to those from the 17 MEM and the larger sample provides for greater generalizability and validity of the results.

In summary, our data suggest that proficient meditators are more efficient in recruiting cognitive resources while at the same time staying highly conscious and apparently in a generally more pleasant affect. They seem to be able to switch more effectively and more clearly between different states of consciousness and to also hold a state of pure consciousness in a highly awake yet contentless state.

CONCLUSION

The results demonstrate that during *idiosyncratic* forms of *meditation* (mainly Zen-Buddhism, Sahaja Yoga, and Western contemplative methods) most EEG band activities were down-regulated compared to a normal resting awake state. A very similar picture could be seen for experienced meditators who were asked to enter a state of *TE*.

The missing increase of slow wave activity (theta and delta waves) during *TE* could serve as an important indicator that wakeful consciousness is maintained while, at the same time, giving up most of the information processing activities. It is worthwhile pointing out that an implicit teaching of cognitive science suggests that consciousness without content is not possible, dating back to Franz Brentano's notion of intentional consciousness. This states that consciousness is always accompanied by some intention toward which it is directed (Brentano, 1982, p. 21). Our data suggest that this might not be the case: even in a state of reduced cognitive processing clear consciousness seems to be possible in experienced meditators. Their phenomenological first person accounts can also be supported by their neurophysiological data.

These results suggest that states of TE are different from higher cognitive and mentally focused states and from default-mode resting states as well as states of sleep and drowsiness; this can be observed in a general down-regulation of brain activities that also affect the resting rhythms and the lower brain frequencies such as alpha, theta and delta. These findings contribute to solving the question of which brain processes may be required for the experience of being conscious with and without content.

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A phenomenology of meditation-induced light experiences: traditional Buddhist and neurobiological perspectives

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The scientific study of Buddhist meditation has proceeded without much attention to Buddhist literature that details the range of psychological and physiological changes thought to occur during meditation. This paper presents reports of various meditation-induced light experiences derived from American Buddhist practitioners. The reports of light experiences are classified into two main types: discrete lightforms and patterned or diffuse lights. Similar phenomena are well documented in traditional Buddhist texts but are virtually undocumented in scientific literature on meditation. Within Buddhist traditions, these phenomena are attributed a range of interpretations. However, because it is insufficient and problematic to rely solely upon the textual sources as a means of investigating the cause or significance of these phenomena, these qualitative reports are also considered in relation to scientific research on light-related experiences in the context of sensory deprivation, perceptual isolation, and clinical disorders of the visual system. The typologies derived from these studies also rely upon reports of experiences and closely match typologies derived from the qualitative study of contemporary practitioners and typologies found in Buddhist literary traditions. Taken together, these studies also provide evidence in support of the hypothesis that certain meditative practices – especially those that deliberately decrease social, kinesthetic, and sensory stimulation and emphasize focused attention – have perceptual and cognitive outcomes similar to sensory deprivation. Given that sensory deprivation increases neuroplasticity, meditation may also have an enhanced neuroplastic potential beyond ordinary experience-dependent changes. By providing and contextualizing these reports of meditation-induced light experiences, scientists, clinicians, and meditators gain a more informed view of the range of experiences that can be elicited by contemplative practices.

Keywords: meditation, buddhism, concentration, light, hallucinations, neuroplasticity

INTRODUCTION

Meditation practices that were previously taught within the context of religious traditions are now increasingly being practiced in non-traditional and secular contexts. Since the rise of mindfulness-based interventions (MBIs) such as mindfulness-based stress reduction (MBSR), "meditation" is also being prescribed in a clinical context as treatment for a variety of psychological and physiological ailments (e.g., Kabat-Zinn et al., 1985; Kristeller and Hallett, 1999; Goldin and Gross, 2010). Current research has focused almost exclusively on the beneficial effects of meditation, such that the scientific community has not thoroughly investigated the full range of experiences that can arise as a result of meditative practices. It is important to recognize that the trajectories of practice outlined in the traditional literature of contemplative traditions include a wide range of experiences that fall outside the commonly reported positive health effects, including unusual affective, perceptual, and somatic changes (Kornfield, 1979). Especially as practitioners move into more advanced stages of practice, a number of experiences may arise that can be bewildering to those who are not expecting them and who are not prepared to manage them.

Part of the reason for this lacuna in the scientific understanding of meditation derives from the fact that scientific research on meditation, especially at the clinical level, has become increasingly divorced from the study of the literature and practitioners from contemplative traditions. Consulting traditional sources is an essential and important step in furthering the *scientific* understanding of meditation. The literature on Buddhist meditation not only clearly delineates the stages of practice that comprise contemplative disciplines, it also details a range of psychological and physiological experiences that might be expected from undertaking such practices (e.g., Nanamoli, 1997; Buddhaghosa, 1999; Dalai Lama, 2001; Namgyal, 2006; Wallace, 2011). Without adequate knowledge of the range of possible meditation-related experiences, there is a risk that in the clinical application of meditative practices – where meditation training is divorced from its traditional religious, social, and cultural contexts – reports of such experiences could be misdiagnosed as a more serious physiological or psychological disorder. In order to have realistic and accurate expectations of the possible outcomes of meditative practices, clinicians and researchers in this field should be aware of the trajectories of practice and experience detailed in traditional religious literature.

The data in this study are derived from a larger on-going project that is investigating the full range of contemplative experiences. In this paper, we focus in particular on addressing experiences described as lights or as having luminous characteristics. We have selected these experiences from among the possible range of meditation-induced experiences for three primary reasons. First, with the exception of one study that included lights among dozens of different meditation-related symptoms (Kornfield, 1979) and one study in which light-related metaphors are used to describe an experience of "inner energy" (Lo et al., 2003), lights are fairly common meditation experiences that have gone undocumented in the scientific research on meditation. Second, reports of light-related experiences are well documented in scientific literature on visual hallucinations, and their neurobiology is fairly well understood. Third, traditional Buddhist literature provides a rich typology of meditation-induced light experiences that contextualizes these experiences within the trajectories of meditative progress.

The qualitative data for this paper are derived from first-person reports of meditative experiences provided by contemporary American Buddhist practitioners in a variety of lineages. These data are contextualized in relation to typologies of meditative experiences derived from traditional Buddhist literary traditions. While Buddhist literature abounds with detailed references to experiences of lights or luminosity (e.g., Nanarama, 1983; Dondrup, 1997; Chagme and Gyatrul, 2000; Wangyal, 2000, 2002; Gyatso, 2004; Wallace, 2011), to our knowledge, this is the first study that attempts to connect historical, textual data on meditation-induced light experiences with reports from living practitioners of different lineages as well as with related data from experimental scientific research.

Our analysis is restricted to assessing simple visual hallucinations – unstructured points of light, patterns of light, and diffuse changes in the visual field – because these are the types of experience emphasized both in the qualitative data derived from our interviews with Buddhist meditators and in the typologies of meditation-induced light experiences in Buddhist literature. However, it is insufficient to rely solely upon traditional textual sources as a means of investigating the cause or significance of these phenomena. For this reason, our qualitative data are considered in relation to scientific research on sensory deprivation (e.g., Zubek et al., 1961; Zuckerman, 1969; Merabet et al., 2004), perceptual isolation (homogenous stimuli; e.g., Wackermann et al., 2002, 2008; Pütz et al., 2006; Lloyd et al., 2012), and clinical disorders of the visual system (e.g., Santhouse et al., 2000; Wilkinson, 2004; Vukicevic and Fitzmaurice, 2008; Ffytche et al., 2010). These studies, discussed below, also provide evidence in support of the hypothesis that certain contemplative practices – especially those that deliberately decrease social, kinesthetic, and sensory stimulation and emphasize focused attention – have perceptual and cognitive outcomes similar to sensory deprivation. Finally, we suggest that since sensory deprivation has been shown to introduce a period of enhanced neuroplasticity (Boroojerdi et al., 2000; Fierro et al., 2005; Pitskel et al., 2007; Maffei and Turrigiano, 2008), meditation may also have an enhanced neuroplastic potential beyond ordinary experience-dependent changes.

MATERIALS AND METHODS

PARTICIPANTS

Twenty-eight meditators (39% female, 61% male, mean age = 43.3, SD = 14.1, range = 21–74) participated in the "Varieties of Contemplative Experience" study. The subject pool was recruited via snowball sampling (Faugier and Sargeant, 1997). General inclusion criteria required a minimum age of 18 years, a regular meditation practice in one or more recognized Buddhist traditions, and a meditation-related experience that was significant, unexpected, challenging, or was associated with physiological or psychological changes. Twenty (71%) participants practiced in an American Vipassanā or an Asian Theravāda Buddhist tradition, seven (25%) in a Tibetan Buddhist tradition, and seven (25%) in a Zen Buddhist tradition[1]. Nearly half (46%) of the sample were meditation teachers. The average number of prior years of practice before the onset of unexpected experiences was 10.33 (SD = 10.88, range = 0.25–41).

PROCEDURE

The project was approved by the Brown University Institutional Review Board, and all participants provided informed consent. Interviews were conducted via telephone and in person either by the PI (WB) or by other study personnel (CK, EW). After preliminary demographic information was collected, subjects were interviewed in a semi-structured, open-ended format.

Since the primary data are narratives and the aim of the study is to generate descriptions of the participants' meditation experiences, qualitative methodology is the most appropriate approach. Thus, interviews were conducted, recorded, transcribed, and coded in line with qualitative methodology standards (Miles and Huberman, 1994; Patton, 2002; Flick, 2006; Fonteyn et al., 2008; DeCuir-Gunby et al., 2011; Miles et al., 2013). Content analysis is a systematic and objective means of describing and quantifying phenomena (Krippendorff, 1980; Downe-Wamboldt, 1992; Elo and Kyngas, 2008), and may be either inductive or deductive. We chose to use inductive content analysis, where categories are derived from the data, because this is the method that is recommended if there is little former knowledge about a phenomenon (Elo and Kyngas, 2008).

Because the varieties of meditation-related experiences have not been well documented in scientific literature, it was crucial that the interview content was driven by the subject, not the researcher. Subjects were allowed to respond freely to the initial open-ended prompt "What was your experience with meditation?" Additional queries included non-specific prompts for elaboration such as "Can you tell me more about that?" In order to minimize researcher's influence on interview content, directed queries about specific experiences or queries that interrupted the narrative were discouraged.

A total of 2157 min of audio recording were transcribed into 605 pages and separated into 6594 separate units of analysis. Within the transcripts, a new unit of analysis was created for each change in speaker, concept, or event, and each unit was allocated to a

[1]The total percentage surpasses 100% due to some participants practicing in multiple traditions.

separate row in an excel spreadsheet (Cavanagh, 1997; Graneheim and Lundman, 2004; Elo and Kyngas, 2008).

The qualitative content analysis followed a grounded theory approach (Glaser and Strauss, 1967) using open coding techniques (Strauss and Corbin, 1998), which are intended to "open up" the text in order to uncover its content and meaning. Following the methodology of open coding, coders assign a tentative heading or category to each unit of analysis. They then read and code the transcript repeatedly until all aspects of the content are categorized. As the coding structure evolved from the initial open coding, the research team met repeatedly to create and revise a list of standardized definitions for each type of experience with inclusion and exclusion criteria, supported by example texts (MacQueen et al., 1998; Fonteyn et al., 2008). To establish reliability for the codebook, an interview was chosen at random and was coded independently by each of the researchers. All interviews were coded by pairs of researchers with the finalized manual, and any disagreements led to iterative discussions that refined coding criteria until consensus (80%) was achieved.

More than forty categories of experience were aggregated into six higher-order clusters: cognitive, perceptual, sense of self, affective/emotional, somatic/physiological, and social/occupational. "perceptual" is defined as pertaining to the senses, i.e. the visual, auditory, gustatory, olfactory, and tactile systems. "Light experiences" emerged as a sub-category of perceptual experiences in the visual domain. Inclusion criteria for light-related visual experiences included use of the word "light" or description of an experience either directly linked to visual perception with the phenomenal quality of luminosity or brightness. Exclusion criteria were metaphorical uses of light that were not directly linked with visual perception or that had ambiguous phenomenal quality (cf., Lo et al., 2003). Complex involuntary mental images involving objects, figures, and scenes that were not linked to a light-related experience were included in another category and therefore are not addressed in this paper. Because the purpose of this paper is to discuss light-related experiences from traditional Buddhist and neurobiological perspectives, only cells that received the <Perceptual.Visual.light> code are included below.

RESULTS

Nine individuals (32% of total participants) voluntarily reported lights or other forms of luminous experiences [mean age = 41, SD = 9.7, range = 31–60, two females (22%), seven males (78%)]. Six (67%) of these participants practiced in an American Vipassanā or Burmese Theravāda tradition, two (22%) in a Zen Buddhist tradition, and one (11%) in a Tibetan Buddhist tradition. Five (56%) of the meditation-induced light experiences appeared on retreats, and the remaining four (44%) arose in the context of daily practice. Among these reports, the level of light of the meditation environment varied according to setting and time of day and was not intentionally manipulated. None of the practitioners engaged in a "dark retreat" practice where the level of light is deliberately attenuated. Practitioners who reported lights had been practicing within one or more Buddhist traditions for an average of 5.0 years (SD = 2.0, range = 2–8) before these experiences arose (**Table 1**).

DISCUSSION

Our discussion begins by presenting a basic typology of meditation-induced light experiences based upon the data derived from the coded interviews from our subject pool. Data from these first-person reports of meditation-induced light experiences are then compared to typologies of related phenomena derived from traditional Buddhist literary sources. We also present traditional Buddhist interpretations of their significance in terms of the practitioner's progress in meditation.

The second main subsection discusses the neurobiology of light-related experiences according to scientific research on sensory deprivation, perceptual isolation, and clinical disorders of the visual system. We draw upon this literature both to posit the possible underlying mechanisms of meditation-induced light experiences and in order to suggest a novel interpretation of meditation that calls attention to its structural similarities with sensory deprivation and perceptual isolation.

We end our discussion with the implications of our findings for the scientific study and clinical application of meditation.

A TYPOLOGY OF MEDITATION-INDUCED LIGHT EXPERIENCES BASED UPON QUALITATIVE DATA AND TEXTUAL SOURCES

Class one: discrete lightforms

Four practitioners reported discrete lightforms appearing as either "globes," "jewels," or "spots." These lights appeared in various colors and were also described as being "very vivid" or "very distinct." Discrete lightforms could be either singular or multiple in number and were generally small, being described as "little stars" or "small radiant bursts." Some of these bright, luminous shapes were characterized by some practitioners as being stable, or as "hanging out in space," whereas for others they were more animated. For example, one practitioner described spots of lights as floating "together in a wave, sort of like a group of birds migrating." Small lights – singular or multiple – that appear as generally round points of colored light are the first group of phenomena that can be linked with accounts derived from traditional Buddhist literature.

Literature throughout the Theravāda Buddhist tradition describes a particular mental phenomenon called a *nimitta*. The *nimitta* arises once a preliminary mastery of concentration has been established, and especially through developing concentration by focusing attention on the inhalation and exhalation of the breath (Ledi Sayadaw, 1999). Although the particular mental image or form of the *nimitta* varies across practitioners and depends upon the object of concentration, the most common Buddhist meditation practice involves taking the breath as a primary object of attention. A fifth century treatise entitled *The Path of Purification* (Buddhaghosa, 1999, p. 277) describes the *nimitta* that arises through concentration on the breath as follows:

> It appears to some as a star or cluster of gems or a cluster of pearls, [. . .] to others like a long braid string or a wreath of flowers or a puff of smoke, to others like a stretched-out cobweb or a film of cloud or a lotus flower or a chariot wheel or the moon's disk or the sun's disk.

Many of these initial descriptions of the *nimitta* are consonant with the reports of small points of light described as "globes," "jewels," or "stars" discussed above. One practitioner from our

Table 1 | Practitioner data and reports of meditation-induced light experiences.

Subject no.	Sex	Dominant practice tradition	Duration of practice before lights (years)	Retreat or daily practice	Light experience excerpts
99000	M	Vipassanā (Bur), Shamatha (Bur)	7	Retreat	I started getting these meditative states that were like seeing a curtain of light, so even in a dark room meditating at night there would be a sense of – as if there were lights on in the room, and when I opened my eyes there wouldn't be, but. . .there was often a curtain, this internal curtain of light. I began to have very luminous imaginations where. . .if I pictured something it was as if I was actually there, so when I pulled back a memory or a fantasy of being on a beach my mind became so bright it was as if I was actually there, I could see all the details of all the trees and hear the birds calling and. . . it was as if I was actually standing at the beach. So this very luminous mind. . . was coming a lot also when I was sleeping; I was getting incredibly vivid dreams. . . I would be walking around my cabin, and after ten-fifteen minutes of this I realized I was still dreaming, but it was so incredibly vivid as a first-hand experience. This is all talked about in the developing of concentration.
99003	M	Vipassanā (USA)	5	Retreat	Even with my eyes closed, there would be a lot of light in the visual frame, so to speak. Diffuse, but bright. . . My eyes were closed – there was what appeared to be a moon-shaped object in my consciousness directly above me, about the same size as the moon if you lay down on the ground and look into the night sky. It was white. When I let go I was totally enveloped inside this light. . . I was seeing colors and lights and all kinds of things going on... Blue, purple, red. They were globes; they were kind of like Christmas tree lights hanging out in space except they were round. They were very distinct; they weren't fuzzy, they were very clear.
99005	M	Zen	8	Daily	So most people see that if they do eyes open meditation (they have) the sense that reality is pixelating a little bit and becoming very very vivid. . . My personal experience of it... definitely the Christmas lights and definitely the shimmering. . . my tendency is to perceive it that way. The Christmas lights (. . .were) almost like small radiant bursts.
99008	M	Vipassanā (Bur)	2	Retreat	The mind became very strong and bright. By the end of the retreat, it was just on, the lights were on all the time... The last night, I sat the whole night (with) no effort just all kinds of stuff would be happening, energetic stuff, painful things, it's just the mind was totally unmoving.
99009	F	Vipassanā (USA)	2	Retreat	I was just bursting with light, I would just close my eyes and it was just brilliant light. I just felt like I was radiating, like there were rays of light coming out of me. . . . It felt like it was just emanating from my body and my system. But this wasn't my entire retreat by any means, it was just near the end.

(Continued)

Table 1 | Continued

Subject no.	Sex	Dominant practice tradition	Duration of practice before lights (years)	Retreat or daily practice	Light experience excerpts
99011	M	Vipassanā (USA)	6	Daily	And…I had the lights out, so I had this sensation of lights passing over my eyes, but they weren't external. … It seemed to be something just happening to my inner eye, or maybe on my retina, or something when you close your eyes and become deeply relaxed and you start seeing these sort of pleasant pulsations of color, of various forms of color. I think it was that, but like times one hundred, it was just all sped up to a ridiculous degree… It created this perceptual distortion which I felt like I was in a tunnel, or in some kind of train, and there were lights passing me as I moved forward. It was almost as if I was being carried forward…lying on my back through some sort of…crazy roller coaster ride.
99019	F	Shamatha (Tib)	5	Retreat	Sometimes there were, oftentimes just a white spot, sometimes multiple white spots, sometimes the spots, or "little stars" as I called them, would float together in a wave, like a group of birds migrating, but I would just let those things come and go. All of a sudden this tremendous amount of bliss, the jet engine feelings of bliss, would come up while I was sitting and meditating. Or the white lights, or sometimes blue lights, would come up while I was meditating. It was not associated with an unpleasant feeling, or with any kind of palpitations, or rushes, other than this energetic jet engine vibration feeling.
99021	M	Vipassanā (USA)	5	Daily	I've put all of these experiences more in the arising and passing part of the path… golden light that fills the sky and my body feeling like the same nature as that, and the combining and unitive kind of experience, but also there was one night…where my body just was breaking apart into sparkles and like electrical sparks being sent off everywhere in all directions with…so that kind of light and physical…so that the sparks one is obviously more dynamic, the gold one is more unitive, and then during meditation there's plenty of states where you'll see jewel lights or blues and greens and oranges and that seems to be associated with being fairly concentrated at that point.
99022	M	Zen	5	Daily	I've seen ropes of shimmering… where it's causing space behind it to shimmer a little bit and move. I've occasionally had the visual field get much brighter than normal for no particular reason (and) I'd say that's attached to concentration of some sort… In concentration I've had rays of white light that go through everything. They're either coming from behind me somewhere or coming out of the object that I was concentrating on. … I saw it with my eyes open and it wasn't really seeing it was something else, even though I still was perceiving that it was there.

study also described a white light that appeared to be the size of moon as seen in the night sky.

While Buddhaghosa suggests that the different lightforms of the *nimitta* are idiosyncratic, Buddhist sources from other traditions present similar phenomena to the "cluster of gems," "puff of smoke," and "film of cloud" as arising in a progressive sequence. Extensive presentations of light-related signs of attainment can be found in the Buddhist *tantras* – a vast body of literature associated with ritual and contemplative practices that developed and flourished in India between the seventh and the eleventh century (Samuel, 2008). According to a traditional commentary on the *tantras*, a typical trajectory for the lightforms is as follows: The first is described as being "like seeing a mirage," the second as a "smoke-like vision," the third a "vision like flickering fireflies," the fourth is like "the glow of a butter-lamp," and the fifth is "like a clear autumn sky pervaded by the light of the full moon" (Dondrup, 1997, p. 85). Various *tantras* present the progressive sequence of mental images in different orders; Gyatso (2004) explains that this is due to the different techniques that can be used to induce the involuntary mental images.

While the reference in the *tantras* to lights "like flickering fireflies" closely resembles the reports of "Christmas lights" and "small radiant bursts" discussed in the first class of light-related phenomena, the depictions of a mirage-like light and an illuminated autumn sky more closely correspond to phenomena we include in the second class of meditation-induced light experiences.

Class two: patterned and diffuse lights

The second class of light-related phenomena includes patterned and diffuse changes to the visual field, most commonly described as shimmering, pixelation, or brightening. This class of phenomena can be distinguished from the first class on account of not having a distinct and circumscribed shape, size, color, or spatial location. Instead, they are characterized as being superimposed on the practitioner's perception of space, and often arise in conjunction with the perception of external objects.

Shimmering. Like the tantric visions of seeing a mirage, one practitioner described space as "shimmering," and alternately as seeing "ropes" that would emerge from objects in space and cause the space behind it "to shimmer a little bit and move." Contemporary authors in a Tibetan Buddhist lineage explain that "when you meditate, many different lights can appear [including. . .] all kinds of shimmering experiences," and these are taken to be "good signs" (Sherab and Dongyal, 2012, p. 94).

Pixelation. Another example of an alteration of the visual field comes from a practitioner who described the visual field as "pixelating a little bit and becoming very very vivid." A similar cluster of phenomena that co-arise with the perception of external objects include reports of "seeing energy instead of seeing solid objects" and "seeing rays of light that go through everything." In a description strikingly parallel to "pixelating," Tibetan author Dudjom Lingpa includes "the perception of all phenomena as brilliantly colored particles" among the list of meditation experiences (*nyams*) that can arise from proficiency in concentration practice (Wallace, 2011, p. 136). Full et al. (2013) documented advanced meditators in a Burmese Theravāda tradition, some of whom also reported perceiving both external objects and their own body as small particles as a result of directing a concentrated mind toward the investigation of the body.

Brightening. In addition to the shimmering and pixelation described above, six practitioners reported a homogenous brightening of the visual field. Two of these practitioners reported that the visual field was brighter when the eyes were open, including a report of a "golden light that fills the sky," which is quite similar to the imagery used in the Buddhist *tantras* to characterize the fifth sign of attainment.

Four other practitioners characterized the homogenous field of light as a mental image arising behind closed eyes. For example, one practitioner described an "internal curtain of light" that would be most apparent when meditating in a dark room or with eyes closed. On account of this curtain of light, this practitioner reported being able to perceive memories and dream-like reveries as clearly as external objects. This increasing brightness of the visual field may again be related to the fifth, unstructured "sky-like" sign of attainment presented in the *tantras*, or, it may be closer to a phenomena described in the canonical sources of early Buddhism as the "pure bright mind." This "pure bright mind" is associated with the fourth state of meditative absorption (*jhāna*) attained through the cultivation of concentration. In one passage, this quality of awareness pervades the body in a manner compared to a man "sitting covered from the head down with a white cloth, so that there would be no part of his whole body unpervaded by the white cloth; so too, a [monk] sits pervading this body with a pure bright mind" (Nanamoli and Bodhi, 1995, p. 369).

Two practitioners also reported a proprioceptive dimension to their meditation-induced light experience. One practitioner explained that "my body just was breaking apart into sparkles and like electrical sparks being sent off everywhere in all directions"; the other "felt like I was radiating, like there were rays of light coming out of me." In contemporary Theravāda accounts (Sayadaw, 2010, p. 122), concentration directed toward the body is similarly associated with seeing "a smoky gray light [that will] become whiter like cotton wool, and then bright white, like clouds," and furthermore with seeing the body "sparkle and emit light." Experiences of light emanating from the meditator's body are also associated with a calm mind and with a particular stage of insight called the "knowledge of arising and passing away" (Nanarama, 1983, p. 36), the significance which is discussed below.

Textual interpretations of meditation-induced light experiences

As suggested above, reports of meditation-induced light phenomena can be found across Buddhist traditions, in both historical, textual accounts and among accounts from contemporary practitioners. A survey of both historical and contemporary accounts reveals that there is no single, consistent interpretation of meditation-induced light experiences in Buddhist traditions. Some types of light may signal that a particular discipline such as concentration has reached a certain stage of development, whereas other lights may be the result of imbalanced practice.

Some interpret lights as a vehicle for investigating the constructed nature of phenomenal appearances; other light experiences are deemed unimportant side effects of meditation.

In the context of Theravāda and Tantric Buddhism, meditation-induced light experiences are often deliberately sought as part of the method of transforming consciousness or are interpreted as a sign that such transformations have occurred. According to typical Theravāda instructions on concentration practice, such as those found Buddhaghosa's *The Path of Purification*, once a *nimitta* arises, it is take as a sign that an initial stage of meditative absorption has been reached. At that point, this involuntary light experience can then replace the breath or an external object as the new object of concentration (Ledi Sayadaw, 1999). Similarly, in Tibetan traditions, the progressive sequence of signs that are thought to manifest on account of tantric practices, including both discrete lightforms and diffuse lights such as shimmering, are interpreted as positive signs that the clarity and luminosity of the mind is becoming apparent to the practitioner (Gyatso, 2004; Sherab and Dongyal, 2012).

However, similar typologies of light-related experiences are elsewhere treated as involuntary side effects of meditation. Some Theravāda Buddhist authors from contemporary Burmese lineages (Nanarama, 1983, p. 36; Sayadaw, 1994, p. 13–14) identify the arising of a "brilliant light," a "flash of lightning," a "lamplight in the distance," or a "light [that] emanates from [the meditator's] own body" as "illumination" experiences – one of 10 "imperfections of insight" that can arise during a stage of practice called the "knowledge of arising and passing away." These light-related meditation experiences, while still taken as signs of a calm mind capable of carefully investigating present moment experience, are nevertheless treated as "corruptions" or "imperfections" because they are so enticing that they can lead the meditator astray from the practice instructions. Similarly, the phenomena classified in Tibetan Buddhism as "meditation experiences" (*nyams*) also include light-related experiences among the range of phenomena that can arise in meditation. Like the lights that arise in the context of the imperfections of insight, light-related *nyams* such as pixelation are to be left alone, and the practitioner is to proceed without becoming attached to them (Wallace, 2011). In Zen Buddhist traditions, the term *makyo* is used to refer to a similar category of "side-effects" or "disturbing conditions" that can arise during the course of practice (Austin, 1999, p. 373). Consonant with Southeast Asian Theravāda and Tibetan Tantric Buddhist sources, Sogen (2001, p. 84) associates the arising of *makyo* with "proof of considerable maturity in Zen concentration." However, "even if a glorious light shines, [. . .] they all belong to *makyo* regardless of whether they are good or bad," and the practitioner should respond by "paying no attention to them" (p. 87).

According to other traditional interpretations, especially prominent in the Dzogchen tradition of Tibetan Buddhism, one of the objectives of advanced meditation practices is to stabilize the lightforms that arise and investigate them (Chagme and Gyatrul, 2000, p. 159; Namdak, 2006, p. 197). Temple wall paintings featuring both descriptions and representations of these lightforms describe a trajectory beginning with "countless minor circles like pearls on a string" that develop into visions of "luminous spheres, grids, and disk of light" (Baker, 2000, p. 119). Such meditation-induced light experiences are not important in and of themselves; rather, they are valuable only insofar as they assist the practitioner in recognizing the way in which the mind constructs visual appearances and reifies them as external objects (Wangyal, 2002, pp. 131–133; Namdak, 2006, p. 198). In this trajectory of practice, certain Buddhist meditation traditions utilize visual hallucinations as a means of gaining insight into the way in which perceptual experience of the phenomenal world is constructed, rather than given. Some contemporary theories in cognitive science have characterized phenomenal consciousness as a process that simulates the relationship between the body and its environment (e.g., Metzinger, 2003; Revonsuo, 2006) in a manner compatible with certain Buddhist approaches to insight (Waldron, 2006). As the following section will demonstrate, the neurobiology of visual hallucinations and veridical visual perceptions are closely related (Ffytche et al., 1998; Lloyd et al., 2012).

NEUROBIOLOGICAL PERSPECTIVES ON LIGHT-RELATED EXPERIENCES

Scientific studies of light-related experiences tend to classify such phenomena as visual hallucinations. This section presents findings from sensory deprivation, perceptual isolation, and disorders of the visual system.

Sensory deprivation

Sensory deprivation includes exposure to environments that present the subject with minimal sensory input. Through darkness, silence, isolation, and bodily stillness, respectively, the subject's visual, auditory, social, and kinesthetic experience is reduced as much as possible (Zubek et al., 1961; Rossi, 1969; Merabet et al., 2004; Kjellgren et al., 2008; Mason and Brady, 2009). Sensory deprivation may include occlusion of individual sense organs, such as with earplugs or blindfolds, or multiple senses at once, such as through sitting alone in a dark and silent room.

Perceptual isolation

Perceptual isolation refers to exposure to homogenous, invariant, or unstructured stimuli (Wackermann et al., 2002, 2008; Pütz et al., 2006; Lloyd et al., 2012). While sensory input is not technically absent in perceptual isolation, the monotony leads to habituation where input is "filtered out," which can mimic the effects of decreased input of sensory deprivation (Pütz et al., 2006).

Visual impairment

Among disorders of the visual system, Charles Bonnet Syndrome is classically associated with visual hallucinations and light-related experiences. Charles Bonnet Syndrome is most commonly found among elderly patients who have very poor vision or are blind on account of an impairment of their visual system, ranging from eye abnormalities to dysfunctions in the occipital lobe (Vukicevic and Fitzmaurice, 2008; Kazui et al., 2009).

All three of these conditions – sensory deprivation, perceptual isolation, and Charles Bonnet Syndrome – are characterized by impaired sensory input to the visual system, and all result in the rise of involuntary visual hallucinations, where "hallucinations" are defined as a "percepts, experienced by a waking individual, in the absence of appropriate stimuli from the extracorporeal world"

(Blom, 2013, p. 44). Hallucinations are different both from illusions, which are distortions of actual external stimuli, and from intentionally constructed mental imagery, which remains under volitional control and lacks perceptual vividness (Reichert et al., 2013).

While the sensory loss that occurs at sleep onset may also result in hallucinations, these "hypnagogic" hallucinations are more similar – both neurologically and phenomenologically – to dreams that occur during REM sleep than to visual hallucinations that occur during wake (Wackermann et al., 2002; Collerton and Perry, 2011; Fenelon, 2013). Like dreams, hypnagogic hallucinations tend to occur in multiple sensory modalities at once, are panoramic or "full screen" rather than circumscribed, and are associated with lack of insight and strong, often negative affect (Cheyne et al., 1999a,b; Ohayon, 2000; Collerton and Perry, 2011). Thus, our typologies of visual hallucinations will focus on those that arise during wake, as the phenomenology of waking visual hallucinations is the most congruent with the reports from participants in our study.

SCIENTIFIC TYPOLOGY OF VISUAL HALLUCINATIONS

Researchers of sensory deprivation (Zubek et al., 1961; Zuckerman, 1969; Merabet et al., 2004), perceptual isolation (Wackermann et al., 2002, 2008; Pütz et al., 2006; Lloyd et al., 2012), and visual disorders (Santhouse et al., 2000; Wilkinson, 2004; Ffytche et al., 2010) have developed similar typologies of visual hallucinations. Documented visual hallucinations range from simple forms or flashes of light or color to grid-like patterns to animated figures or scenes. While "complex" hallucinations include faces, objects, and landscapes, light-related experiences of both discrete lightforms and patterned or diffuse lights fall into the category of "simple hallucinations." As explained above, our present analysis is limited to "simple" visual hallucinations.

SIMPLE HALLUCINATIONS

Simple hallucinations often include circumscribed objects, patterns, and diffuse changes across the visual field. Circumscribed hallucinations include points of light, colored lights, or shapes (phosphenes), or flashes of light (photopsia) sometimes described as "dots" or "stars."

Patterned hallucinations may include regular, overlapping patterns (tessellopsia) like lattices, grids, and cobwebs, branching forms (dendropsia) like vines, ropes or roads, and zigzag patterns (teichopsia). Other patterns include the perception of visual snow or television-like static. Diffuse hallucinations include a brightening of the visual field, descriptions of mist or fog, shimmering, or bright sunsets (Ffytche and Howard, 1999; Merabet et al., 2004; Wilkinson, 2004; Ffytche et al., 2010; Lloyd et al., 2012; **Table 2**).

Both circumscribed and diffuse simple visual hallucinations arise as result of sensory deprivation (Zubek et al., 1961; Zuckerman, 1969; Merabet et al., 2004) and perceptual isolation (Wackermann et al., 2008; Lloyd et al., 2012). In some cases of perceptual isolation, the visual field may disappear entirely, leaving subjects "uncertain whether their eyes were open or closed, or even unable to control their eye movements. In the 'luminous fog' of the (homogenous visual field) the subjects do not see anything; in the 'blank-out' periods, they may experience the presence of 'nothingness' " (Wackermann et al., 2008, p. 1367). The authors also point out that natural environments, such as a uniformly blue or cloudy sky, can function in a manner similar to intentionally constructed perceptual isolation environments (p. 1365), and that depending upon the subject's disposition, perceptual isolation experiences and especially "blank out" episodes "may elicit even mystical or religious interpretations" (p. 1368).

Simple hallucinations are much more common than complex ones. Among those with disorders of the visual system, more than 50% of visually impaired individuals report simple hallucinations, while only 15–25% report complex hallucinations (Menon et al., 2003; Vukicevic and Fitzmaurice, 2008). Simple hallucinations can be evoked with very brief exposure to attenuated input, whereas complex hallucinations require more prolonged or more extensive sensory deprivation or perceptual isolation (Wackermann et al., 2002, 2008; Pütz et al., 2006; Lloyd et al., 2012). Complex hallucinations are thought to draw upon many brain areas, including those involved in memory (Collerton et al., 2005), and require more widespread and extensive neuroplastic modifications (Ffytche et al., 2010). More prolonged or extensive deprivation and brain changes may also begin to include cross-modal experiences where visual phenomena are experienced proprioceptively and incorporated into body schema and emotional meaning or value structures (Ffytche et al., 2010).

Researchers have found that simple visual hallucinations are associated with activity in the occipital cortex, the primary visual-processing center of the brain (Boroojerdi et al., 2000; Merabet et al., 2004). Ffytche et al. (1998, p. 740) presents fMRI-based evidence of a specific "correlation between the location of activity within a specialized cortex and the contents of a hallucination." Visual hallucinations of grid-like patterns, for instance, correlated with activity in the collateral sulcus, and color hallucinations correlated with activity in the fusiform gyrus. This led the researchers to conclude that in terms of their neurobiology, visual hallucinations are more like ordinary perceptions than they are like visualized mental images. Similarly, a perceptual isolation study (Lloyd et al., 2012) demonstrated that subjects responded to and could modulate their attention in relation to visual and auditory hallucinations as they would with ordinary perceptions.

WHY SENSORY LOSS CAUSES HALLUCINATIONS

Attenuation of sensory input reliably leads to hallucinations, even after a short time. Decreased sensory input leads to spontaneous firing and hallucinations through homeostatic plasticity – a set of feedback mechanisms that neuronal circuits use to maintain stable activity and firing rates close to a set point (Desai, 2003). Homeostatic plasticity may include adjusting synaptic input strength (synaptic homeostasis) or changing the intrinsic excitability of the neuron (intrinsic plasticity) (Turrigiano, 2011). When sensory inputs are attenuated or lost, the homeostatic plasticity mechanisms increase neuronal excitability and firing thresholds (Boroojerdi et al., 2000; Fierro et al., 2005; Pitskel et al., 2007), which may be experienced as heightened sensory acuity or perceptual sensitivity (Suedfeld, 1975). In the case of sensory attenuation, homeostatic mechanisms often overcompensate to the point of generating spontaneous firing, which is experienced subjectively

Table 2 | Comparative typology of visual hallucinations and meditation-related light experiences.

Typologies derived from sensory deprivation, perceptual isolation, and disorders of the visual system	Typologies derived from qualitative reports from contemporary practitioners of Buddhist meditation	Typologies derived from Buddhist literary sources
Class 1: Discrete lightforms		
Phosphenes: colored spots, dots, or points of light	Blue, purple, and red globes	Cluster of pearls
	Jewel lights	Cluster of gems
	Christmas tree lights	Luminous spheres
	White or blue lights	Lamplight in the distance
	White spots or little stars	A star
Photopsia: flashes of lights	Small radiant bursts	Flickering fireflies
Sun's disk and sunset	Moon-shaped object	Moon's disk
		Sun's disk
Class 2: Patterned and diffuse lights		
Teichopsia: zigzag colors		Stretched-out cobweb
Tessellopsia: lattice, nets, grids, or cobwebs		Grids
Shimmering	Ropes of shimmering	Shimmering experiences
Mist	Seeing energy instead of solid objects	Mirage
Luminous fog		Film of cloud
		Smoke-like vision
Visual snow, television-like static	Reality is pixelating	All phenomena as brilliantly colored particles
	Electrical sparks in all directions	Perceiving body and objects as small particles
	Rays of light that go through everything	
Lighter visual field	Brighter visual field	Glow of a butter lamp
	Lights always on	
	Curtain of light	Clear autumn sky pervaded by the light of the full moon
	Golden light that fills the sky	
Bright sunsets	Body feeling like the same nature as light	Pervading the body with a pure bright mind
	Bursting with light	
	Light emanating from the body	Light emanates from his own body
	Bright mind	

as hallucinations (Schultz and Melzack, 1991; Burke, 2002; Maffei and Turrigiano, 2008; Reichert et al., 2013).

A wide variety of conditions of sensory attenuation or monotony lead to increased cortical excitability, spontaneous firing, and hallucinations. Given that meditators are reporting visual hallucinations in the context of meditation, it is worth considering the sensory attenuating qualities of meditation practices.

BUDDHIST MEDITATION AS A FORM OF SENSORY DEPRIVATION AND PERCEPTUAL ISOLATION

Structural components

While there are a variety of approaches to meditation, many practices incorporate structural components analogous to sensory deprivation and perceptual isolation, including sensory, social and kinesthetic deprivation, or invariance. The practice of meditation tends to be done in social isolation or in groups in which social interactions are minimized. During a formal practice session, practitioners adopt a stable, seated posture. The locations for meditation practice also tend to be quiet environments removed from excessive auditory stimuli. Through dimly lit environments or through practicing with the eyes closed or open with a fixed gaze, visual stimuli are restricted.

It is important to note that even when meditation is not practiced within such sensory minimal environments, the *practice* of meditation functions in a manner analogous to perceptual isolation through restricting attention to monotonous or homogenous stimuli. In practices that involve movement, the emphasis is on monotonous, repetitive movements, such as slow walking. In concentration practice on the breath, other kinesthetic, auditory, and visual stimuli are deselected in order to attend, again and again, to the repetition of inhalation and exhalation. Even when meditators practice with their eyes open, the gaze either remains unfocused and on the entirety of the visual field or is restricted to a single invariant object.

Thus, whether through practicing in environments with minimal sensory input, or through attending only to monotonous, repetitive stimuli, the context and function of meditation is similar to both sensory deprivation and perceptual isolation (**Table 3**). That advanced practitioners often deliberately choose to isolate themselves further by practicing in remote caves or in sensory deprivation environments demonstrates how Buddhist meditation traditions have recognized the importance of practicing within sensory minimal environments. For example, the Tibetan Buddhist practice of "dark retreat" (*mun mtshams*) suggests that deliberate and intensive sensory deprivation is thought to be particularly effective in producing profound shifts in perception and cognition (Chagme and Gyatrul, 1998; Wangyal, 2000, 2002; Gyatso, 2004; Reynolds, 2011). Not surprisingly, discussions of meditation experiences in dark retreat closely resemble the typology of visual hallucinations discussed above. Tenzin Wangyal Rinpoche, who undertook an extensive dark retreat when he was a young boy, reports both simple and complex visual hallucinations arising as a result of the prolonged sensory deprivation (Wangyal, 2000, 2002, pp. 32, 132). Tibetan Buddhists also prescribe a shorter-term technique of fixing the gaze upon a cloudless sky as a means of inducing simple visual hallucinations (Gyatso, 2004). As mentioned above, Wackermann et al. (2008) suggest that a uniform sky serves as a natural perceptual isolation condition.

Concentration as sensory deprivation

In addition to the structural aspects of meditation practices listed above, it is possible that the intense attentional engagement of Buddhist meditation practices also functions as a form of sensory deprivation. By "guarding the sense doors," some meditation practices aim to limit the sensory input impinging on awareness through restricting attention to a single object of perception, such as a visual object or the breath (Buddhaghosa, 1999; Dalai Lama, 2001). Whether in "focused attention" types of meditation, where one object is continually selected, or in "open monitoring" meditation, where many different objects are selected sequentially (Lutz et al., 2008), attention facilitates the processing of relevant information by suppressing irrelevant sensory inputs (Briggs et al., 2013), and can therefore be viewed as a largely inhibitory process (Kerlin et al., 2010; Foxe and Snyder, 2011).

The act of paying attention facilitates the processing of relevant stimuli while inhibiting irrelevant stimuli. In terms of the brain's electrical activity, fast excitatory frequencies and slow inhibitory frequencies interact to facilitate attention (Jensen and Mazaheri, 2010). The active processing of relevant stimuli is associated with increased fast frequency (gamma) oscillations and decreased slow frequencies (i.e., decreased alpha power or increased alpha desynchronization) in the engaged areas (Pfurtscheller and Lopes da Silva, 1999). In contrast, suppression or inhibition of irrelevant stimuli is associated with the opposite pattern, decreased beta and gamma and increased alpha power or alpha synchronization in areas not related to the task (Pfurtscheller and Lopes da Silva, 1999; Suffczynski et al., 2001; Lutz et al., 2007; Kerr et al., 2011). Alpha activity is also associated with decreases in fMRI BOLD signal and is thought to reflect the functional inhibition of neural activity in task-irrelevant areas (Goldman et al., 2002; Feige et al., 2005). For example, during visual tasks, information from non-visual (e.g., motor) areas is inhibited via increased alpha power (Pfurtscheller, 1992). Studies of spatial attention have shown decreases in alpha power in areas related to active processing of target locations but increases in alpha in areas related to non-target locations (Thut et al., 2006; Rihs et al., 2007; Kerr et al., 2011). Although most early research on attention focused on gamma activity in task-relevant areas and ignored alpha activity in task-irrelevant areas, it now appears that alpha inhibition is as important or more important than gamma facilitation. Indeed, optimal task performance on a number of cognitive tasks, including selective and sustained attention, is determined by the extent of alpha activity in task-irrelevant areas rather than gamma in task-relevant areas (Dockree et al., 2007; Jensen and Mazaheri, 2010). Similarly, widespread increases in alpha power in meditators (Cahn and Polich, 2006) that were initially viewed as "idling" (Pfurtscheller et al., 1996) or relaxation (Fenwick et al., 1977) are now thought to reflect the active inhibition of irrelevant cortical inputs as a means of facilitating attention (Jensen and Mazaheri, 2010; Britton et al., 2013; Kerr et al., 2013).

Various meditation practices, especially focused attention or concentration practice, involve selecting target or relevant stimuli

Table 3 | Comparison of sensory deprivation, perceptual isolation, and meditation.

	Sensory deprivation	Perceptual isolation	Meditation
Social	Isolation from human interaction and communication	Isolation from human interaction and communication	Retreat environment temporary social isolation
Kinesthetic	Immobilization, floatation tank	Restricted to comfortable chair	Stable, seated posture, monotonous movements
Auditory	Silence, soundproof room, earmuffs	Headphones with white noise monotonous sound, consistent volume	Quiet retreat environment, redirection of attention away from sound
Visual	Darkness, blindfolds	Eye shields and lighting create homogenous visual field	Eyes closed, gaze fixed on single object, gaze directed at space

and deselecting non-target or irrelevant stimuli. Areas of the body that are related to the sensations of breathing or walking are a common target of focus in many forms of Buddhist meditation, and the ability to maintain focus on these target areas and inhibit distracting non-target stimuli is considered to be a hallmark of proficiency in focused attention forms of meditative practice. Meditation-related increases in interoceptive accuracy to frequently attended targets (Kerr et al., 2011; Silverstein et al., 2011; Fox et al., 2012) are associated with longer lifetime meditative experience (Fox et al., 2012) and are thought to be determined by the extent of alpha-modulated inhibition in non-target areas (Kelly et al., 2009; Jones et al., 2010; Foxe and Snyder, 2011). Thus, it could be argued that proficiency or expertise in focused attention as a result of meditation can be indexed by the degree of cortical inhibition.

Increased throughput of frequently attended-to "target" areas (e.g., improved interoception) is a straightforward example of experience-dependent neuroplasticity that underlies successful skill acquisition. However, the model in this paper suggests that inhibition of non-target sensory input can also result in a compensatory increase in neuronal excitability, which is often measured either by a decreased sensory threshold or by increased firing rates or spontaneous firings (hallucinations). In terms of decreased sensory thresholds, studies of Tibetan Shamatha (MacLean et al., 2010) and Theravāda Vipassanā (Brown et al., 1984) practitioners who were not using visual objects as their primary target have found long-lasting (more than 5 months) decreases in visual perception thresholds. In terms of increased firing rates, long-term practitioners in both Theravāda Vipassanā (Cahn et al., 2010; Ferrarelli et al., 2013) and Tibetan Shamatha (Ferrarelli et al., 2013) traditions were found to have unexplained increases in occipital gamma during meditation and NREM sleep that was associated with lifetime expertise in meditation. The reports of visual hallucinations from this paper suggest that visual areas of the occipital cortex have become hyperexcitable as a result of focused attention on non-visual target areas.

While it is still unknown if meditation-related light experiences are indeed caused by suppression of sensory input via alpha inhibition leading to compensatory disinhibition, this model is supported by perceptual isolation and sensory deprivation studies. Visual hallucinations in perceptual isolation (Wackermann et al., 2002; Pütz et al., 2006) and in sensory deprivation (Hayashi et al., 1992) are preceded by increases in global alpha power, followed by sudden high frequency EEG at occipital sites just before the hallucination (Pütz et al., 2006). Although the relationship to a *visual* hallucination is unclear, Lo et al. (2003) found a similar progression in EEG power among meditators who reported an experience of "inner energy" or "inner light."

In support of concentration playing a role, it is worth noting that seven of the nine practitioners who reported lights (78%) spontaneously connected their meditation-induced light experiences with a period of increased concentration, a claim also made in Buddhist literature across traditions. This association fits with existing neurobiological models that suggest that hallucinations can be related to alpha inhibition (Hayashi et al., 1992) and to the "attentional spotlight" of concentrated attention (Aleman and Laroi, 2008, p. 173). Together these data suggest that the attentional and structural components of meditation serve to attenuate sensory input, which activates homeostatic forms of neuroplasticity that lead to hyperexcitability, spontaneous firing, and hallucinations.

IMPLICATIONS

Implications for clinical neuroscience

The possibility of viewing meditation practice as a form of sensory deprivation has potentially profound implications. Current medical technologies are combining non-invasive brain stimulation techniques that alter neuronal excitability and enhance cortical plasticity with training protocols to enhance outcomes in neuropsychiatric patients, including dementia, pain, addiction, anxiety, and depression (Nitsche et al., 2008; Halko et al., 2011; Kuo et al., 2013). In addition to improving symptoms, this enhanced neuroplasticity is also associated with improved learning, working memory, attention, and other cognitive improvements (Guse et al., 2010). Similarly, the attenuation of sensory inputs increases neuronal excitability and facilitates a period of enhanced neuroplasticity (Ffytche et al., 1998; Boroojerdi et al., 2000, 2001). Whether through brain stimulation or sensory attenuation, changes in neuronal excitability that accelerate neuroplasticity can be used to facilitate therapeutic changes beyond usual training protocols. Since meditation training contains sensory attenuation components, it is possible that this form of cognitive training may have enhanced neuroplastic potential. Furthermore, the appearance of visual lights or other hallucinations could potentially serve as an indicator of a period of enhanced neuroplasticity, during which the ability to make a significant affective, perceptual, or cognitive shifts could be maximized.

Implications for the scientific study of meditation

Current researchers assert that "the mental training of meditation is fundamentally no different than other forms of skill acquisition that can induce plastic changes in the brain" (Davidson and Lutz, 2008, p. 176). However, the meditation-induced light experiences described in this paper suggest that meditation is a form of sensory attenuation that is capable of activating an enhanced period of neuroplasticity that may not occur in other forms of skill acquisition. Visual hallucinations arising in the context of meditation practice may serve as indicators that homeostatic plasticity has been activated and that the brain may be more malleable to learning and change. While still highly speculative, this suggests that the sensory attenuation components of meditation may enhance its neuroplastic potential beyond other forms of skill acquisition.

Meditation researchers are also currently struggling with ways to measure meditative proficiency or expertise. Current attempts to measure expertise include self-reported "mindfulness" scales and the estimated number of hours of practice, both of which are problematic (Grossman and Van Dam, 2011; Van Dam et al., 2012). Meditation-induced light experiences are worthy of further consideration and study as a potential indicator of meditative proficiency. Converging reports from our subjects, Buddhist textual sources, as well as multiple scientific research domains suggest that lights may, at least in some cases, be signs that the practitioner has attained a certain degree of concentration. Proficiency in concentration could be determined by the degree to which a practitioner is able to inhibit irrelevant inputs from impinging on attention. Meditation-related light experiences may serve as a fairly consistent signpost of concentrative attainment across Buddhist traditions because such visual hallucinations tend to arise as a result of the attenuation of sensory input. In addition, because the spontaneous firings that generate visual hallucinations are associated with the activation of homeostatic plasticity, they may also herald entry into a time of enhanced learning, progress, and insight. However, any traditional or well-known marker of progress potentially introduces demand characteristics. Further research that triangulates self-reports with both behavioral and neurobiological markers is necessary.

Implications for clinical applications of meditation

While light-related experiences arising in the context of meditation are well documented in traditional contexts, they are largely unknown in clinical settings. In assessing meditators practicing outside of traditional contexts, it is important to carefully attend to the nuances of light-related discourses when evaluating whether lights are signs of positive changes or inconsequential side effects of meditation. In traditional contexts, meditation-induced light experiences are frequently subject to scrutiny before they are attributed either positive or negative value. Without the traditional safeguards of a student-teacher relationship, the clinical application of meditation practices may be particularly susceptible to misinterpreting lights and other meditation experiences, since visual hallucinations are well-known indicators of both psychosis and vision system impairment. It is important, therefore, not to uncritically pathologize these anomalous perceptual experiences. Light-related experiences are likely to be benign, but may cause distress to the practitioner if they are unexpected or accompanied by other psychological changes. By empirically studying and documenting meditation-induced light experiences and describing them within their traditional Buddhist frameworks, we hope to help educate clinicians and meditation teachers about some of the common side effects of meditation in order to create more appropriate support structures for practitioners.

Study limitations and suggestions for future research

The investigation of phenomena that has received little empirical attention requires inductive methods that are intended to be free of both assumptions and hypotheses. Thus, our grounded-theory-based approach, which is appropriate for this stage of research, is both a strength and a limitation. As a strength, the open-ended approach, which discourages researchers from asking specific questions that would bias the subjects' answers, helps to minimize demand characteristics of the interview. As a limitation, by not asking participants if they had certain experiences, such as lights, the current report may have underestimated the actual prevalence of light-related meditation experiences. Our current approach can only answer the question "What types of experiences arise in the context of meditation?" Many other important questions will need to be pursued through additional theory-driven research.

This study has a number of other limitations. Demand characteristics and subject expectations are an inherent limitation of many types of studies, including nearly all intervention studies, meditation studies, and pharmacology studies. In clinical meditation studies, the simple fact that the name of a meditation program includes the phrase "stress reduction" sets up expectations that the program will reduce stress. Similarly, certain experiences may be more or less frequently reported depending on the subject's expectations of what is supposed to happen in the context of meditation. There are several reasons why the influence of subjects' expectations are minimized in this study. First, lights are not commonly described in American Buddhist meditation literature and are likely not well known to most American practitioners. Participants in this study were deliberately recruited on the basis that the experiences they had with meditation were *unexpected*. In our sample, only one participant made an explicit association between their own experience and Buddhist theories about the significance of lights. The subjects also tended to describe their experience in non-Buddhist terms such as the "curtain of light," "Christmas lights," "electrical sparks," or "little stars."

It may seem plausible that the light-related experiences in our sample were just hypnagogic hallucinations that were caused by falling asleep and not by meditation practice. We find it unlikely that sleep played a role in these experiences for several reasons. First, hypnagogic hallucinations are extremely common (Ohayon et al., 1996) and we would therefore expect the prevalence in our sample to be much higher and also much more well known to the average meditator. Second, Buddhist meditation practice, especially among more-experienced practitioners, is associated with an increased alertness that is neurologically distinct from and resistant to sleepiness (Britton et al., 2013). Third, as described previously, hypnagogic hallucinations are phenomenologically and neurologically different from waking hallucinations that arise in the context of sensory deprivation or perceptual isolation (Cheyne et al., 1999a,b; Ohayon, 2000; Wackermann et al., 2002; Collerton and Perry, 2011; Fenelon, 2013). Finally, several of our subjects reported that their eyes were open during these experiences, and mentioned them in conjunction with concentration, never drowsiness or sleep. Nevertheless, future studies of meditation-induced light experiences should include real-time measurements of brain activity to rule out this possibility.

Now that some of the basic phenomenology of meditation-related light experiences has been described, we can begin to investigate follow-up questions in a hypothesis-driven experimental design that uses quantitative statistical analyses. Future studies would benefit from investigating light-related experiences in larger sample of practitioners, with a range of practice types and durations, including secular, clinical meditation practices (e.g., MBSR). The hypothesized link between concentration and meditation-induced light experiences could be empirically investigated with neuropsychological tests of attention (e.g., SART) and concurrent neuroimaging (fMRI, EEG). Real-time neuroimaging concurrent with reports of light experiences may be able to determine neurological mechanisms as well as the possible relationship to hypnagogic hallucinations. Future studies should also make an effort to control for light exposure, both in terms of the ambient light in the environment, and in terms of whether the eyes are open or closed. Changes in light exposure can result in compensatory changes in the retina (dark adaptation) that may also cause short-lived changes in visual experience (Lamb and Pugh, 2004). Similarly, visual after-effects are also brief adaptations in response to certain stimuli that may be mediated at the level of the eye or brain (Rhodes et al., 2003). Because eye-based changes are less enduring than brain-based changes, more information about the duration of meditation-induced light experiences may also help elucidate their underlying sensory and neural mechanisms.

CONCLUSION

This paper demonstrates importance of engaging with traditional Buddhist presentations of the states and stages of meditation, as what is described in the texts in many cases is very closely linked with reports of meditation experience derived from contemporary practitioners. By investigating traditional Buddhist sources, meditation researchers and clinicians will be more informed about the varieties of meditation experiences and their possible significance. Investigating meditation-induced light experiences suggests that on account of restricting attention by deselecting sensory stimuli, certain meditation practices may function in a manner analogous to sensory deprivation and perceptual isolation. The arising of lights may signal a period of enhanced neuroplasticity and potential for important and enduring shifts. Further research should investigate whether it is the unique configuration of sensory deprivation, attentional training, and investigative processes that accounts for why meditative practices tend to lead to enduring perceptual and affective changes and cognitive insights.

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The neuroscientific study of spiritual practices

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The purpose of this paper will be to provide a perspective on the current state of the research evaluating the neurobiological correlates of spiritual practices and review the methodological issues that confront this research field. There are many types of spiritual practices that might be studied including prayer and meditation, as well as unusual practices such as mediumistic trance states, speaking in tongues, and also drug-induced experiences. Current studies have utilized neuroimaging techniques including functional magnetic resonance imaging, single photon emission computed tomography, and positron emission tomography. These studies have helped elucidate the neurobiological mechanisms associated with spiritual practices. Such studies confront unique challenges for scientific methodology including determining the most appropriate objective measures such as neuroimaging studies and physiological parameters, and correlating them with subjective measures that help capture states of spiritual significance. Overall, a neuroscientific study of spiritual practices and experiences has the potential to provide fascinating data to further our understanding of the relationship between the brain and such phenomena.

Keywords: spiritual practice, meditation, prayer, neuroimaging, physiology, methodology

INTRODUCTION

The recently expanding field of research exploring the neuroscience of religious and spiritual practices and associated experiences has raised important issues regarding the validity, importance, relevance, and need for such research. At the outset, it should be stated that the focus of this paper is specifically on practices that have a spiritual or religious context such as prayer, speaking in tongues, or certain types of meditation. However, it should also be noted that there are a substantial number of studies that have evaluated meditation practices that are not specifically spiritual (i.e., secular mindfulness programs). There are fewer studies on specifically spiritual practices. Studies of meditation practices not related to a particular religious or spiritual tradition still provide information that may contribute to the overall study of religious and spiritual phenomena, but that is not the focus of this paper. The best way to develop this field is to determine the methodological issues that currently affect the field and explore how best to address such issues so that future investigations can be as robust as possible. This paper will review four components of this area of research with a critical perspective on methodology and analysis: (1) appropriate measures and definitions; (2) subject selection and comparison groups; (3) study design; and (4) theological and epistemological perspectives.

MEASUREMENT AND DEFINITION OF SPIRITUALITY AND RELIGIOUSNESS

DEFINITIONS

As someone who has studied the neurophysiology of a variety of practices with both spiritual and non-spiritual goals, I have realized that great importance and complexity in first trying to define spirituality and religiousness as terms and also to differentiate spiritual experiences from spiritual practices (Newberg, 2010). This latter issue has significant implications for research as the practices might be studied using different approaches from the experiences (Nash and Newberg, 2013). Although a variety of approaches may be used, for an adequate development of this field, it is important to define terms operationally so that they can be studied effectively. There is significant overlap between these terms with both having personal and group elements, emotional and cognitive elements, and experiential elements. One of the primary distinctions is that religiousness tends to relate to a particular religious tradition. Perhaps the most important point to be made is that every researcher or scholar should provide in their writings the definition of religiousness or spirituality that they applied so that others can better assess the usefulness of their scholarship.

SUBJECTIVE MEASURES

In some sense, the most relevant measures of religious and spiritual practices are those that relate to the subjective nature of their associated experiences. When a person has a religious or spiritual experience, it is frequently described in terms of cognitive, behavior, and emotional parameters. Importantly, a person will label or define the experience as "spiritual" which differentiates the experience from others which are regarded as "non-spiritual." The issue with measuring the subjective elements of these phenomena is crucial since these elements are not immediately observable by an outside investigator. The problem becomes more difficult when comparing experiences across individuals and cultures. The question for any researcher is how to get some handle on the subjective component of such experiences. Is there a way to quantify and compare these subjective feelings and thoughts individuals have regarding their spiritual experiences? And how does a researcher evaluate the authenticity of a "religious or spiritual" experience? For example, some researchers suggest that the concept of "certainty" or "meaningfulness" is an important element of spiritual practices and experiences. Other scholars have explored the relationship between meaningfulness, social connectedness, and love (Frederickson, 2013), all of which can also be tied to specific areas of the brain.

A number of attempts have developed self-reporting scales that measure the subjective nature of a particular religious or spiritual elements. The book, Measures of Religiosity (Hill and Hood, 1999) provides an extensive review of various scales and questionnaires that assess everything from feelings of religious commitment, to mystical experiences, to the direct apprehension of God. Some have been assessed for validity and reliability which is critical if these scales are to have any use in future research studies. Of course, defining what a spiritual experience is, while of critical importance, proves to be highly problematic from a scientific perspective. If someone defines spiritual as a feeling of "awe" and another as a feeling of "oneness," what types of questions should be used to assess and measure spirituality? Most scales of spirituality and religiousness require the individual to respond in terms of psychological, affective, or cognitive elements. Such measures are quite valuable for exploring the neural correlates of spiritual experiences because psychological, affective, and cognitive elements can usually be related to specific brain structures or functions. However, a problem with phrasing questions in this way is that one may not get at something that might be "truly" spiritual. Finally, it is unclear how science should handle what are frequently referred to as anomalous elements of such experiences. These elements include near death experiences in which people purportedly describe the environment around them at the time of death, or mediums who perceive encounters with different spirits (Beauregard et al., 2009; Peres et al., 2012). Such anomalous events are important for science to consider, but certainly pose a substantial challenge as well.

OBJECTIVE MEASURES OF SPIRITUALITY

Objective measures of religious and spiritual phenomena that pertain to the neurosciences include a variety of physiological and neurobiological measures. Most studies to date have been performed on meditation practices that are not specifically spiritual in nature, but the methods and results from these studies should inform future studies of spiritual practices. A number of studies have revealed changes in blood pressure and heart rate associated with meditation based practices, although these practices were not associated with spiritual approaches (Sudsuang et al., 1991; Jevning et al., 1992; Koenig et al., 2001). The autonomic nervous system changes may be complex involving both a relaxation and also an arousal response (Hugdahl, 1996). Several studies have reported predominant parasympathetic activity during spiritual practices which includes decreased heart rate and blood pressure, decreased respiratory rate, and decreased oxygen metabolism (Sudsuang et al., 1991; Jevning et al., 1992; Bernardi et al., 2001; Travis, 2001). However, other studies have suggested a mutual activation of parasympathetic and sympathetic systems by demonstrating an increase in the variability of heart rate during meditation (Peng et al., 1999). Measures of hormone and immune function have also been explored especially as an adjunct measure to various clinical outcomes (O'Halloran et al., 1985; Walton et al., 1995; Tooley et al., 2000; Infante et al., 2001). Hormonal changes associated with spiritual practices include those to cortisol, noradrenaline, endorphins, sex hormones, and growth hormone (Werner et al., 1986; MacLean et al., 1997; Nidhi et al., 2013; Sooksawat et al., 2013). Again though, these practices were not specifically spiritual. There are only a few report of physiological changes associated with specifically spiritual practices such as the Rosary.

Neurobiological changes associated with religious and spiritual practices can be observed through a number of techniques that each have their own advantages and disadvantages. Early studies of meditation practices often used electroencephalography (EEG) which measures the electrical activity in the brain (Banquet, 1973; Hirai, 1974; Hebert and Lehmann, 1977; Corby et al., 1978). EEG is valuable because it is relatively non-invasive and has very good temporal resolution, although it can suffer from artifact related to the skull or scalp. Overall, EEG has continued to be useful in the evaluation of specific meditation states (Lehmann et al., 2001; Aftanas and Golocheikine, 2002; Travis and Arenander, 2004). The major problem with EEG is low spatial resolution which can only be localized over very broad areas of the brain. A newer technique, with improved spatial resolution, called magnetoencephalography (MEG) has been developed and already used to explore meditation practices (Yamamoto et al., 2006; Kerr et al., 2013).

Functional neuroimaging studies of religious and spiritual practices have utilized positron emission tomography (PET), single photon emission computed tomography (SPECT), and functional magnetic resonance imaging (fMRI). Each technique has its advantages and limitations with respect to evaluating religious and spiritual phenomena. Functional MRI primarily measures changes in cerebral blood flow in brain structures during a specific task. Functional MRI has very good spatial resolution and also has excellent temporal resolution, although not as good as EEG or MEG. For example, fMRI can evaluate the differences in blood flow between 10 different prayer states in one imaging session over a period of 20 min. Furthermore, fMRI does not involve any radioactive exposure. The disadvantages are that images must be obtained while the subject is lying in the scanner which can make up to 100 decibels of noise. This can be distracting when individual are performing spiritual practices and also prevents studying practices that require certain postures or movements. However, several investigators, including our group, have successfully utilized fMRI for the study of meditation (Lazar et al., 2000; Wang et al., 2011; Vago and Silbersweig, 2012). A final disadvantage is that at the present moment, fMRI cannot be used to evaluate neurotransmitter systems which might ultimately be of interest in the study of spiritual practices. However, one study did utilize magnetic resonance spectroscopy to find an increase in gamma amino butyric acid during yoga training (Streeter et al., 2007).

Positron emission tomography imaging has relatively good spatial resolution (comparable to fMRI) but SPECT is slightly worse. PET and SPECT both require the injection of a radioactive tracer which results in some radiation exposure, although this is usually low. Depending on the tracer utilized, a variety of neurobiological parameters can be measured including cerebral blood flow, metabolism, and different neurotransmitters. The ability to measure neurotransmitter systems is unique to PET and SPECT imaging at the present time. Some of the more common tracers can be injected through an existing intravenous catheter when the subject is not in the scanner allowing for a more favorable environment for performing spiritual practices (Herzog et al., 1990–1991; Newberg et al., 2001). A major disadvantage to PET and SPECT imaging is that these techniques have generally poor temporal resolution. Depending on the tracer, this resolution can be as good as several minutes and as bad as several hours or even days. Usually only two or three states might be measured in the same imaging session if the appropriate radiopharmaceutical is used (Lou et al., 1999; Newberg et al., 2006). Since spiritual experiences may be quite brief, it is not clear how effectively neuroimaging studies might be able to capture the specific moment related to something spiritual.

In spite of these and other technical limitations, neuroimaging studies have been successfully utilized to evaluate specific spiritual and meditative practices. There are a growing number of studies which have spanned the different neuroimaging techniques (Lou et al., 1999; Newberg et al., 2001, 2003; Kjaer et al., 2002; Lutz et al., 2008; Brewer et al., 2011; Xue et al., 2011). Interestingly, there appears to be some coherence of their findings with the frontal lobes, parietal lobes, thalamus, and limbic system frequently related in a network associated with such practices. However, different practices also yield distinct brain function patterns. For example, meditation practices often demonstrate increased frontal lobe function while trance practices often demonstrate decreased frontal lobe function (Herzog et al., 1990–1991; Lazar et al., 2000; Newberg et al., 2001; Tang et al., 2009; Peres et al., 2012). Future studies will certainly be necessary to more thoroughly evaluate the neurobiological changes that occur in the brain during various religious and spiritual phenomena. Ultimately, such studies should also attempt to integrate neurological changes with body physiological effects as there are a number of studies which have demonstrated a neurovisceral response between the body and various emotions and thoughts (Thayer and Lane, 2000).

SUBJECT SELECTION AND COMPARISON GROUPS

An interesting methodological issue in the study of religious and spiritual phenomena is determining the most appropriate subjects to study and the appropriate comparison group(s). If a researcher wanted to study the physiological effects of the Catholic ritual of the Rosary, the subject group would have to consist of individuals who actually practice the Rosary. This raises another important issue which is the level of expertise or proficiency of the study subjects. How do we know how proficient a practitioner of a particular practice actually is? Should expertise be based upon subjective measures, duration of practice, or other measures? There could be very different results between novice, experienced, and master level individuals of particular practices.

In terms of comparison states and control groups, one common approach in functional neuroimaging studies is that the individual acts as their own comparison. For example, the subject can perform two similar tasks, one with and one without spiritual meaning (Azari et al., 2001). The more global issue of comparison states is to make them as equivalent as possible to the spiritual practice regarding a wide range of elements including whether eyes are opened or closed, speaking or not speaking, listening or not listening, etc. But ultimately, the comparison state should not result in a concomitant spiritual experience. Placebo effects pose another interesting problem in the study of spirituality or religiosity, and require careful consideration when designing a study so that there is an adequate placebo or control group. It is not clear what a placebo group would represent since most people know whether or not they are actually performing a spiritual practice. Perhaps more importantly is the potential overlap between the placebo response and spiritual responses in terms of their similar elements and potential underlying brain functions (Kohls et al., 2011).

STUDY DESIGN APPROACHES

There are at least four general neuroscientific paradigms which can readily contribute to the initial operationalization of studying spiritual experience (Larson et al., 1998). There are likely many others, but these initial four paradigms include: (1) the neurophysiology of spiritual interventions, (2) drug-induced spiritual experiences, (3) neuropathologic and psychopathologic spiritual experiences, and (4) physical and psychological therapeutic interventions.

THE NEUROBIOLOGY OF SPIRITUAL PRACTICES

The first paradigm involves studying specific spiritual practices using subjectively derived psychological and spiritual measures which can then be compared to simultaneously derived neurobiological parameters, such as electroencephalographic activity, cerebral blood flow, cerebral metabolism, and neurotransmitter activity (Newberg and Iversen, 2003). Such measures can be performed with EEG, PET, SPECT, or MRI. Many studies have now been performed utilizing imaging to evaluate meditation (see supplementary materials), but these imaging techniques may be applied to the vast array of spiritual practices such as prayer, religious singing, rituals, etc., or while a person is reflecting on a previous spiritual experience (Beauregard et al., 2009). Body physiological parameters such as blood pressure, body temperature, heart rate, and galvanic skin responses can also be measured. Other parameters such as immunological assessments, hormonal concentrations, and autonomic activity can also be evaluated to provide a thorough analysis of the effects of spiritual practices. These physiological parameters can be correlated with experiences and also with neuroimaging measures to obtain a more thorough analysis of the overall effects of spiritual practices. Further, physiological measures might yield interesting results and point to the directionality of functional changes in the brain and body associated with such practices.

DRUG-INDUCED SPIRITUAL EXPERIENCES

A second paradigm that might be employed utilizes hallucinogenic agents that are known to result in intense spiritual experiences. Since it has long been observed that drugs taken recreationally such as opiates, LSD, and stimulants can sometimes induce spiritual-like experiences; and specific traditions use exogenous substances to induce spiritual states and experiences; careful studies of these drug-induced experiences, perhaps utilizing modern imaging techniques, may help elucidate which neurobiological mechanisms are similarly involved in more "naturally derived" spiritual experiences (i.e., through prayer or ritual). Some neuroimaging studies exploring hallucinogenic agents have already been performed (Vollenweider et al., 1997, 1999, 2000), but a more extensive study of such agents, particularly in relation to religious and spiritual experiences is required. There are obvious ethical and legal considerations with these studies, however, such studies provide fascinating perspectives on the relationship between various neurotransmitter systems affected by these drugs and religious and spiritual experiences. Further, there is growing evidence that hallucinogenic drugs might be useful in the management of addiction disorders which might help relate spirituality to the neuronal circuits associated with addition (MacLean et al., 2011).

NEUROPATHOLOGIC AND PSYCHOPATHOLOGIC SPIRITUAL EXPERIENCES

A third paradigm would utilize patients with various neurological and/or psychological conditions. Neurological conditions including temporal lobe seizures, brain tumors, and stroke, have been associated with spiritual experiences or alterations in religious beliefs. Temporal lobe epilepsy has been associated with hyperreligiosity and religious conversions (Bear and Fedio, 1977; Bear, 1979). Head injury in the parietal lobes has been associated with feelings of self-transcendence (Urgesi et al., 2010). Psychiatric disorders such as schizophrenia and mania also have been associated with spiritual experiences and religious conversions. Delineating the type and location of pathology will aid in determining the neurobiological substrates or networks related to spiritual experiences. However, care must be taken to avoid referring to spiritual experience only in pathological terms as well as not reducing spiritual experiences only to pathophysiological mechanisms (Newberg and Lee, 2005).

PHYSICAL AND PSYCHOLOGICAL THERAPEUTIC INTERVENTIONS

There are a growing number of studies which have explored the therapeutic effects of meditation, stress management, prayer, and other related interventions for various psychological and physical disorders including anxiety, hypertension, heart disease, and cancer (Levin and Vanderpool, 1989; Leserman et al., 1989; Kabat-Zinn et al., 1992; Levin, 1994; Miller et al., 1995; Massion et al., 1995; Schneider et al., 1995; Zamarra et al., 1996). Performing high quality studies is essential to demonstrating the relationship between spirituality and health especially in light of the various criticisms that have been raised regarding methodological issues with these early studies (Sloan et al., 1999; Sloan and Bagiella, 2002). Such studies also provide insight into the longer term effects of spiritual practices and experiences.

THEOLOGICAL AND EPISTEMOLOGICAL IMPLICATIONS

In considering the neuroscientific approach to religious and spiritual phenomena, one can ponder whether theological and epistemological issues can actually be addressed, sometimes referred to as "neurotheology" (Newberg, 2010). For example, brain correlates may help explain certain elements of spiritual practices. However, a biological correlate does not necessarily negate an actual spiritual component. Even situations in which religious states are induced by pharmacological agents does not necessarily detract from the spiritual nature of these states for the individual. For example, Shamanic practices in which various substances are ingested to aid in the spiritual journey are not viewed as less real or less spiritual by the participants because of the use of these exogenous substances. However, it is also important to recognize that religious practices do not confer an epistemically privileged position from which to ascertain "the reality." Either way, this field of research may ultimately tread upon some fascinating, and problematic, philosophical issues. Such issues as they pertain to the experience of reality and the realness of religious phenomena should at least be kept in mind by researchers as this field expands.

CONCLUSION

While the neuroscientific study of religious and spiritual phenomena has advanced substantially since some of the initial studies performed over 30 years ago, this field of research is still in its nascent stages. There are many unique methodological challenges facing this field in addition to the usual barriers of funding and academic stature. However, pursuing such projects may pay large dividends both for science and spiritual disciplines. From the religious perspective, such studies may help toward a better understanding of the human experience of spirituality and religion. From the scientific perspective, such research may help elucidate the complex workings of the human brain as well as the overall relationship between brain states and body physiology. Ultimately, if the methodological challenges can be met, studies of spiritual practices and their associated experiences could provide important knowledge for linking our scientific and spiritual pursuits.

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Toward a unifying taxonomy and definition for meditation

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One of the well-documented concerns confronting scholarly discourse about meditation is the plethora of semantic constructs and the lack of a unified definition and taxonomy. In recent years there have been several notable attempts to formulate new lexicons in order to define and categorize meditation methods. While these constructs have been useful and have encountered varying degrees of acceptance, they have also been subject to misinterpretation and debate, leaving the field devoid of a consensual paradigm. This paper attempts to influence this ongoing discussion by proposing two new models which hold the potential for enhanced scientific reliability and acceptance. Regarding the quest for a universally acceptable taxonomy, we suggest a paradigm shift away from the norm of fabricatIng new terminology from a first-person perspective. As an alternative, we propose a new taxonomic system based on the historically well-established and commonly accepted third-person paradigm of Affect and Cognition, borrowed, in part, from the psychological and cognitive sciences. With regard to the elusive definitional problem, we propose a model of meditation which clearly distinguishes "method" from "state" and is conceptualized as a dynamic process which is inclusive of six related but distinct stages. The overall goal is to provide researchers with a reliable nomenclature with which to categorize and classify diverse meditation methods, and a conceptual framework which can provide direction for their research and a theoretical basis for their findings.

Keywords: meditation, taxonomy, definition, contemplative traditions, contemplative neuroscience, cognition, affect, consciousness

ANALYSIS OF THE DEFINITIONAL AND TAXONOMIC ISSUES

OVERVIEW OF THE PROBLEMS RELATED TO DEFINITION AND DESCRIPTION

In this section we consider various attempts to define meditation, and discuss the conceptual issues and the difficulties encountered.

The contemplative traditions and subsequent westernization have produced a proliferation of many disparate meditative practices utilizing different techniques and espousing different goals. For example, if one searchers the Yellow Pages Online Directories for major international cities one can find numerous listings under the heading "meditation" i.e., Los Angeles—156, Chicago—122, N.Y.C.—307, London—126, Sydney—139, and Stockholm—108 (as of August 1, 2013). It is quite apparent that "meditation" has become a generic term, used to describe a host of secular, spiritual, and/or religious contemplative activities; as well as becoming a synonym for many other more mundane cognitive functions such as contemplation, reflection, concentration, and terms such as ponder, ruminate, cogitate, and deliberate. Although convenient for everyday usage, the casual use of a generic term to group any activity or practice can cause obvious difficulties in communication due to false assumptions of similarity.

Neuroscientists and other meditation researchers have also floundered on this point by commonly using the generic term "meditation" to refer to a wide variety of disparate methods which "inevitably trivializes the practices themselves" (Lutz et al., 2007, p. 500). In addition there has been a tendency to mix-and-match different methods as if they were equivalent which has resulted in an unfortunate conflation of definition (Awasthi, 2013). This struggle to clearly define meditation is affirmed by Bond et al. (2009) who identified five commonly used definitional themes in their review of the meditation research literature. Currently, the scientific literature contains two popularly used definitions for meditation. One "camp" has defined meditation essentially as a family of mental training techniques (e.g., Cahn and Polich, 2006; Lutz et al., 2008b; Raffone and Srinivasan, 2010)—which we shall call the "method definition." The other "camp" has defined meditation by reference to the enhanced experiential states or altered states of consciousness which arise from the use of these methods e.g., "pure consciousness[1]," "absolute unitary being[2]," and "non-dual awareness[3]"—which we shall call the "state definition." It is obvious that difficulties in comparing research results are inevitable when investigators use two essentially different definitions to refer to the same term.

This conflation of definition is exemplified by recent commentary regarding attempts to classify Transcendental Meditation™ (Josipovic, 2010; Travis and Shear, 2010a,b), in which the authors use several conceptually distinct lexicons to argue their positions. There is a discussion as to whether "focused-attention" (FA)[4], "open-monitoring" (OM)[5], or "non-dual awareness" (NDA) are appropriate classifications for TM. However, FA and OM were formulated as theoretical categories of meditation techniques based on two different cognitive strategies employed during the method stage (Lutz et al., 2008b); whereas NDA was devised to describe a particular enhanced state of awareness. In this case, one author was objecting to the appropriateness of using a certain definition of method, while the other author was using a definition based on the resultant state. Adding to the perplexity, Travis asserted that TM should not be classified into any of the aforementioned lexicons. He offered a fourth category based on an entirely different notion—"automatic self-transcending"; a hypothetical proposal of what happens when there is a shift from one state of consciousness to another.

On the other side of the coin, several authors have stressed the importance of making an explicit distinction between method and state, whereas the state is considered to be the causal result of the successful application of the method (West, 1987b; Koshikawa and Ichii, 1996; Lutz et al., 2007; Awasthi, 2013).

Contributing to this definitional problem is the ubiquitous paucity of information given when researchers describe methods of meditation chosen for study (Lutz et al., 2007; Ospina et al., 2007). Researchers typically select their meditator-subjects from a locally available group of individuals who have been engaged in a particular method of practice; and then identify the method by its name and tradition as if this was sufficient. Occasionally a general description is offered, but mostly there is a failure to account for and report many of the salient particularities of the chosen method—such as non-verbal vs. verbal, eyes open vs. closed, natural vs. regulated breathing, static vs. kinetic body movements, etc. Although there have been some attempts to describe meditation methods by utilizing certain salient features (Koshikawa and Ichii, 1996; Lutz et al., 2007; Ospina et al., 2007), as of yet neuroscientists have not employed a standardized protocol to describe the meditation methods they are studying. We contend that this omission is a significant impediment to the advancement of this field given that any, and perhaps all, of the salient features of a given technique may affect neurobiological findings (see section The Taxonomic Keys).

To summarize, even a casual review of the literature reveals a frequently occurring theme lamenting the lack of a standardized approach to define "meditation," and the challenge this poses for researchers (West, 1987b; Taylor, 1997; Lutz et al., 2007; Ospina et al., 2007).

We concur that it is counter-productive if the term "meditation" is employed in a generic or non-descript way, and if there is an unclear distinction between the notions of method and state. We posit that these definitional issues may have contributed to the confusing, contradictory, and inconsistent findings that have emerged from the field of contemplative neuroscience. As we discuss later on in this paper, since method and state demonstrate different neurobiological correlates, researchers need to recognize what they are measuring during a given meditation session and carefully distinguish method from state. For example, the effects on resting state functional connectivity (the Default Mode Network) in various meditation styles, often reported in the literature with seemingly inconclusive/mixed findings (Awasthi, 2013), may be attributed to this conflation of definition.

OVERVIEW OF THE PROBLEMS RELATED TO TAXONOMY

> *A well-conceived and useful taxonomy has the power to frame all theoretical considerations of a particular field of study. It is natural, and in fact historical, for scientists and philosophers to desire to segregate and classify the things and processes of this world.* (Ereshefsky, 2000, p. 50–51).

In this section we review and analyze various attempts to devise taxonomic categories for meditation methods, an approach quite similar to Overview of The Problems Related to Definition and Description above. In some ways this can be viewed as an artificial distinction, in that the issues and particulars of taxonomy often overlap with those of definition, especially from an historical perspective. However, we feel that certain important distinctions warrant separate consideration.

The struggle to formulate a universally acceptable taxonomy of meditation has been well-documented and is exemplified by the work of Ospina et al. (2007). Their Evidence Report: Meditation Practices for Health: State of the Research was undoubtedly the largest, most ambitious, and most comprehensive survey of meditation research ever undertaken. It included an analysis of over 1000 published papers and references. They attempted to group over 30 meditation methods into "five broad categories" using an empirical taxonomic approach: Mantra, Mindfulness, Tai Chi, Qigong, and Yoga. However, this nomenclature appears to have been contrived without an overarching theoretical framework. The first category refers to the conceptual focus of attention, the second refers to the cognitive strategy employed, and the others were based on three different traditional forms of practice. It is understandable then that their effort to construct a taxonomy was frustrated "given the variety of the practices and the fact that some are single entities . . . while others are broad categories that encompass a variety of different techniques." They concluded that it was "impossible to select components that might be considered universal or supplemental across practices" (p. 2–3); that "characterization of the universal or supplemental components of meditation practices was precluded by the theoretical and terminological heterogeneity among practices" (p. 5); and that since the term "meditation is an umbrella term . . . this lack of specificity . . . precludes developing an exhaustive taxonomy of meditation practices. (p. 10).

Currently, neuroscientists and other researchers still do not have an overarching, consensual framework with which to understand and study this highly specialized form of mental "exercise" and its many different forms. It has occurred to us that this situation, with its robust semantic difficulties, is somewhat similar to the conundrum that Linnaeas faced in the 1700's.

> *"Three hundred years ago biological taxonomy was a chaotic discipline marked by mis-communication and misunderstanding. Biologists disagreed on the categories of classification, how to assign taxa to those categories, and even how to name taxa. Fortunately for biology, Linnaeas (attempted to) . . . bring order to taxonomy. The system he introduced offered clear and simple rules for constructing classifications. It also contained rules of nomenclature that greatly enhanced the ability of biologists to communicate."* (Ereshefsky, 2000, p. 1).

Common reasons given for the taxonomic difficulties we face today are the complexity and diversity of meditation techniques and the ineffable nature of the meditative state. However, we posit that many of these difficulties can also be attributed to the exclusive use of first-person constructs, and the limitations of the taxonomic methods that have been employed.

The first point is illustrated by the plethora of lexicons that have been devised to classify meditation methods over the last 40 or so years. Early proposals [as reviewed by West (1987a)] used terms such as "concentrative vs. opening-up" (Ornstein), "concentrative vs. insight" (Goleman), and "wide angle lens attention vs. zoom lens attention" (Shapiro); and recently new terminology has been introduced such as "open presence[6]" (6); the "active" and "passive" approaches (Newberg et al., 2001); and the previously mentioned "focused attention," "open monitoring," "non-dual awareness," and "automatic self-transcending." These first-person semantic constructs have undoubtedly been helpful, but their use as a basis for taxonomy is not without problem. We argue that this strategy has contributed to misunderstanding, ambiguity, and confusion, and has been an impediment toward consensus. This is not to minimize or reject the value of first-person accounts as important phenomenological data for meditation research (Pekala, 1987). They have certainly been necessary for such tasks as the recording of "peak experience" (Newberg and d'Aquili, 2001) and "transcendence" (Travis and Pearson, 2000; Travis et al., 2002), or in the broader study of consciousness (Wallace, 2000; Costall, 2006). However, such accounts can be somewhat unreliable as they depend on the accurate recording of the mental states of the subject and the proper accounting of a host of varied external and internal factors. Hence, first-person accounts lack the stability and consistency required to provide a stand-alone, reliable foundation for scientific research. Although first-person reports are potentially useful as data, first-person constructs are theoretically and semantically ill-suited for the formulation of orthogonal taxonomic domains. The difficulties facing the scientific use of first person accounts has been well known to cognitive scientists since the early 20th Century critique of "introspectionism," but for some reasons this seems to have escaped the scholars and neuroscientists attempting to establish scientifically usable categories for meditation taxonomies (Dreyfus, 2013, pers. commun.).

We have concluded that an alternative approach is required. We contend that the use of a widely accepted third-person paradigm offers the potential for a clearer semantic distinction and a more reliable platform/framework for research, as opposed to the use of unique but ambiguous first-person categories, however enticing those may be.

In addition, prevailing taxonomies of meditation have employed a "piecemeal" approach similar to classical "phenetic" taxonomic philosophy (Ereshefsky, 2000). That is, they have attempted to segregate meditation methods based on observable characteristics or features e.g., grouping all methods that use a mantra under one rubric; or trying to group methods according to the particular cognitive strategy employed. We argue that while such particulars may be suitable for lower order classifications of meditation, they are not sufficient for the formulation of an over-arching system of orthogonal Domains. There are simply too many different methods, features, nuances, and traditions to permit higher-order categorization based solely on characteristics (Ospina et al., 2007). While taxonomic pheneticism may be effective for biological systems, we propose that an alternative taxonomic approach may prove to be more suitable for the classification of meditation.

Summary

We propose to use the above analysis of the extant problems and their root causes to devise a new definition and taxonomy for meditation. A multi-faceted approach will include: defining meditation as a dynamic process with separate stages that unfold over time; a new taxonomic system which uses a well-established third-person paradigm, in conjunction with some necessary first-person perspectives, to formulate three Linnaean-type overarching Domains; and describing and segregating methods within each Domain according to a table of taxonomic keys.

A PROPOSAL FOR A NEW DEFINITION AND TAXONOMY

Given the extant problems of definition and classification, how then can we proceed to formulate a more effective descriptive model for the discussion and study of meditation?

We proceed by defining the difference(s) between method and state, and then propose a model which describes how they interact as distinct stages of a dynamic process.

DEFINITION

Rationale

As previously discussed, meditation has been typically defined in one of two ways—as either a family of mental training techniques (the "method definition"), or in relation to the particular altered states of consciousness that arise from the implementation of the technique (the "state definition"). We address this potentially confusing duality by proposing a model of meditation which is inclusive of both method and state. In this paradigm, method and state are viewed as separate stages in a dynamic process which unfolds over time. The method is considered to be a potentially facilitative tool and the state is the causally-related intended result. As such, we support the premise that researchers need to recognize and carefully segregate these two stages so as not to confound "the neural correlates of the meditation techniques that are used to get to particular 'states' of consciousness, with the correlates of the 'states' themselves" (Josipovic, 2010).

A new definitional model of meditation as a dynamic process

The various stages of this dynamic process can be represented by a standard flow diagram (see Illustration 1) which depicts their relationship to each other as a meditation session progresses, and helps to explain how the model works. A given meditation session is defined as the time allocated by the meditator to the engagement of the process; whereby the meditator starts from a mundane state of alert/waking consciousness, moves through the specific stages of the process over time, and then returns to that same state of waking consciousness. This does not infer that nothing has changed with regard to trait or plasticity, but rather that one begins and ends in essentially the same state of consciousness.

This idea of considering meditation as a series of stages has been proposed by others, most recently by Tang et al. (2012) who advanced the idea of three stages of meditation practice. In this model, meditation is codified into six stages. We also suggest that there are important neurobiological correlates associated with most of these stages.

Normal (N). This is the pre-meditative stage of normal waking/resting consciousness. This is the baseline state where one is mentally preoccupied with the mundane thoughts, feelings, and activities of daily life; and which can be distinguished from other states of consciousness by certain defining neurobiological correlates (Lou et al., 1999; Vaitl et al., 2005; Lutz et al., 2007). Interestingly, this is an area that has received some attention in the neuroscientific literature. Specifically, this subjective state appears to be linked to what is currently regarded as the "default network" in the brain, first described by Raichle et al. (2001). The structures that tend to be involved in this resting or baseline state of the brain play a role in how we ultimately utilize the brain for various cognitive and affective tasks. The default mode network essentially allows the brain to be poised to be able to react to various stimuli or activities. There are several studies that have suggested that the resting brain is actually altered by meditation practices. Studies of long term meditators have revealed differences in the baseline structure and function of the brain (Lazar et al., 2005; Pagnoni and Cekic, 2007; Pagnoni, 2012) and, more specifically, in the default network (Jang et al., 2011; Berkovich-Ohana et al., 2012). Furthermore, longitudinal studies have shown that the resting state of the brain can be altered by employing a regular meditation practice. Thus, the normal resting state of the brain is still a highly relevant concept in the context of meditation techniques and their effects.

Intention to begin (IB). This is the willful intention to initiate the process, which manifests in the actions taken to implement the subsequent stages of the process. One can speculate that this intention could be sustained through the preliminary stage until the actual engagement of the Method. This is a key denotation in our model because it highlights the importance of volition in the engagement of the meditation process. In this paradigm meditation is considered as a conscious and willful act unaided by any extrinsic mind-altering substances, whereby the meditator exercises personal control to employ a particular method. Therefore, we also exclude the occasional transcendent experience brought on by a serendipitous "special moment," as well as the experience of being hypnotized by someone else through the power of suggestion.

Initial models of meditation have indicated that this stage has a neurophysiological correlate, most likely in the prefrontal cortex (PFC) which is involved in the initiation of willful behaviors. Early studies demonstrated increased activity in the PFC during many different types of meditation practices. Brain imaging studies suggest that willful acts and tasks that require sustained attention are initiated via activity in the PFC, particularly in the right hemisphere (Posner and Petersen, 1990; Frith et al., 1991; Pardo et al., 1991; Ingvar, 1994). The cingulate gyrus has also been shown to be involved in focusing attention, most likely in conjunction with the PFC (Vogt et al., 1992). Since meditation methods often require intense focus of attention, it seems appropriate that the initiation of the meditation process begins with activation of the PFC (particularly the right) as well as the cingulate gyrus. This notion is supported by the increased activity observed in these regions in several of the brain imaging studies of volitional types of meditation (Herzog et al., 1990–1991; Lazar et al., 2000). In a study of Tibetan Buddhist meditators, there was increased activity in the PFC bilaterally (greater on the right) and the cingulate gyrus during meditation (Newberg et al., 2001). Therefore, meditation appears to start by activating those areas of the cortex associated with the will or intent to clear the mind of thoughts or to focus on an object.

Preliminaries (P). This is a preparatory phase in which a particular setting and certain rituals may be employed to set the "proper tone" for the meditation session. This could consist of simply going into a specially designated room, turning off the lights, and sitting comfortably; and/or using a special pillow or cushion, lighting incense and/or candles, donning a special shawl, playing certain types of music, etc.

Rituals have certainly been found to have a substantial impact on brain function, in part through rhythmic or repetitive elements. Thus, specific music, phrases, or objects for which the brain is familiar, may initiate those processes that will proceed in the method stage. For example, a number of studies have suggested that music affects the brain (Satoh et al., 2003; Saito et al., 2006; Eldar et al., 2007) particularly in the limbic or emotional centers of the brain (Newberg et al., 2010). While there is less evidence for the neurophysiological effects of specific preparatory processes, one might speculate that activation of the amygdala to signify that an important activity is about to occur may help to move the brain from the default network processes to the purposeful processes of the method stage involving the PFC (Newberg and Iversen, 2003).

Method (M). Methods, in a general sense, can be thought of as procedures or techniques that are employed in order to do or accomplish something. With regard to meditation, methods have been defined as "a family of complex emotional and attentional regulatory training regimes developed for various ends, including the cultivation of well-being and emotional balance" (Lutz et al., 2008b, p. 163). Typically, one would use a training regime in an attempt to acquire a particular skill for a particular purpose, through practice and instruction over a period of time. When we apply this notion to meditative practices we see that the method is used to develop the skills to regulate (control or direct) the mental faculties of attention and emotion. We will return to these notions of attention (cognition) and emotion (affect) later on in this paper.

Meditation methods typically purport to yield both immediate and long-term outcomes: the attainment of certain altered states of consciousness during a given meditation session—often referred to as the "state" effect (Lehmann et al., 2001; Lutz et al., 2007); and that continued practice can lead to the realization of other goals or benefits that relate to a person's overall approach, skill set, or perspective on life—often referred to as the "trait" effect (Cahn and Polich, 2006; Lutz et al., 2007; Raffone and Srinivasan, 2010). For the purposes of this proposal, we have chosen to focus on that which transpires during a given meditation session—the state effect.

In this model we consider the Method to be simply the prescribed set of instructions that the meditator employs during a meditation session. These instructions are usually imparted by a teacher, or another form of didactic medium such as books, videos, tapes, etc. Methods invariably contain various cognitive strategies variously described as: concentration, mindfulness, "focused awareness," passive observation, "open-monitoring," memorization and repetition (of certain words, phrases, or narratives), self-inquiry, contemplation, imagination and visualization, and perception (of sounds, lights, and bodily sensations). Also, the mental functions of metacognition and control (Koriat, 2007) play an important role in the meditation process (Hasenkamp et al., 2012; Pagnoni, 2012). The use of metacognitive awareness and control of mind-wandering allows the meditator to be aware of the stages of the process and stay on task.

In addition, we think it is important to recognize that the Method itself only holds a potential for success. One cannot assume that the employment of a particular method is a guarantee of efficacy because there are a host of extrinsic and intrinsic factors that may obviate the desired shift in consciousness e.g., predispositions, biases, the presence of certain drugs or intoxicants, mental disorders, inability to concentrate, external distractions or interruptions, etc. For these reasons we utilize the notion of the "intention" of the method in the formulation of our taxonomic nomenclature (see sections Determination of the Functional Essence of Meditation Methods and Formulation of a Taxonomic Nomenclature for Meditation Methods).

Enhanced mental state (EMS). This is the causal result of the successful application of the Method—an altered state of consciousness, commonly referred to as the meditative state. It is usually accompanied by subjective first-person reports of a shift in consciousness to a different and more "profound" state such as: an enhanced sense of well-being, focus, calm, detachment, insight, affect, bliss, emptiness, etc. EMS has been shown to have neurobiological correlates distinct from the normal resting state and other mundane states of human consciousness (Travis and Pearson, 2000; Newberg and d'Aquili, 2001; Vaitl et al., 2005; Bærentsen et al., 2009). We will consider the evidence and theory supporting this distinction in the following section. EMS may manifest as a fleeting, momentary state (as typically reported by novice practitioners), or may be sustained for considerable periods of time (as typically reported by advanced/experienced practitioners).

Our model articulates three primary types of EMS which will be discussed in detail in section Formulation of a Taxonomic Nomenclature for Resultant States.

Intention to finish (IF). Is the termination of the meditation session in which the practitioner elects to end the process and return to a mundane state of waking consciousness.

STAGES OF THE MEDITATION PROCESS

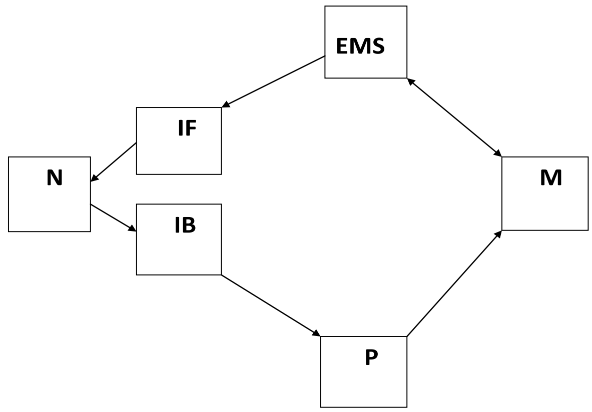
FLOW CHART 1

N = normal(mundane) waking state **IB** = intention to begin

IF = intention to finish **P** = preliminaries

M = method **EMS** = enhanced mental state

* Note the bi-directional arrows between stages 4 and 5 to indicate that during the process the meditator may experience shifts back-and-forth between Method and EMS.



Other possibilities

Our definitional model of meditation as a dynamic process is intended to be inclusive of several different possibilities, and defines meditation as an engagement of the process with the intent of attaining an EMS. Under certain circumstances, even though a practitioner may not engage all the stages of the process, this would still be considered to be "meditation" according to our model e.g., in the case of a novice practitioner who engages the first three stages but is not successful in attaining EMS; the practitioner who is disturbed during the Preliminary or Method stages and quits due to extrinsic factors outside of his/her control; or in the case of an experienced practitioner who no longer needs the "training wheels" *per se*, and is capable of going directly to an EMS at will without the aid of the Preliminary or Method stages.

TAXONOMY

The rationale for a new taxonomic model

We have attempted to avoid the problems encountered by previous efforts by employing alternatives to the prevalent first-person/phenetic strategies.

A third-person approach. As previously noted, researchers and scholars have typically relied on first-person perspectives and their own linguistic ingenuity to fabricate original categories and new terminology. We have argued that such first-person attempts often lack scientific reliability and are thus easy targets for criticism and disagreement when used in such a manner; and that an accepted third-person construct could provide a more reliable semantic paradigm. Since meditation can be considered to be a mental phenomenon, we decided to look to the fields of Psychology and Cognitive Science for an appropriate third-person paradigm that could serve as the cornerstone of a new taxonomic nomenclature. We chose the historically well-founded and commonly accepted paradigm of Affect and Cognition (although this is admittedly an arbitrary decision and other third-person paradigms may also be suitable). We have made this choice fully recognizing that modern theories speak to the inter-relationship of Affect and Cognition and do not consider them to be totally separate and distinct faculties (Forgas, 2008). Therefore, when we refer to affective or cognitive states in this paper, we are referring to the predominant subjective and neurobiological correlates of those states, and are not assuming that such states are in some way "totally pure"—see Formulation of a Taxonomic Nomenclature for Resultant States. For the purposes of this paper we reduce to commonly accepted definitions; whereas Affect includes emotions and feelings, and Cognition includes a multitude of mental processes associated with thinking, including (but not limited to): learning, reasoning, observing, perceiving, remembering, imagining, processing information, and acquiring knowledge.

An essentialist approach. In addition, we attempt to avoid the problems created by classifying meditation methods solely according to their particular characteristics or features (the aforementioned "phenetic" approach), which we have argued is problematic for such a complex phenomenon. We have adopted an "essentialist"-type approach similar to the Aristotelian and Linnaean schools of taxonomy (Ereshefsky, 2000), which requires that we first determine the functional essence of whatever it is that we want to taxonomize. We attempt to describe this functional essence not in a philosophical way, but rather in a way that would be useful and measurable for researchers.

Determination of the functional essence of meditation methods

Based on our review of the various contemplative traditions and the published research in this field, we utilize the following properties and assumptions regarding meditation methods:

- We assume that meditation methods have been derived for specific purposes and goals.
- There is mention of ultimate, long-term benefits and goals (the aforementioned "trait" effect) such as: the attainment of enhanced attentional and emotional acumen, purification of the mind and/or the heart, stress-reduction, a greater sense of well-being, attainment of wisdom, equanimity, compassion, liberation, enlightenment, etc.
- In order to accomplish these ultimate goals, meditation methods utilize techniques that have been designed to accomplish a more immediate goal—to facilitate a shift from the normal state of consciousness to an altered state of consciousness within a given meditation session—the aforementioned "state" effect. We have used the term EMS to describe this altered state.
- Methods will vary depending on their ultimate goal(s) and their particular techniques that have been designed to engender a targeted EMS relevant to that goal.
- The successful attainment of the targeted EMS ultimately depends on a host of extrinsic and intrinsic factors. With regard to the practitioner, one must account for such factors as experience and expertise, motivation, current state of mind and body, the presence of intoxicants or other drugs, etc. These intrinsic factors will undoubtedly affect the quality and experience of the EMS regardless of what the method purports or intends to accomplish.
- Therefore, we must consider the method to be just a facilitative tool, which only offers the potential, not a guarantee, for the attainment of immediate and ultimate goals.
- The ultimate goals are more challenging (if not impossible) to measure and evaluate given current scientific knowledge and instrumentation.

For these reasons, we have defined the functional essence of the method in terms of its intended immediate goal—the targeted EMS. That is, what it was designed to do during a given meditation session that could be measured in a laboratory setting. This idea that a given method can possess a specific intended or targeted outcome is supported in the literature by those who discuss the need to account for the aims, purposes, goals, and effects of particular meditation techniques (West, 1987b; Koshikawa and Ichii, 1996; Lehmann et al., 2001; Carter et al., 2005; Hankey, 2006; Lutz et al., 2007; Ospina et al., 2007). Since it is somewhat awkward to think of methods as having intention, for the purposes of this paradigm we use the idea of "directionality" to convey this notion of a targeted outcome. In this sense the EMS can be thought of as the immediate destination, and the Method as the set of instructions, or the map, of how to get there.

Formulation of a taxonomic nomenclature for meditation methods

We proceed by combining taxonomic essentialism with a third-person approach. By framing this notion of directionality within the aforementioned paradigm of Affect and Cognition, we have formulated a new taxonomic nomenclature consisting of three overarching Domains:

- **The Affective Domain** represents those methods which purport to engender an enhanced affective state (EAS) during the meditation session. These are typified by traditional methods such as the compassion and loving-kindness techniques of Tibetan and Theravada Buddhism. These methods would be classified as affective-directed methods (**ADM**).
- **The Null Domain** represents those methods which purport to create an enhanced empty state that is devoid of phenomenological content—a non-cognitive/non-affective state (NC/NA EMS). Such methods would be classified as null-directed methods (**NDM**), typified by such techniques as TM, Zen satori methods, and Yoga methods aimed at the dissolution of the sense of self.
- All remaining techniques (by default) fall to **the Cognitive Domain** and thus would be classified as cognitive-directed methods (**CDM**). These are typified by traditional methods such as *samatha* and *vipassana* and would include all those methods that purport to engender an enhanced cognitive state (ECS) i.e., one-pointedness, mindfulness, or insight.

The assignment of Domains to actual meditation methods is demonstrated by example in section Use of the Taxonomic Keys and Domains, Nine Examples.

Formulation of a taxonomic nomenclature for resultant states

Once we have devised a classification of methods based on directionality, we then formulate an appropriate nomenclature for the resultant states. In this taxonomic model, each type of method is causally related to one of the following three resultant states[a] (see Ill. #2 below). This hypothesis is based in part on the idea that enhanced states of cognition, affect, and emptiness demonstrate distinctly different and measurable subjective and neurobiological correlates (Travis and Pearson, 2000; Lehmann et al., 2001; Dagleish, 2004; Carter et al., 2005; Hankey, 2006; Lutz et al., 2007, 2008a; Davidson, 2010; Travis and Shear, 2010a; Josipovic et al., 2012; Leung et al., 2013).

Enhanced cognitive state (ECS). Is defined as the resultant state of consciousness due to the successful employment of a CDM, in which the phenomenological content is primarily cognitive in nature. For example, we would classify the resultant state to be an ECS if a particular technique resulted in complete "one-pointedness"—"the maintained focus of attention on a single object" (Carter et al., 2005, p. 412). There is a significant body of research in support of this notion of an enhanced cognitive meditative state.

Supportive neuroscientific findings. From a brain perspective, we would likely consider such a state as involving activity in one or more of the cortical areas of the brain that subserve higher cognitive processing such as areas of the brain that support verbal reasoning or abstract processes. A number of studies have reported increased functioning in the frontal lobes particularly the PFC in subjects performing a concentration-based cognitive directed meditation practice (Herzog et al., 1990–1991; Lou et al., 1999; Lazar et al., 2000). For example, Tibetan Buddhist meditation that incorporated concentration on a visual object demonstrated a number of complex changes including relatively increased cerebral blood flow (CBF) in the PFC and cingulate gyrus (Newberg et al., 2001). Another study found that Vipassana meditation activated the rostral anterior cingulate cortex (ACC) and the dorsal medial PFC in both hemispheres (Holzel et al., 2007). In addition these investigators found that Vipassana meditation might enhance cerebral activity in brain areas related to interoception and attention, such as the PFC, the right anterior insula and the right hippocampus (Holzel et al., 2008). Thus, these findings support the taxonomic approach that cognitive-directed meditation practices activate cortical areas involved in cognitive functions such as attention and abstract thought. Additional support for this notion can be found in studies evaluating differences in "trait" characteristics and task performance between experienced and less-experienced meditators; and several of these reports have shown that such cognitive-directed practices result in overall improved cognitive processing which can be related to site-specific cortical function (Valentine and Sweet, 1999; Carter et al., 2005; Chan and Woollacott, 2007; Pagnoni and Cekic, 2007; Moore and Malinowski, 2009; Hodgins and Adair, 2010; van den Hurk et al., 2010; Pagnoni, 2012).

Enhanced affective state (EAS). Is defined as the resultant state of consciousness due to the successful employment of an ADM, in which the phenomenological content is primarily an emotion or feeling such as loving-kindness or compassion (so called matters of the "heart"). Lutz describes this as "the generation of a state in which an unconditional feeling of loving-kindness and compassion pervades the whole mind as a way of being, with no other consideration, or discursive thoughts" (2008a, p. 1) Although these are not considered as emotions by traditional Buddhist philosophy, they can be considered as affect when interpreted into Western/English "mental typologies" (Dreyfus, 2002), and many modern researchers have done so. There is a significant body of research in support of this notion of an enhanced affective meditative state.

Supportive neuroscientific findings. Affect can be distinguished by distinct and measurable subjective and neurobiological correlates (Dagleish, 2004; Hanson and Mendius, 2009). Many modern researchers consider compassion/loving-kindness not only to be an expression of affect but have reported distinct neurophysiological correlates associated with this state (Lutz et al., 2008a; Davidson, 2010; Menezes et al., 2012; Leung et al., 2013; Mascaro et al., 2013). For example, Lutz et al. (2008a) reported distinctive activation of the limbic regions including the insula and cingulate cortices; right temporoparietal junction; and posterior superior temporal sulcus during Tibetan Buddhist compassion meditation. Davidson (2010) hypothesized that loving-kindness meditation activates circuits associated with positive affect including the ventral striatum, orbital frontal cortex, and dorsolateral regions of the PFC. Lutz et al. state that certain meditation methods can "regulate emotions associated with altered activation of the limbic system" (2008a, p. 2). Mascaro et al. (2013) reported increased neural activity in the IFG and the dmPFC during compassion meditation. Leung et al. (2013) reported increased gray matter volume in the right angular gyrus and right posterior parahippocampal gyrus in subjects performing loving-kindness meditation. Furthermore, there appears to be a distinct pattern of brain activity associated with meditation practices associated with an EAS vs. those associated with an ECS. For example, Carter et al. (2005) reported distinct differences of functional effects on the visual switching rivalry between one-pointedness meditation and compassion meditation, and Travis and Shear (2010a) reported different EEG patterns for compassion meditation vs. focused attention vs. TM.

Enhanced non-cognitive/Non-affective state (NC/NA). Is defined as the resultant state of consciousness due to the successful employment of a NDM. This enhanced state is much more challenging to define as it infers the absence of affect and cognition—an empty state with no phenomenological content. This notion of emptiness has manifested in a host of semantic constructs derived

[a]It is important to note that we are not assuming that these three states are in some way totally "pure" and unrelated to each other, but rather that they are essentially different. For example, we are not saying that an ECS needs to be totally and completely devoid of any affective phenomenological content, and vice versa. Rather, we are proposing that each of these categories represents a specific and distinctive type of experience that allows each one to be differentiated from the others.

from diverse spiritual/religious traditions and languages i.e., nirodha-samāpatti (Pali), samadhi (Sanskrit), satori (Japanese), dzogchen (Tibetan). However, attempts to translate these terms into English have struggled to capture the essence of this ineffable and non-conceptual state of consciousness. As such, many different terms have evolved depending on cultural/religious belief systems, linguistic perspectives, and perceptions of the underlying ontology of meditation practice. The examples are numerous and include such ideas as: God Consciousness, Christ Consciousness, Buddha Consciousness, cosmic consciousness, pure consciousness, true-Self, non-Self, NDA, absolute unitary being; and other terms such as Formless, Void, emptiness, and undifferentiated "beingness" or "suchness." We can also look to well-known Yogic teachers or Masters for their commentary. According to Sri Nisgaradatta Maharaj, there is a merging into a state of nothingness accompanied by a loss of sense of Self and duality (Powell, 1994); Osho describes samadhi as "no object in the mind, no content ......, not meditating upon something, but dropping everything (so that) not even a ripple arises in the lake of your consciousness." (Osho, 2003); and Sri Ramana Maharshi states that "samadhi is the state in which the unbroken experience of existence is attained by the still mind" (Godman, 1985). For the purposes of this essay, we consider all these terms and descriptions to refer to the same state. There is a significant body of research in support of this notion of an enhanced non-cognitive/non-affective meditative state.

Supportive neuroscientific findings. From a neurophysiological perspective, we might posit that this NC/NA state is associated with decreased activity levels in the areas that subserve both cognition and affect. Newberg et al. have long postulated a relationship with the parietal lobe (Newberg and Iversen, 2003). The PSPL is heavily involved in the analysis and integration of higher-order visual, auditory, and soma-esthetic information (Adair et al., 1995). It is also involved in a complex attentional network that includes the PFC and thalamus (Fernandez-Duque and Posner, 2001). Through the reception of auditory and visual input from the thalamus, the PSPL is able to help generate a three-dimensional image of the body in space, provide a sense of spatial coordinates in which the body is oriented, help distinguish between objects, and exert influences in regard to objects that may be directly grasped and manipulated (Lynch et al., 1980; Mountcastle et al., 1981). These functions of the PSPL might be critical for distinguishing between the self and the external world. It should be noted that a recent study has suggested that the superior temporal lobe may play a more important role in body spatial representation. This has not been confirmed by other reports (Karnath et al., 2001), so the actual relationship between the parietal and temporal lobes in terms of spatial representation remains speculative.

Regardless, deafferentation of these orienting areas of the brain has been suggested as an important mediator in the physiology of meditation (Newberg and Iversen, 2003). We have postulated that the mechanism by which deafferentation might occur is through the action of GABA, released by the reticular nucleus. Thus, GABA, acting as the primary inhibitory neurotransmitter [originally hypothesized by Austin, 1999], might inhibit incoming neuronal information into the PSPL. One can speculate that there is something about certain meditation techniques (NDM) that can trigger this deafferentation effect. If this occurs to a substantial degree it could result in the dampening of cognitive and affective processes creating a state devoid of phenomenological content in which the person may begin to temporarily lose their usual ability to spatially define their notion of self or differentiate the self from the rest of the world—an experience which one could interpret as non-self, or emptiness. Such a notion is supported by clinical findings in patients with parietal lobe damage who have difficulty orienting themselves. The effects of meditation are likely to be more selective and do not destroy the sense of self, but alter the perception of it. This concept of deafferentation of the PSPL has been supported by two imaging studies demonstrating decreased activity in this region during intense meditation (Herzog et al., 1990–1991; Newberg et al., 2001). Other investigators have found support for specific brain functions associated with the non-cognitive, non-affective state. For example, Lehmann et al. (2001) investigated multi-states engendered by a single advanced meditator and found that meditation on the dissolution of the self resulted in increased right brain activity more anterior and superior than other forms of meditation that were visual or mantra dependent: right superior frontal gyrus; right PFC. Hankey (2006) reported psychophysiological correlates for "pure consciousness" associated with TM that were distinctly different than one-pointed and compassion techniques. These changes appear to extend beyond brain processes as Travis and Pearson (2000) reported distinct changes in sympathetic and parasympathetic measures during these states of "pure consciousness."

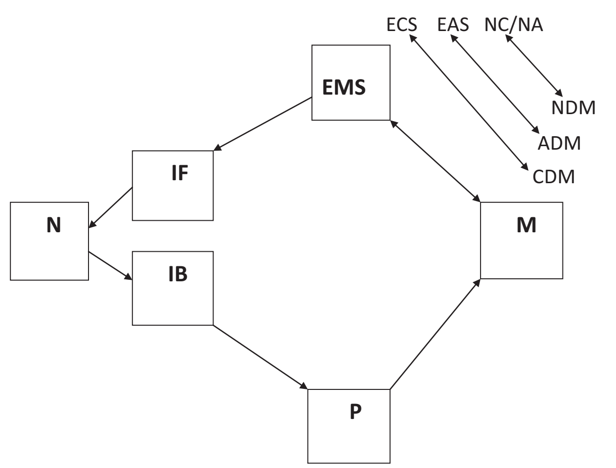
STAGES OF THE MEDITATION PROCESS

FLOW CHART 2

N = normal waking state **IB** = intention to begin **IF** = intention to finish

P = preliminaries **M** = method: (CDM)(ADM)(NDM)

EMS = enhanced mental state: (ECS) (EAS) (NC/NA)



The taxonomic keys

Sub-classification of methods within the three Domains is accomplished by applying a system of taxonomic keys, a concept borrowed from the Science of Systematics (Mayr, 1969). We propose that this idea can also be used to address the need for a standardized description of meditation methods (a Standard Profile of Meditation Methods). We argue that this approach enables methods to be more thoroughly and accurately compared. In addition, it allows researchers to account for the neurophysiological effects associated with many of these elements as described in some detail below (for a condensed version of these keys see **Table A1** of Taxonomic Keys—Appendix).

Initial descriptor. The initial descriptor should include the name of the technique with reference to any particular style or subset (because several techniques may be grouped together under one generic name, when in fact they may be significantly different). A general reference to the history, origin and culture would be optional.

The specific keys. The keys are based on the explicit directions contained within the method, the overall approach that is employed, and third person elements that can be observed in the laboratory.

(1) Description of the specific cognitive strategy(ies) which are prescribed for the practitioner within the method's directions (what one has to do in order to achieve the intended result) i.e., concentration; focused attention or awareness; passive observation without attachment; visualization and imagination; memorization and repetition; selective awareness; effortless awareness; contemplation, introspection, and inquiry; sensual perception(s), etc. Neuroscientifically, this is an important element since there could be distinct changes observed in the brain and body depending on the strategy used. For example, a visualization task is likely to activate the visual cortex, whereas reciting a prayer or phrase is likely to activate the verbal centers of the brain (Newberg et al., 2003, 2010; Peres et al., 2012).
(2) Description of the conceptual and/or physical foci—the object(s) of attention i.e., mantra, symbol, image, phrase, idea, narrative, sound, light, etc. Similar to above, the focus on distinct images might produce different physiological effects depending on whether the images are simple, complex, color, or black and white. Listening to music or a voice guiding the meditation might result in activation of the auditory pathways in the brain.
(3) Description of any beliefs or special knowledge either suggested or required; i.e., in relation to a particular theoretical, religious, spiritual, metaphysical, or philosophical system. While this is more difficult to identify from a neurophysiological perspective, several studies have explored the neural bases of different beliefs, especially between those who are believers and non-believers (Harris et al., 2009).
(4) Notation of whether the eyes are closed or are open and used in some specific fashion. Brain function is clearly affected by visual processes and there is substantial activation in the visual cortex when the eyes are open, especially when observing a complex scene.
(5) Notation of whether the process is static or kinetic. "Static" refers to a stationary body but not necessarily an immobile body. Therefore, bodily movements may occur but the body still remains essentially in one place as when the meditator changes postures during a single meditation session (i.e., from an upright sitting position to a more reclined position), or experiences involuntary jerking motions (kriyas). "Kinetic" refers to prescribed movements of the body with specific postural instructions; usually, but not limited to, movement of the extremities such as in walking mindfulness training, Tai Chi, mudras (hand movements), or even "bouncing" as in TM-Siddhi "yogic flying." This element relates to motor activity in the brain including the motor cortex, basal ganglia, and cerebellum which are all involved in body movement. In addition, movement can be associated with differences in energy utilization, adrenal function, cardiovascular function, and respiratory function.
(6) Notation of whether the process is silent or auditory or both. Vocalization will certainly demonstrate specific cortical activity and the auditory cortex and thalamus may be differentially activated in the presence of sound. Regarding silent vs. the vocal use of mantra and chanting, scientists may need to account for the sub-vocalization effect associated with inner speech, even when it is quiet.
(7) Notation of whether a specific type of postural position is suggested or required i.e., normal seated, straight spine, lotus position, fully reclined, etc. This key could be considered as a sub-set of the "static" denotation in #5 above. The brain may respond differently to being in, and maintaining, different postures. Proprioceptive functions are likely to be particularly related to this element as the brain works to ensure that a posture is maintained.
(8) Notation of whether the process is intrinsic (self-reliant/independent) or extrinsic (dependent on an outside person or process). There is some evidence to suggest that performing meditation under one's own volition vs. being guided can result in substantial differences in brain function. Frontal lobe activity in particular might be affected as evidence suggests decreased frontal activity during externally guided word generation compared to internal or volitional word generation (Crosson et al., 2001). Thus, prefrontal and cingulate activation may be associated with the intrinsic vs. extrinsic aspects of meditation.
(9) Notation of whether there are any specific recommendations for type or control of breathing. Breathing, especially when controlled, can result in specific changes in brain and body physiology. Controlled breathing may alter heart rate, blood pressure, and metabolism while also changing the function of the brain (Floyd et al., 2003; Barnes et al., 2008).

Considered in their totality, these taxonomic keys should help to present a relatively full description of the overall meditation technique. Furthermore, since many of these keys can be observed from a third person perspective (i.e., eyes open or closed; body static or kinetic), they provide a more objective way of assessing the method and the extent to which the subject has performed the method.

It should be noted that it has been suggested that some meditation methods could be considered to be essentially "somatic" in nature and therefore warrant classification into a separate Somatic Domain (i.e., Tai Chi, standing Qigong, and some forms of Yoga). However, given that meditation methods are considered to be mental training regimes and not physical training, we concluded that it would be inappropriate to devise an over-arching domain based on somatic considerations. Rather, we account for somatic characteristics as a sub-classification under the fifth (kinetic/static) and seventh (postural) taxonomic keys.

Use of the taxonomic keys and Domains, nine examples

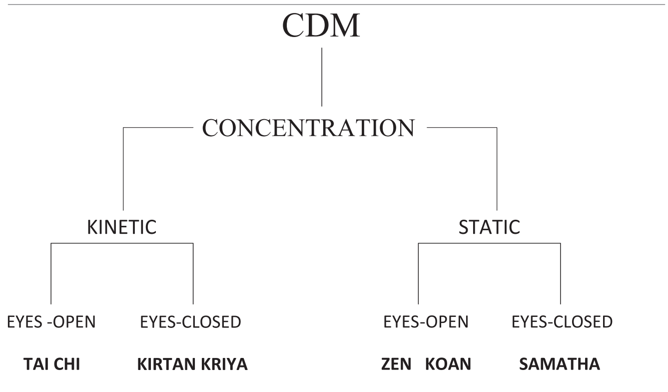
This section demonstrates how meditation methods can be classified, described, and sub-classified (see **Tables 1**, **2**) using the three Domains and the taxonomic keys. For this demonstration we have selected nine examples (in no particular order) based on the following criteria: fairly well-known Eastern meditation methods which possess historical tradition; meditation methods favored by researchers in recent studies; meditation methods which give the practitioner (and researcher) a reasonable idea of what to expect from a successful meditation session.

The following assignment of taxonomic keys and Domains is only intended to demonstrate how the application of this model can be used to more thoroughly describe various meditation methods, and should not be taken to be a final delineation, only a tentative one. Our determinations were based on a review of the relevant literature, personal communication with experienced practitioners, and the personal experience of the authors with several of the following methods. We recognize that this is far from sufficient for the formulation of definitive method profiles and classifications. It would be far better to recruit the input of expert practitioners and attempt to arrive at a consensus regarding the keys and the assignment of Domain. In addition, "final" determinations of Domain would also require confirmation through scientific research (see Suggestions for Future Studies below). For example, in order to make a more definitive assignment of a particular method into the Affective Domain there would first need to be some sort of consensus among experts that the method in question does in fact purport to engender an EAS. Secondly, this claim would need to be supported by research findings of affective phenomenological content and affective neurobiological correlates.

Table 1 | Examples of the sub-classification of the three domains.

CDM	ADM	NDM
Samatha	NRLK (dmig med snying rje)	TM
Vipassana		
Kirtan Kriya	Samatha metta and karuna	So'ham Japa
Tai Chi Chuan		

Table 2 | Sub-classification of four different cognitive-directed methods.



1. Transcendental meditation (TM). Coined and introduced to the West by Maharishi Mahesh Yogi in the late 1950s—early 60s; proponents claim that TM is derived from ancient Indian tradition while others consider it to be based on "a neo-Vedanta metaphysical philosophy" (Olson, 2007).

(1) Utilizes awareness, and repetition which proponents claim to be "effortless," and which induces "automatic self-transcending" to a state of "pure consciousness" (Travis and Shear, 2010a,b; Travis, 2013, pers. commun.).
(2) Attention is on a mantra, although proponents state that this is not a form of focused attention, but rather an awareness of mantra (Travis, 2013, pers. commun.).
(3) There are no religious/belief requirements.
(4) The eyes are closed.
(5) The basic form is static; and there is a more advanced kinetic form known as Siddhi "Yogic –flying."
(6) Non-verbal, whereas the mantra is repeated silently, not out-loud.
(7) Seated comfortably, no strict postural requirements.
(8) Intrinsic.
(9) Normal breathing, no special breathing instructions or requirements.

We have classified TM into the **NDM** Domain because the technique as we understand it aims to engender a non-cognitive/non-affective EMS.

2. Tai Chi Chuan.[b] A technique of Chinese Taoist origin has evolved into many different styles; originally developed as a form of martial art (literally translated as grand ultimate fist, and it was known as a boxing style); today is rarely used as a self-defense technique but rather is considered by many to be a form of "movement meditation" (Ospina et al., 2007) for the promotion of good health.

(1) Utilizes focused concentration, memorization, and visualization.
(2) The physical focus is on the body, the conceptual focus is on the "chi."

[b] We chose to include Tai Chi on this list because it is a good example of a kinetic form, even though the field currently does not have unobtrusive instrumentation with which to evaluate such a method and it is still debatable whether it is truly a form of meditation or not.

(3) Understanding of, and belief in the Taoist chi energy system is suggested but not required, knowledge of the founder and the lineage of the particular style is also encouraged.
(4) Eyes are opened and the gaze is used to "lead" the bodily movements.
(5) Kinetic.
(6) Usually non-verbal.
(7) Specific postural forms are required.
(8) Usually learned in an extrinsic manner (guidance by an instructor) but progresses to an intrinsic, self-guided practice.
(9) Control of breathing may or may not be required.

We have classified Tai Chi into the **CDM** Domain because the technique as we understand it aims to produce a highly concentrative EMS.

3. Vipassana Meditation. A traditional Buddhist technique; Pali/Sanskrit language commonly translated as insight or mindfulness. Caution must be exercised when attempting to classify this method because there are several different forms and styles in current practice all under the same name of Vipassana. For the purposes of this paper we will consider the Goenka method (Goenka, 1987) since many research studies use subjects who employ this technique.

(1) Utilizes mindfulness, detached observation, contemplation, and insight.
(2) The physical foci of attention is on the body using a "body-scan" technique with a prescribed narrative.
(3) Knowledge and belief in the teachings of Buddhism is essential in order to relate the experiences of the meditation to an insight/wisdom into your own nature and to develop an experiential understanding of the "Three Universal Characteristics" (see The Discourse Summaries, Goenka, 1987).
(4) Eyes are closed.
(5) Static.
(6) Non-verbal.
(7) Upright seated position on the floor, lotus posture if possible.
(8) Intrinsic.
(9) Normal breathing, no special breathing instructions or requirements.

We have classified Goenka Vipassana into the **CDM** Domain because the technique as we understand it aims to lead the meditator to an understanding/insight of essential Buddhist principles via a cognitive EMS.

4. Tibetan Non-Referential Unconditional Loving-Kindness technique (NRLK)(dmigs med snying rje). Of traditional Tibetan Buddhist origin.

(1) Utilizes concentration, contemplation, and visualization.
(2) The conceptual foci of attention is on a prescribed narrative and the emotions that are generated.
(3) Understanding and belief in the teachings of Buddhism is suggested but not required, belief in the value of extending loving-kindness to all sentient beings is required.
(4) Eyes-open.
(5) Static.
(6) Non-verbal.
(7) Upright seated position, lotus posture if possible.
(8) Intrinsic.
(9) Normal breathing, no special breathing instructions, or requirements.

We have classified NRLK into the **ADM** Domain because the technique as we understand it aims to create an affective EMS.

5. Samatha Meditation. An ancient contemplative practice believed to have originated in India, traditionally associated with Buddhism, of Pali/Sanskrit language translated as "calm" or "quiescence" but usually considered to mean concentration. There are several forms of samatha meditation and many different objects of focus (forty are listed in traditional Buddhist texts), but all are intended to calm and focus the mind. Here we will consider only two of them.

- **Concentration on the breath.**

(1) Utilizes concentration and visualization as the main cognitive strategies.
(2) The physical focus of attention is on the breath and the parts of the body associated with breathing, especially the nose.
(3) Knowledge and belief in the teachings of Buddhism is recommended but not essential.
(4) Eyes closed.
(5) Static.
(6) Non-verbal.
(7) Seated with straight spine.
(8) Intrinsic.
(9) There are specific breathing instructions.

We have classified *samatha* concentration on the breath into the **CDM** Domain because the technique as we understand it aims for the practitioner to attain a one-pointed, cognitive EMS.

- **Metta (loving-kindness) and karuna (compassion).**

(1) Utilizes concentration and visualization as the main cognitive strategies.
(2) The conceptual foci of attention is on a prescribed set of instructions and the emotions that are generated.
(3) Knowledge and belief in the teachings of Buddhism is suggested but not required, belief in the value of extending compassion and loving-kindness to all sentient beings is required.
(4) Eyes closed.
(5) Static.
(6) Non-verbal.
(7) Seated with straight spine.
(8) Intrinsic.
(9) No special breathing instructions or requirements.

We have classified *samatha metta* and *karuna* meditation into the **ADM** Domain because the technique as we understand it aims to create an affective EMS.

6. Zen Meditation (zazen). Translated from the Japanese as "seated meditation," of traditional Buddhist Mahayana tradition introduced to Japan in the 11–12th Century. Today there are various schools in the East and West, such as Rinzai and Soto, and there are various techniques, some of which are reserved for more advanced and experienced practitioners. For the purposes of this essay we have chosen an elementary form of the kufu-zazen koan technique used in the Rinzai approach.

(1) Utilizes concentration, memorization and repetition, analysis and insight as the primary cognitive strategies.
(2) The conceptual focus is on various *koans* (paradoxical riddles).
(3) Usually no particular knowledge or belief is required for beginners, knowledge and belief in Buddhist teachings is essential for advancement.
(4) Eyes-open.
(5) Static.
(6) Non-verbal.
(7) Specific instructions for seated posture, traditionally with cushion on the floor.
(8) Intrinsic and/or extrinsic if there is a Master-student interaction(*sanshi-manbo*).
(9) Specific breathing instructions may be applied.

We have classified this particular Zen technique into the **CDM** Domain because, according to our understanding, it aims to lead the practitioner to insight through inquiry. Other Zen techniques directed toward the attainment of one-pointedness would also be classified as CDM; and if an experienced practitioner uses a Zen technique to attain satori it would be considered a NDM.

7. So'ham Japa (also known as Hamsa). Considered to be a Yoga technique of Indian origin, and introduced to the West by Swami Muktananda in the late 1960's—early 1970's.

(1) A concentrative strategy.
(2) The focus is on mantra and breathing.
(3) Belief in the basic teachings and tenants of Hindu philosophy such as Vedanta, and Kashmir Shaivism is suggested but not required; in addition, there is often a strong belief in the power of the Guru-disciple relationship and that the mantra and the technique must be empowered by a Spiritual Master in order to be efficacious and to facilitate a spiritual "awakening" (Muktananda, 1969; Shankarananda, 2003).
(4) Eyes are closed.
(5) Static.
(6) Non-verbal.
(7) Comfortable seated posture is suggested.
(8) Intrinsic.
(9) Specific instructions for awareness and method of breathing.

We have classified So'ham Japa into the **NDM** Domain because the technique, as we understand it, aims at producing a non-cognitive/non-affective EMS, a state of samadhi in which the meditator experiences his "true nature" (Muktananda, 1969).

8. Kirtan Kriya. Is a Yogic practice introduced to the West by Yogi Bhajan in the late 1960's—early 70's. Proponents claim it to be a traditional form of Kundalini Yoga of Northern Indian origin, and taught by a lineage of Sikh Masters for over 500 years (see Kundalini Yoga websites www.3ho.org and www.kundaliniresearchinstitute.org). There are many forms of Kirtan Kriya meditation. The following application of the taxonomic keys is based on the "12 minute" form studied in recent neuroscientific investigations (Khalsa et al., 2009; Wang et al., 2011; Black et al., 2013).

(1) Utilizes concentration, memorization, repetition, and visualization.
(2) Conceptual focus is primarily on mantra and breath.
(3) Knowledge and belief in the basic tenants of Hindu philosophy, and the notions of kundalini energy and chakras, is suggested but not required.
(4) Eyes closed.
(5) Static in overall body position but also kinetic during those times when the practitioner employs prescribed hand movements known as mudras[c].
(6) Uses both verbal chanting and non-verbal recitation of a series of four mantras[c].
(7) Seated on a chair or on the floor with straight spine.
(8) Intrinsic, although extrinsic guided-mediations are also used at times[c].
(9) Normal comfortable breathing, although some practitioners use various forms of pranayam breathing techniques[c].

We have classified this style of Kirtan Kriya into the **CDM** Domain because the technique, as we understand it, aims at calming and focusing the mind by producing a cognitive EMS.

SUMMARY

This paper has attempted to be helpful to researchers and writers in the field of contemplative neuroscience in several ways. In order to improve communication among scholars, we proposed a conceptual model of meditation as a dynamic process that could help to avoid the conflation of definition that has plagued this field for many years. Considering meditation as a series of connected yet distinct stages also presents new opportunities for targeted research and evaluation.

Our effort was also motivated by the belief that in order for this (or any) relatively new field to progress it is essential for researchers to have a valid, reliable, and universally acceptable means with which to taxonomize and compare their findings.

[c]The Kirtan Kriya method poses descriptive, taxonomic, and research challenges because there are options for applying several opposing keys during a single meditation session. As such, in this case, and in other similar cases, it is important to note which options are, and are not, being employed by the practitioner at any given point in time.

To this end we have attempted to influence due consideration toward the utilization of a third-person codification for meditation methods, for which we chose the domains of Affect and Cognition. In addition, we have attempted to demonstrate the advantages of utilizing an essentialist-type taxonomic system to identify the functional essence of methods in terms of their immediate intended goal, which we labeled "directionality." This approach enabled us to formulate three overarching, potentially orthogonal categories, and segregate meditation methods into three Linnaean-type Domains: CDM, ADM, and NDM. We also used this nomenclature to describe the causally related enhanced states associated with each of these Domains.

Finally, we attempted to address the current lack of a standardized descriptive protocol for the study of meditation methods, which we feel is an important oversight and impediment. We proposed the use of a taxonomic key system as a means of delineating the salient features into a Standard Profile of Meditation Methods. We also provided examples of how such a protocol could be used to describe several well-known and often studied methods, and how it could be used to sub-classify methods within a given Domain.

SUGGESTIONS FOR FUTURE STUDY

- The use of a system of validated taxonomic keys to create definitive descriptive profiles, sorted by Domain, that could serve as a comprehensive compendium of meditation methods. This can be accomplished by soliciting the input of expert practitioners and proponents of each method (similar to the approach used by Koshikawa and Ichii (1996) and by using a questionnaire and standardized interview methodology similar to the modified Delphi consensus technique employed by Ospina et al. (2007) and Bond et al. (2009).
- Research studies utilizing a variety of established neuroscientific methods to test the usefulness and orthogonal relationship of the various stages of the proposed process model.
- Research studies utilizing a variety of established neuroscientific methods to test the validity of our three Domains based on affective, cognitive, and null enhanced states. The hope would be to develop a neurophysiological "signature" or profile for each Domain. There is support for this notion that a given EMS can be identified in the laboratory setting using standardized methods (Travis and Pearson, 2000; Travis et al., 2002; Travis and Arenander, 2006; Newberg and d'Aquili, 2001; Lutz et al., 2007). We posit that the three types of EMS proposed in this paper can be similarly defined using the methodologies that have been previously developed and tested.
- Developing the methodology and instrumentation for monitoring and measuring kinetic forms of meditation, as well as devising additional taxonomic keys for these types of methods.

CONCLUSION

Our proposal for a new taxonomy of meditation is intended to offer a fresh approach to this difficult but necessary task, and hopefully will help to further the process for developing a much needed standard. It is not to be construed that we are here claiming to have arrived at a complete and final explication. Rather we have offered an alternative paradigm with the intention of stimulating interest in the advantages of using an essentialist third-person approach. Should this model prove useful to the current field of contemplative neuroscience, we fully expect it to be tested and challenged by future findings and new theories. Even the "Mother" of all taxonomies, the great work of Linnaeas (which has been a standard for almost 300 years), has become somewhat obsolete given recent findings from cellular and genetic biology (Ereshefsky, 2000).

Our three overarching Domains are intended to provide researchers with a reliable conceptual framework for their findings by pointing to cognitive and affective states and their neurobiological correlates. We contend that it is essential for researchers (and all interested parties) to know more than just the name and a general description of the particular meditation method that is being studied. The use of the taxonomic keys in conjunction with the three Domains presents a replicable descriptive standard for the study of meditation methods. This protocol offers a way for researchers to more effectively account for the neurobiological correlates associated with those salient features of the method that could confound their findings. Undoubtedly, research findings are affected by factors such as whether the subject is meditating with their eyes open or shut, using specific body movements, or verbalizing in some manner. Such information, when presented in a standardized fashion, could facilitate a more cogent analysis of the differences and similarities reported for various meditation methods, and help with the task of trying to isolate the state from the method.

We recognize that this proposal, as with any taxonomy, must ultimately be evaluated by its usefulness to scholars and researchers. As such, we have purposely steered clear of metaphysically charged claims of attainment and non-conceptual realms commonly associated with contemplative practices and beliefs, since such considerations are currently outside of the scope of scientific measurement and analysis. This is not a value judgment, but simply a matter of practicality. We do not dismiss or discount such phenomena as "enlightenment" or the role of the Guru-disciple relationship in the process of "awakening"; we simply have chosen to focus on the more tangible aspects of meditation practice.

We fully expect that as we learn more about the phenomenon of meditation, the assumptions and structure of our definitional and taxonomic models will need to be modified or replaced to adapt to new understandings. Hopefully researchers will be interested in our proposals, will test their efficacy, and offer suggestions and improvements that will ultimately lead to the attainment of a consensual definition and taxonomy for the field of meditation research.

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END NOTES

1. "pure consciousness":
"…. 'pure *consciousness*' or '*emptiness*' is devoid of phenomenological content, and by its nature requires transcending of the processes and objects of meditation. If processes or objects were there, it would not be this widely described experience." Travis and Shear (2010b) It "is 'pure' in the sense that it is free from the processes and contents of knowing. It is a state of 'consciousness' in that the knower is conscious through the experience, and can, afterwards, describe it. The 'content' of pure consciousness is self-awareness. In contrast, the contents of normal waking experiences are outer objects or inner thoughts and feelings." (p. 79). "Subjectively, this state is characterized by the absence of the very framework (time, space, and body sense) and content (qualities of inner and outer perception) that define waking experiences. Physiologically, this state is distinguished by the presence of apneustic breathing, autonomic orienting at the onset of breath changes, and increases in the frequency of peak EEG power." Travis and Pearson (2000, p. 77).

2. "absolute unitary being" (AUB):
"…. an absolute sense of unity — without thought, without words, and without sensation …without ego in a state of pure, undifferentiated awareness." Newberg and d'Aquili; (2001, p. 119–27).

3. "non-dual awareness" (NDA):
There is "a more profound difference, one that cannot be adequately captured within a single-dimension characterization of attentional strategy. Both focused attention and open monitoring styles of meditation contain an essentially dualistic orientation of 'subject-observing-object'. there is another group of meditations that do not employ this strategy, but instead rely on accessing a level of awareness that is inherently free from this dualistic subject-object construct. This non-conceptual awareness has sometimes been termed non-dual awareness, open awareness or open presence." Josipovic (2010).

"There are 2 aspects of non-duality: (1) non-duality without experiential content, also known as 'pure consciousness' in Vedanta or 'isolated clear light' in Tibetan Buddhism; which is Absolute only and (2) non-duality with full experiential content; a.k.a 'open presence' in Tibetan Buddhism, Saguna Brahman of Vedanta, etc., in other words the unity of Absolute and Relative." Josipovic (2013, pers. commun.).

4. "focused attention" (FA):
"A widespread style of Buddhist practice consists in sustaining selective attention moment by moment on a chosen object, such as a subset of localized sensations caused by respiration. To sustain this focus, the meditator must also constantly monitor the quality of attention. … while cultivating the acuity and stability of sustained attention on a chosen object, this practice also develops three skills regulative of attention: the first is the monitoring faculty that remains vigilant to distractions without destabilizing the intended focus. The next skill is the ability to disengage from a distracting object without further involvement. The last consists in the ability to redirect focus promptly to the chosen object." Lutz et al. (2008b, p. 163–169).

5. "open-monitoring" (OM):
"Open monitoring or mindfulness-based meditations, involve the non-reactive monitoring of the content of ongoing experience, primarily as a means to become reflectively aware of the nature of emotional and cognitive patterns." Raffone and Srinivasan (2010). "Open monitoring practices are based on an attentive set characterized by an open presence and a non-judgmental awareness of sensory, cognitive and affective fields of experience in the present moment and involves a higher-order meta-awareness of ongoing mental processes" (Cahn and Polich, 2006)—in Travis and Shear (2010a).
"While varied, OM practices share a number of core features, including especially the initial use of FA training to calm the mind and reduce distractions. As FA advances, the well developed monitoring skill becomes the main point of transition into OM practice. One aims to remain only in the monitoring state, attentive moment by moment to anything that occurs in experience without focusing on any explicit object. To reach this state, the practitioner gradually reduces the focus on an explicit object in FA, and the monitoring faculty is correspondingly emphasized. Usually there is also an increasing emphasis on cultivating a 'reflexive' awareness that grants one greater access to the rich features of each experience, such as the degree of phenomenal intensity, the emotional tone, and the active cognitive schema." Lutz et al. (2008b, p. 163–169).

6. "open-presence" (OP):
"… unlike other meditations, at advanced stages of the practice there is no attempt either to suppress or to cultivate any particular mental content. One does not focus, for example, on a visualized image or on a sensory object such as a sensation made by the breath. In this sense the state of Open Presence is objectless. Nevertheless, even though higher levels of the practice do not involve any particular content or object, it also is important for content to be occurring in the mind because to cultivate an awareness of the invariant nature of experience, one must be having experiences. Indeed, for beginners it is preferable that the experiences be especially striking or clear. Thus, even though the meditation is objectless, it is not a state of blankness or withdrawal. Sensory events are still experienced, sometimes even more vividly. In terms of technique, this facet of the meditation is indicated by the fact that one meditates with the eyes open and directed somewhat upward." "The move to an emphasis on subjectivity is further encouraged by dropping any deliberate focus on an object. As a sensory content or mental event occurs, one observes it (sometimes along with the momentary use of a

discursive strategy), and then one releases any focus on it. This is similar to the Vipassanâ practice discussed above, except that after releasing the content or event one does not return to any object. Instead, one releases the mind into its 'natural state' (rang babs), which one understands to be the state reflecting only the invariant nature of consciousness, and not the accidental properties of subject and object." Lutz et al. (2007, p. 38–42).

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APPENDIX

Table A1 | The taxonomic keys.

The **initial descriptor** should include the name of the method including mention of any particular style or subset (because several techniques may be grouped together under one generic name, when in fact they may be significantly different). A general reference to the history, origin and culture is optional.

THE SPECIFIC KEYS

(1) Description of the specific cognitive strategy(ies) which are prescribed for the practitioner within the method's directions (what one has to do in order to achieve the intended result) i.e., concentration; focused attention or awareness; passive observation without attachment; visualization and imagination; memorization and repetition; selective awareness; effortless awareness; contemplation, introspection and inquiry; sensual perception(s), etc.
(2) The conceptual and/or physical foci—the object(s) of attention i.e., mantra, symbol, image, phrase, idea, narrative, sound, light, etc.
(3) Any beliefs or special knowledge either suggested or required i.e., a particular theoretical, religious, spiritual, metaphysical, or philosophical system
(4) Whether the eyes are closed or are open and used in some specific fashion
(5) Whether the process is static* or kinetic**
(6) Whether the process is non-verbal (silent) or verbal (auditory) or both
(7) Whether a specific seated or reclined postural form is suggested or required
(8) Whether the process is intrinsic (self-reliant/independent) or extrinsic (dependent on an outside person or process)
(9) Whether there are any specific recommendations for type or control of breathing

**"static": refers to a stationary body but not necessarily an immobile body. Therefore, bodily movements may occur but the body still remains essentially in one place as when the meditator changes postures during a single meditation session (i.e., from an upright sitting position to a more reclined position), or experiences involuntary jerking motions (kriyas). Specific postural criteria may or may not be present.*

***"kinetic": refers to prescribed movements of the body with specific postural instructions; usually, but not limited to, movement of the extremities such as in walking mindfulness training, Tai Chi, mudras (hand movements), or even "bouncing" as in TM-Siddhi "yogic flying."*

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Meditation and neurofeedback

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Dating back as far as 1957, the academic investigation of meditation and the Asian contemplative traditions have fascinated not only the likes of philosophers and religious scholars, but researchers in the fields of neuroscience, psychology, and medicine. While most of the contemplative traditions are comprised of spiritual practices that aim to bring the practitioner closer to self-actualization and enlightenment, from a neuroscientific and clinical perspective, meditation is usually considered a set of diverse and specific methods of distinct attentional engagement (Cahn and Polich, 2009).

Over the last decade, we have witnessed an exponential increase in the interest in meditation research. While this is in part due to improvements in neuroimaging methods, it is also due to the variety of medical practices incorporating meditation into therapeutic protocols. With the general aim of understanding how meditation affects the mind, brain, body and general health, particularly interesting findings in recent research suggest that the mental activity involved in meditation practices may induce brain plasticity (Lutz et al., 2004).

With its increasing popularity, many people in Western societies express an interest and motivation to meditate. However, for many it can often be quite difficult to maintain a disciplined and/or regular practice, for various reasons, ranging from a lack of time to general laziness. It is possible that machine assisted programs such as neurofeedback may help individuals develop their meditation practice more rapidly. Methods such as neurofeedback incorporate real-time feedback of electro-encephalography (EEG) activity to teach self-regulation, and may be potentially used as an aid for meditation.

While Neurofeedback and Biofeedback have been used since the 1960's, previous neuroscientific and clinical research investigating its efficacy has been limited, lacking controlled studies and significant findings (Moriyama et al., 2012). However, a recent overview of the existing body of literature on neurofeedback research has now led the American Academy of Pediatrics to recognize Neurofeedback, as well as working memory training, as one of the most clinically efficacious treatments for children and adolescents with attention and hyperactivity disorders (ADHD) (Dename, 2013). Neurofeedback has been used to treat a wide variety of other disorders such as insomnia, anxiety, depression, epilepsy, brain damage from stroke, addiction, autism, Tourette's syndrome, and more (Tan et al., 2009; Coben et al., 2010; Cortoos et al., 2010; Messerotti Benvenuti et al., 2011; Mihara et al., 2013). As with all therapeutic interventions it is important to note that individuals who are seeking neurofeedback for diagnostics or for clinical and medical purposes seek qualified and licensed practitioners, as adverse effects of inappropriate training have been documented (Hammond and Kirk, 2008).

Interestingly, many of the conditions that benefit from Neurofeedback treatment are consistent with the conditions that improve with regular meditation practice. For example, both ADHD patients and individuals diagnosed with depression benefit from meditation training (Hofmann et al., 2010; Grant et al., 2013) as well as neurofeedback training protocols (Arns et al., 2009; Peeters et al., 2013). In addition, both meditation and neurofeedback are methods of training mental states. Thus, it is plausible that the mental training involved in meditation may be fundamentally no different than other types of training and skill acquisition that can induce plastic changes in the brain (Lazar et al., 2005; Pagnoni and Cekic, 2007).

One hypothesis to explain the similarity between meditation and neurofeedback is that both techniques facilitate and improve concentration and emotion regulation, for which both attentional control and cognitive control are necessary. When one aims to alter attentional control, one must learn to manipulate the amount of attention that is naturally allocated to processing emotional stimuli. Similarly, when an individual is attempting to exercise or gain some form of cognitive control they must alter their expectations and judgments regarding emotional stimuli (Braboszcz et al., 2010; Josipovic, 2010). These core principles are central to both meditation and neurofeedback, with the distinguishing feature being that meditation is self-regulated, and neurofeedback is machine aided. It is worth noting that the alpha and theta frequency bands trained in most cognitive enhancement neurofeedback protocols (Zoefel et al., 2011) share many similarities with the EEG frequency bands that show the most significant change during the early stages of meditation practice (Braboszcz and Delorme, 2011; Cahn et al., 2013).

The integration between meditation and neurofeedback has already happened in popular culture. Numerous neurofeedback companies already provide so-called "enlightenment" programs to the public. The programs developed by these companies, however, are not all based on the scientific study of meditation and/or neurofeedback, and the reliability and accuracy of signal detection in many of the portable devices currently on the market remains questionable. While many of these companies are relying on the intuitions of their founders for various neurofeedback protocols, it is necessary for these programs to adopt a more rigorous scientific approach, such as those developed for clinical patients being treated using neurofeedback (Arns et al., 2009).

Assuming that reliable and reproducible EEG signatures are associated with specific meditation practices, we may expect that training subjects to reproduce these signatures would support and strengthen their meditation practice. Clinical neurofeedback protocols are aiming toward comparing patients' EEG with large EEG data sets from normal subjects in order to produce a neurofeedback algorithm which rewards subjects (patients) whose EEG becomes closer to that of the normal population (Thornton and Carmody, 2009). Similarly, it might be possible to train users to make their EEG brainwaves similar to the brainwaves of an expert practitioner in a given meditation tradition. Note that we do not argue that the task of the user should be only to up-regulate or down-regulate their EEG. Instead, they would perform a meditation practice and the neurofeedback device would act in the periphery, providing users with feedback on how well they are doing. For this to be feasible, there needs to be a clear identification of the EEG neural correlates of specific meditation techniques and traditions. As evidenced in the literature, there are an abundant number of meditation traditions and styles, many which have vastly differing techniques, methods, and practices. As the mental states associated with particular meditations differ, so does the corresponding neurophysiological activity (Cahn and Polich, 2006). Recent research suggests that complex brain activity during meditation may not be adequately described by basic EEG analyses (Travis and Shear, 2010). Thus, more research and the use of more advanced signal processing tools are needed in order to understand the differences in meditative techniques, and to better define a normative population which EEG brainwaves could be used in a neurofeedback protocol.

Another type of neurofeedback program could help detect mind-wandering episodes. In all of the meditation traditions, practitioners often see their attention drifting spontaneously toward self-centered matters. These attentional drifts are termed mind wandering, and have recently been focused on in neuroscientific research (Braboszcz and Delorme, 2011). Interestingly, in this study on mind wandering, EEG changes in the alpha and theta frequency bands have been observed. A neurofeedback device could provide an alarm to users when their mind starts to wander, therefore supporting and improving upon their meditation practice. Although future research should assess the reliability of these measures to detect single mind wandering episodes, such a neurofeedback system might help support users in their meditation.

Most neurofeedback systems provide auditory or visual feedback that fully engage and demand the attention of the subject. For neurofeedback-assisted meditation, the goal would be to provide subtle cues that do not disturb the subjects' meditation. For example, white noise could be made louder as the subject's EEG departs from the EEG of the normative population of meditators. Similarly, the same white noise amplitude could also reflect the likelihood of the subject's mind wandering. As mentioned earlier, the neurofeedback device would not be a substitute to meditation practice, but rather a means to facilitate and support it in its early to middle states of practice.

Over the last century, and ever more so at present, machines have become extensively integrated into a vast range of human activity. The practice of meditation requires sustained attention that is often hard to achieve for novices, as compared to more advanced practitioners (Brefczynski-Lewis et al., 2003). Therefore, an inspiring application of machine-aided learning may be to help offer alternatives for beginners who struggle with maintaining a regular meditation practice. Learning how to meditate faster and more easily may facilitate access to meditation techniques to a wider audience. Still, it may also be beneficial for more experienced meditators who are interested in deepening their meditation practices. Even the Dalai Lama has publicly stated that he would be the first to use this type of technology, and believes that neuroscience will improve Buddhist practices (Mind and Life Institute, 2004).

This type of application also has the potential of reaching the masses as neurofeedback could be introduced to the domain of smartphones and apps (Szu et al., 2013). In fact, some EEG systems are already compatible with portable and smartphone technology, and it will not be long before we start seeing neurofeedback-based programs for smartphones. Community building over social media using cloud based computing could help users support one another and their meditation practices. In addition to supporting meditation practice, neurofeedback applications can help track the progress of users over weeks and years and assess changes that users may not be consciously aware of, thus encouraging users to pursue their practice. Using neurofeedback to learn meditation truly reflects new, cutting edge science, and via real time feedback we may be able to develop a precise ways to rapidly learn and achieve deeper states of meditation.

In conclusion, it is our belief that mobile neurofeedback systems and protocols that are derived and extend upon meditative traditions and practices offer a promising new direction and platform in mobile technology. These technologies would be not only for people who have taken interest in these kinds of practices or people who have already established themselves in a meditative practice, but for people who are looking for new methods to train, improve, and develop attention and emotion regulation. We want to emphasize that neurofeedback should be used as an aid to meditation while people perform their meditation and not as a replacement to meditation, and that while these devices may aid and assist those in their meditative practices, the goal of these practices themselves is ultimately the decrease of reliance on objects and constructs that provide support. This type of research should also integrate neurophenomenological approaches that take into account first-person reports of subjective experience in conjunction with the experimental investigation of brain activity (Braboszcz et al., 2010; Josipovic, 2010). Real time feedback of brain activity as implemented in neurofeedback may help develop new frameworks for the scientific investigation of embodied consciousness and the interactions between mind and body.

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Can enlightenment be traced to specific neural correlates, cognition, or behavior? No, and (a qualified) Yes

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A NEUROSCIENCE OF ENLIGHTENMENT?

The field of contemplative science is rapidly growing and integrating into the basic neurosciences, psychology, clinical sciences, and society-at-large. Yet the majority of current research in the contemplative sciences has been divorced from the soteriological context from which these meditative practices originate and has focused instead on clinical applications with goals of stress reduction and psychotherapeutic health. In the existing research on health outcomes of mindfulness-based clinical interventions, for example, there have been almost no attempts to scientifically investigate the goal of enlightenment. This is a serious oversight, given that such profound transformation across ethical, perceptual, emotional, and cognitive domains are taken to be the natural outcome and principle aim of mindfulness practice in the traditional Buddhist contexts from which these practices are derived. If short-term interventions as short as a few sessions are now beginning to produce neuroplastic changes (Tang et al., 2010; Zeidan et al., 2010; Xue et al., 2011), it may be that even in secular contexts, practitioners are already developing states and traits that are associated with progress toward enlightenment. In order to carefully assess the potential effects of meditative interventions it is of singular importance to ask whether enlightenment can be traced to specific neural correlates, cognition, or behavior.

NO: ENLIGHTENMENT NEEDS SPECIFICATION

Unfortunately, the first answer to this question is "No." The term "enlightenment" is an extraordinarily imprecise construct. Using the term enlightenment or even the term more native to Buddhist traditions, "awakening" (*bodhi*), as if it referred to a single outcome either privileges one conception over others or else assumes that there is some commonality among the traditional goals of diverse contemplative traditions. There are deep disagreements over the nature of the goal between and even within various Buddhist schools. Scientific investigations cannot assume that there is any commonality among the transformative changes referred to as "kensho," "stream entry," "realizing the nature of mind," and so on, that various Buddhist traditions take as various stages of awakening. Empirical investigations of these constructs can only proceed with reference to the specific psychological and behavioral outcomes described in the native discourse of a specific tradition (see Lutz et al., 2007). Because we do not have space here to offer detailed examinations of the theoretical context and neurobiological characterization of enlightenment as it is specified in multiple Buddhist traditions, we focus here on one specific example, that of the Theravāda Buddhist tradition of the Burmese meditation master Mahasi Sayadaw. Nonetheless, by applying more generally the approach we adopt here for this tradition, claims for commonality or differences between psychological states and traits associated with various traditional goals can be operationalized as testable hypotheses.

While some Buddhist traditions understand the goal of *nibbāna* just as a cessation of unwholesome mental states, Mahasi Sayadaw maintains that *nibbāna* "can be seen inwardly as the cessation of all phenomena" (Sayadaw, 1992). This Theravāda Buddhist tradition distinguishes between a "path" moment and the immediately subsequent "fruition" state, which can later be repeated and cultivated. As Khema (1994) describes it, "the path moment doesn't have any thinking or feeling in it…While the meditative absorptions bring with them a feeling of oneness, of unity, the path moment does not even contain that. The moment of fruition, subsequent to the path moment, is the understood experience and results in a turned-around vision of existence…The new understanding recognizes every thought, every feeling as stress (*dukkha*)" (Khema, 1994). Of particular note here is how the "fruition" attainment (*phala-samāpatti*) of experiencing or "seeing" cessation that results from insight practice is sharply distinguished by these Theravâda teachers from various results of concentration, including the cessation of consciousness characteristic of the concentrative absorption *nirodha samāpatti* (Griffiths, 1986), as well as from secular goals of stress reduction, and also from other Buddhist conceptions. For instance, according to some schools of Tibetan Buddhism, an enlightened awareness "sees" all phenomena as truly beyond suffering, as an inseparable emptiness-luminosity-bliss state, not different in nature from awareness itself.

Given the differences between various competing conceptions of awakening, one scientific approach to tracing enlightenment would be to use the tools of social psychology to investigate which states and traits are valued in a particular community. For instance, recent work in moral psychology suggests how value judgments of people and practices as either enlightened or unenlightened could be traced to affective reactions of admiration and disgust (Rozin et al., 1999; Schnall et al., 2008; Brandt and Reyna, 2011; Schnall and Roper, 2011). Some of the most virulent disagreements over what counts as genuine awakening occur between closely related practice traditions, such as the debates between various Theravāda Buddhist traditions in Burma over which states are to count as realizations of *nibbāna* and which are instead to be counted (merely) as states of deep concentration. Surveying these debates, Sharf (1995) concludes "there is no public consensus as to the application of terms that supposedly refer to discreet experiential states within the *vipassanā* movement" (Sharf, 1995, p. 265).

It is important in this regard to separate two sorts of disagreement, the one centering on which states are taken to be worthy of the title of awakening, the other on the accuracy of self-reports of experiential states that may reflect markers of progress. Even within communities where there is consensus on which states/traits deserve to be called enlightened, there can be disagreement over whether or not particular individuals have attained these. In practice, as Sharf (1995) details, Buddhist teachers do not accept self-reports of meditative experience at face value, but instead assess whether a particular reported state should be counted as a case of realization depending on practice history, the manner and emotional state with which the report is given, and retrospective observations of behavior. This kind of skepticism is emphasized in Buddhist theory (Olendzki, 2010) and also recent cognitive science (Clark, 1997; Knauper and Turner, 2003; Mehling et al., 2009) suggesting unreliability of self-report, due to affective biases of attention and memory, as well as poor validity and generalizability. Fortunately, objective measures of such affective biases of perception and cognition have been developed (Elliott et al., 2010), and recent work suggests that certain forms of meditation practice may function precisely by attenuating such biases (Vago and Nakamura, 2011; Garland et al., 2012; Van Vugt et al., 2012; Kang et al., 2013). This leads us to a qualified optimism for studies drawing on a nuanced understanding of the specific traditional context of a specific conception of enlightenment and leveraging objective measures of experiential acuity.

A QUALIFIED YES: RECENT PROGRESS AND METHODOLOGICAL CHALLENGES

By integrating evidence from neuroimaging with evidence of behavioral transformations specified in particular traditional descriptions of meditation practices, some important obstacles may be mitigated. For instance, in an adaptation of the Mahasi method developed by Shinzen Young, practitioners use the label "Gone" to refer to the "fruition" experience of cessation described above. According to Young, this kind of experience is not uncommon for advanced practitioners (Young, 2013). Indeed, in a recent study conducted with adept practitioners of this system, two subjects reported having a temporary experience of cessation while in the scanner environment. The methodology was unique in this experiment given that button presses were used to indicate temporal markers associated with peak level of clarity or contact with a sustained period of "rest" that follows ordinary experience of a particular sensory object passing or vanishing from conscious awareness. Using traditional methods of fMRI analyses, we were able to investigate the functional correlates of the deeper experiences of cessation in comparison to the more common experience of the passing away of a sensory object. The preliminary results suggest a number of very unique functional changes in particular brain regions that were similar in activation for "rest" in the other meditators, but the magnitude of the hemodynamic change from baseline was much larger. For example, the frontal polar cortex (Brodmann area-10), a specialized area for higher cognitive functions (Koechlin et al., 1999; Ramnani and Owen, 2004), showed dramatic increases in functional activity (>50% BOLD signal change) that were not as large for the other meditators. As interesting as this preliminary finding is, we can not simply say we found the neural correlate of cessation, but rather a potential neural marker for the experience of "Gone" in Young's system of training that is relative to the baseline state of mind wandering in this individual. Because of the limitations associated with traditional analyses, we are currently attempting to explore this state using more novel methods that do not require the state of interest to be contrasted with a state of no interest, such as state space analyses [see Janoos et al. (2011)].

One major problem in using neuroimaging methodology is that it is typically dependent upon the general linear model (GLM), a convenient method that flexibly allows for both linear regression and ANOVA; however, the model relies on assumptions that may not hold in all situations. For example, fMRI has a poor temporal resolution limited by a hemodynamic response function for each brain response or "state" that is approximately 12 s in duration; any attempts at exploring discrete states within this timeframe is likely to be influenced by "bleeding over" of hemodynamic activity from the previous state. Furthermore, another limitation of the GLM is its dependence on creating a contrast between states of interest and some other state of no interest. The assumptions and limitations are likely to fail in attempts to capture the subtle changes associated with normative, but transitory, states of enlightenment.

Nonetheless, important progress has been made. Some studies investigating long-term meditators with mixed traditions have attempted to map correlational neurophysiology with first-person experiences of clarity, somatic awareness, nonduality, and mind-wandering in adept meditators (Lutz et al., 2004; Josipovic et al., 2012; Garrison et al., 2013; Hagerty et al., 2013; Kerr et al., 2013; Vago et al., 2013). Indeed, neural correlates of particular meditative states show a developmental trajectory, such that there is a similar pattern of development regardless of cultural background or technique early on in meditative naïve practitioners, but that such markers change throughout expertise and experience (e.g., Brefczynski-Lewis et al., 2007). More recently, attempts have been made to operationalize meditation in very specific contexts of automaticity (Travis, 2011) and non-duality (Josipovic, 2010). Some studies have focused on expert practitioners with the assumption that unique neurophysiology amongst these meditators (in comparison to meditation naïve control subjects) may point to particular biomarkers of advancement toward end-goals of practice. For example, Lutz et al. (2004) found gamma band electroencephalography (EEG) power over lateral frontal and parietal electrode sites to correlate ($r = 0.69$) with self-reported clarity in expert Tibetan practitioners of "non-referential compassion" (Tibetan: *dmigs med snying rje*), suggesting a particular mechanism for increased phenomenal intensity. More recently, a number of studies have also found gamma band activity across different electrode sites to correlate with particular meditative states across different contemplative traditions (Lehmann et al., 2001; Vialatte et al., 2009; Cahn et al., 2010, 2013; Rubik, 2011; Berkovich-Ohana et al., 2012; Ferrarelli et al., 2013; Kozhevnikov et al., 2013), some suggesting increased gamma power correlates with level of experience and may be a marker of plasticity that remains during restful or even states of deep sleep (Ferrarelli et al., 2013).

CONCLUSIONS

Scientific investigation of mindfulness and meditation have already arguably advanced the field of neuroscience and specifically our knowledge of the brain (e.g., "resting states") in the context of functional neuroimaging [see Holzel et al. (2011); Vago and Silbersweig (2012) for review]. Once biomarkers are established for progress along the paths outlined in particular traditions, these can be used as feedback (e.g., Garrison et al., 2013), or for therapeutic targets in the context of neuropsychiatry. It is therefore, necessary to responsibly unpack traditional constructs into common psychological and neurocognitive terms that can correlate with first-person experience with some consistency, but without unwittingly dismissing the deepest and most fundamental features of the practices from which they originate. We are, in the end, cautiously optimistic that progress can be made on well-defined projects in this area that integrate behavior and phenomenology with neuroimaging evidence, but not without a careful consideration of the methodological obstacles. Responsible scientific investigations of enlightenment can proceed only on the basis of rigorous understanding of particular experiential states or behavioral traits within a particular tradition as part of a whole value system, embedded in many other aspects of the models employed in that specific tradition of how the mind works and how awakening progresses.

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Electrocortical activity associated with subjective communication with the deceased

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During advanced meditative practices, unusual perceptions can arise including the sense of receiving information about unknown people who are deceased. As with meditation, this mental state of communication with the deceased involves calming mental chatter and becoming receptive to subtle feelings and sensations. Psychometric and brain electrophysiology data were collected from six individuals who had previously reported accurate information about deceased individuals under double-blind conditions. Each experimental participant performed two tasks with eyes closed. In the first task, the participant was given only the first name of a deceased person and asked 25 questions. After each question, the participant was asked to silently perceive information relevant to the question for 20 s and then respond verbally. Responses were transcribed and then scored for accuracy by individuals who knew the deceased persons. Of the four mediums whose accuracy could be evaluated, three scored significantly above chance ($p < 0.03$). The correlation between accuracy and brain activity during the 20 s of silent mediumship communication was significant in frontal theta for one participant ($p < 0.01$). In the second task, participants were asked to experience four mental states for 1 min each: (1) thinking about a known living person, (2) listening to a biography, (3) thinking about an imaginary person, and (4) interacting mentally with a known deceased person. Each mental state was repeated three times. Statistically significant differences at $p < 0.01$ after correction for multiple comparisons in electrocortical activity among the four conditions were obtained in all six participants, primarily in the gamma band (which might be due to muscular activity). These differences suggest that the impression of communicating with the deceased may be a distinct mental state distinct from ordinary thinking or imagination.

Keywords: mediums, EEG, intuition, mental states, transcendence

INTRODUCTION

Individuals who report experiencing communication with deceased persons are traditionally called mediums. During a typical mediumship reading, a medium conveys messages from deceased persons to the living (i.e., sitters). There are two types of mediumship: mental and physical. In mental mediumship, communication with deceased persons is experienced "through *interior* vision or hearing, or through the spirits *taking over* and controlling their bodies or parts thereof, especially . . . the parts required for speech and writing" (Gauld, 1982, p. 4). During physical mediumship, the experienced communication "proceeds through paranormal physical events in the medium's vicinity" (Gauld, 1982, p. 4), which have included reports of independent voices, rapping sounds on walls or tables, and movement of objects (Fontana, 2005).

The practice of mediumship can be traced to primeval times, where shamans in the earliest communities provided guidance to the tribe through purported communication with the spirit world. Mediumship is generally not regarded in a favorable light by traditional Judeo-Christian-Islamic religions, although it is referred to as a genuine phenomenon in sacred texts (e.g., Samuel 28:1–25 in the Old Testament). Modern societies have seen a recent and dramatic increase in the portrayal of mental mediums in popular culture and a similar increase in practicing mediums offering their services.

The scientific study of mediumship began in the nineteenth century. Books like *The Mediums' Book* published by Kardec (1861/2009) popularized a rational approach to studying these phenomena. Members of the British and American Societies for Psychical Research, which studied mediumship in the heyday of spiritualism in the late 1800s, included psychologist William James, physicist Oliver Lodge, and physiologist and Nobel laureate Charles Richet. William James noted that the study of mediumship "cries aloud for serious investigation" (cited in Moreira-Almeida, 2012, p. 194) because although many mediums were found to be fraudulent, some who were studied under strictly controlled conditions appeared to have genuine access to information by non-ordinary means.

Scientific research on mediumship has also witnessed a small resurrection within the last decade. More recent research has examined the accuracy of statements provided by mediums under double- and triple-blind conditions (e.g., Roy and Robertson, 2004; O'Keefe and Wiseman, 2005; Beischel and Schwartz, 2007; Jensen and Cardeña, 2009; Kelly and Arcangel, 2011) as well as mediums' phenomenology (e.g., Rock and Beischel, 2008; Rock et al., 2009), psychology (e.g., Roxburgh and Roe, 2011), neurobiology (e.g., Hageman et al., 2010), and the therapeutic potential of mediumship readings for the bereaved (Beischel et al., in press). Recent research has also confirmed previous findings that mediumship is not associated with conventional dissociative experiences, pathology, dysfunction, psychosis, or over-active imaginations (Roxburgh and Roe, 2011). Indeed, a large percentage of mediums have been found to be high functioning, socially accepted individuals within their communities (Krippner, 2007; Moreira-Almeida et al., 2007).

Most prior research on this phenomenon has focused on whether mediums can genuinely report accurate information under blinded conditions, and whether their personalities deviate in significant ways from population norms. But little is known about their physiological and electrocortical processes. Scientists have long proposed and used electroencephalography to study mediums in trance (deeply dissociated) states (Prince, 1968; Mesulan, 1981; Hughes and Melville, 1990; Oohashi et al., 2002; Hageman et al., 2010), but to our knowledge mental mediums who do not experience trance states have not been studied using these techniques. The present study investigated electrocortical activity in six professional mental mediums to explore two research questions: first, correlations between the accuracy of mediums' statements and their brain electrical activity were examined; and second, differences in mediums' brain activity were studied when they intentionally evoked four subjective states: perception, recollection, fabrication, and communication (as described below).

MATERIALS AND METHODS

PARTICIPANTS

Six individuals were randomly selected from a pool of 19 Windbridge Certified Research Mediums. These individuals were screened by the Windbridge Institute regarding their ability to report accurate and specific information about deceased individuals under blinded conditions. They also agreed to uphold a code of ethics and to volunteer their time to research (Beischel, 2007). Previous fMRI and other neuroimaging research has similarly used talented individuals to investigate mediumship (Mesulan, 1981; Hughes and Melville, 1990; Oohashi et al., 2002; Hageman et al., 2010; Peres et al., 2012).

Five females and one male participated in data collection. Their average age was 49.3 years and they had been participating in laboratory research for an average of 2.6 years. They each traveled from within the continental United States to the recording facility at the Institute of Noetic Sciences in Petaluma, California. They were not compensated for their time, but their travel expenses were reimbursed. Throughout this report, these six mediums are referred to by randomly assigned digits, e.g., Medium 1 or M1. The experimental protocols for both experiments were approved by the Institutional Review Board of the Institute of Noetic Sciences.

DESIGN

Sitters volunteered to participate in blinded reading sessions through a signup form on the windbridge.org research web page. Co-author MB screened sitters by email and phone prior to the experiment and asked them to provide the first names of deceased persons. A few days prior to data collection, MB provided the sitters with the approximate time at which the reading would take place and asked them to informally think about the deceased person at that time. At the start of each reading, the medium was given the first name of a deceased person and was asked to contact them. First names alone do not provide enough information to bias the medium's responses to specific questions about the deceased's personality, hobbies, profession, preferences, or cause of death (Beischel, 2007). The accuracy of the mediums' responses to these questions was later rated by the sitters who knew the deceased persons; these sitters were the only individuals with enough knowledge to effectively perform the accuracy rating task. The mediums and sitters never met each other and sitters were not present during the experiment.

All experimenters, mediums, and sitters were appropriately blinded to control for conventional explanations for the accuracy of the mediums' statements. This design eliminates the possibility of "cold reading" or fishing for information by the mediums. During the readings, an experimenter who did not know the deceased persons served as a proxy for the absent sitters and asked the questions to the mediums.

SET-UP

The mediums' electrocortical activity was recorded with a 32-channel EGI system (Net Amps 300 with 32 channel HydroCel™ Geodesic Sensor Net, Electrical Geodesics, Inc., Eugene, OR) at a sampling rate of 250 Hz. The default Cz electrode was used as a reference. Electrode impedance was maintained below 50 KOhm, which was the default impedance threshold on the EGI Net Amps 300 system. Electrode impedances were rechecked every 20 min and adjusted if necessary. Autonomic responses (i.e., galvanic skin conductance (GSR), respiration, heart rate, and blood flow) were recorded using a BIOPAC MP150 system (BIOPAC Systems Inc., Goleta, CA). Autonomic results will be reported in other publications.

During each data collection session, a medium and one experimenter (JB) were seated in a small ($8' \times 8'$) double steel-walled room. A microphone placed inside the room allowed a second experimenter (AD) in a nearby room to hear JB and the medium. AD manually marked events into the EEG records based on JB's verbal instructions, as described below. Mediums were instructed to keep their eyes closed for the duration of all of the recording sessions.

EXPERIMENT 1

Each of the six mediums performed two blinded readings of two different deceased persons, for a total of 12 readings. Prior to each medium's two readings, experimenter JB was provided with the first names of the two deceased persons by MB, who had acquired the names from the associated sitters by phone during the screening process. MB had no contact with the mediums and was not present during the readings. Experimenter JB had no contact with the sitters and served as their proxy during the readings.

Mediums were given time to prepare for each reading; a few chose to meditate for about 1 min. Then JB provided him/her with the first name of a deceased person; the order of the two names read by each medium was randomized. All mediums claimed to be able to “connect” with the named deceased person in less than 1 min.

During the reading, JB asked the medium 25 planned questions regarding aspects of the deceased’s physical and personality characteristics, hobbies or interests, cause of death, preferences, experiences, and messages for the sitter (see **Table A1**). The order of the questions was randomized for each reading although questions belonging to similar categories were kept together and randomized within the category. After each question was asked, the medium remained quiet for 20 s to allow for movement-free EEG data to be collected. Investigator AD manually marked the EEG record after each question posed by JB. This was deemed appropriate since data analysis did not require fine temporal precision of the onset and offset of the 20-s response periods. JB notified the medium when this 20-s period was complete, and then the medium verbally answered the question (**Figure 1A**). The questions asked by JB and the mediums’ responses were audio recorded for subsequent transcription.

It should be noted that these questions exceeded the standard question set used in previous research (Beischel, 2007) in both number (25 in the present case vs. 4–6 in other studies) and specificity. A larger number of questions were required in this study to collect sufficient EEG data, so questions about physical and personality characteristics, interests, and causes of death were divided into more specific sub-questions (see questions 1–18 in **Table A1**). Questions about aspects of the deceased persons’ experiences and preferences were also added (see questions 19–25 in **Table A1**). In addition, in previous research mediums were able to respond to the questions immediately and provide as little or as much free-form information as they chose.

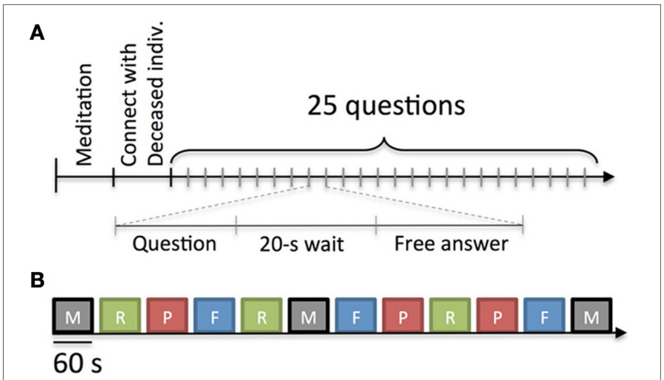

FIGURE 1 | Experimental protocols. (A) Protocol for Experiment 1. After an optional meditation period of 1 min, the medium was given the first name of a deceased person with which to connect. All mediums claimed they connected with the deceased person within 1 min. Experimenter JB then asked the medium 25 questions. Each question was followed by 20 s of silence to provide for movement-free EEG data. **(B)** Protocol for Experiment 2. Mediums were asked to experience four different mental states: M, mediumship communication with a deceased person known to him/her; R, recollecting details about a living person known to him/her; P, perceiving biographical information about a deceased person read aloud by an experimenter; and F, fabricating a person and thinking about that imagined person. Each session lasted for 1 min and was followed by 15 s of rest. Each block of four sessions was repeated three times. The order of sessions was randomized within each block for each subject although a given state was never requested twice in a row. The figure depicts one possible order of experimental conditions.

After the EEG data collection, JB transcribed the medium’s responses to the 25 questions for each of the two readings and formatted the information into two lists of numbered items in which all references to the deceased persons’ names were removed. The two lists were then randomized, identified by two consecutive numbers (e.g., Reading 5 and Reading 6), and emailed to a research assistant blinded to which readings were associated with which sitters and the identity of the medium who performed them. The research assistant then emailed each of the two associated sitters the two lists based on contact information obtained from MB. Later, the same research assistant received the scored readings from the sitters by email. During this procedure, each blinded sitter scored two readings (a target reading intended for him/her and a decoy reading intended for the other sitter) without knowing which was which. The 12 readings contained an average of 95 items each (range: 43–171 items).

The sitters rated the accuracy of each item in each list using a standardized scoring scale (Beischel, 2007). Mediums sometimes gave multiple answers to individual questions. Each of those items was rated independently and the percent accuracy (total items scored as “hits” divided by the total number of items minus those the sitter was unable to score) was calculated for each question.

Two of the 12 sitters did not return their scores. One had another loss in his/her family after the study readings took place and did not complete the scoring. Another sitter failed to respond despite repeated requests. Therefore, only data from 10 readings were available for analysis.

DATA ANALYSIS FOR EXPERIMENT 1

EEG data were preprocessed by performing high pass filtering at 1Hz using a non-linear IIR filter (transition bandwidth of 0.3 Hz and order of 6). Zero to five channels containing large amplitude artifacts were removed by visual inspection of the power spectrum by investigator AD. AD also removed artifactual data segments by visual inspection. These segments contained paroxysmal activity due to head movement, electrical artifacts, or large amplitude eye movements. Minor eye movement artifacts were not removed. The data were converted to an average reference montage and Independent Component Analysis (ICA, Extended Infomax version) was applied to remove eye and muscle artifacts (Delorme and Makeig, 2004). Artifactual ICA components were visually identified by AD on the basis of scalp topography, time course, and power spectrum. Between one and six components were removed for each subject. When both sessions of Experiment 1 were performed without the medium removing the electrode cap, we used a single ICA decomposition for both sessions. If the medium removed the electrode cap between the two sessions to have lunch, we performed two separate ICA decompositions and rejection of ICA components.

After pre-processing the data, experimenter AD segmented data around each question using 20-s epochs: from 3 s before the end of the question to 17 s after the question. Any segment that had artifactual data as defined in the previous step was removed. Experimenter AD was blind to the accuracy ratings during the data-preprocessing phase.

The total number of data segments for the six mediums ranged from 24 to 42 (M1:29; M2:45; M3:24; M4:24; M5:35; M6:42). For some mediums (M3 and M4), scoring data from only one reading was available (as noted in the previous section). Data segments were classified into two categories: segments for which the accuracy of the response was high (i.e., rated above or equal to 50%) and segments for which the accuracy of the response was low (i.e., rated below 50%). High accuracy groups contained from 6 to 24 segments (M1:17; M2:22; M3:6; M4:15; M5:24; M6: 24) and low accuracy segments contained from 11 to 23 segments (M1:12; M2:23; M3:18; M4:9; M5:11; M6: 18).

The power spectrum was then computed for each data segment using a modified Welch method (Welch, 1967). A window of 1 s was used with 0% window overlap. The Welch method was modified to only consider every other window; that is, half of the windows were ignored to minimize autocorrelation between contiguous windows. It was found that for most of the mediums, there was no significant autocorrelation between neighboring selected windows in any of the frequency bands of interest. The absence of autocorrelation is important when performing statistical analyses which assume independence of samples. It may be noted that statistical methods and corrections for multiple comparisons do not always correct for autocorrelated EEG data, but given the controversial nature of the phenomenon under investigation, we chose to employ a more conservative approach. Weak autocorrelations between spectral estimates in neighboring windows remained for some mediums, but not for medium M1 whose data demonstrated the most significant effects.

Spectral power was then compared across all data channels between the two accuracy levels in four different frequency bands (theta 3–7 Hz; alpha 8–12 Hz; beta and low gamma 18–45 Hz; high gamma 75–110 Hz). These frequency bands were used because of their ubiquity in EEG research. We used a Monte-Carlo permutation method to compute statistics and the cluster method to correct for multiple comparisons across data channels (Maris et al., 2007). It should be noted that this method, which takes into account the structure of the data, such as the position of scalp electrodes, is the only valid method for correcting for multiple comparisons in EEG data since it accurately controls for type I errors. Finally, a conservative two-tailed threshold was set for significance at $p = 0.01$.

EXPERIMENT 2

In Experiment 2, the mediums were asked to experience four different mental states: (1) Recollection (think about a living person known to the medium), (2) Perception (listen while an experimenter describes details about a person unknown to the medium), (3) Fabrication (think about a person imagined by the medium), and (4) Communication (interact mentally with a deceased person known to the medium). Each state was experienced for 1 min and mental states were experienced three times each. For the Perception condition, experimenter JB read details from biographies of deceased individuals collected online by a research assistant. The biographies included information similar in content to that requested from the mediums in Experiment 1. None of the mediums reported recognizing the persons depicted in the biographies. For the Communication and Recollection conditions, the medium chose deceased and living, respectively, friends or relatives prior to the beginning of the experiment.

The tasks in Experiment 2 were organized in 12 randomized and counter-balanced sessions of 1 min each (blocks of four conditions repeated three times) as shown in **Figure 1B**. For Recollection, Fabrication, and Communication conditions experienced the second and third times, the medium was asked to think about or connect with the same person as the one chosen for the first block. For subsequent blocks of the Perception condition, the experimenter continued reading from the biographies in 1-min segments. Between blocks, a 15-s break was taken so the mediums could transition more easily between mental states. Finally, a condition was never experienced twice in a row.

At the start of each 1-min block, JB instructed the mediums which mental state they should experience; she also notified them when to relax during breaks between conditions. JB also tracked the time for each condition and break between conditions using a silent stopwatch. As in Experiment 1, AD marked the EEG record according to JB's instructions.

DATA ANALYSIS FOR EXPERIMENT 2

As in Experiment 1, the data were first preprocessed by performing high pass filtering at 1Hz using a non-linear IIR filter (transition bandwidth of 0.3 Hz and order of 6). Zero to five channels containing large amplitude artifacts were removed by visual inspection of the power spectrum by experimenter AD.

Fifty-second data segments were then extracted from 3 s before the end of the instructions to produce a specific mental state to 53 s after the instructions were complete. Since an experimenter manually entered the events, up to 1 s of inaccuracy was expected in terms of event latency. Extracting 50-s instead of 60-s data segments ensured that the medium was experiencing a specific mental state. Electrodes with artifactual data were removed by visual inspection by AD; artifactual data segments were also removed manually by AD from each 50-s epoch. The remaining data were then converted to average reference montage, Infomax ICA was performed, and artifactual components in each subject were removed; ICA components were selected by visual inspection by AD as in Experiment 1.

For each medium, data were compared across the four mental states in the four frequency bands studied in Experiment 1 (theta 3–7 Hz; alpha 8–12 Hz; beta and low gamma 18–45 Hz; high gamma 75–110 Hz). As in that experiment, data were divided into 1-s segments each separated by 2 s; we ignored every other second to reduce autocorrelation between neighboring spectral estimates.

For each frequency band, prior to studying differences between mental states, spectral power was detrended for all of the 1-s spectral estimates over the course of the full 15-min recording before comparing the four conditions. This minimized the effect of spectral power drifts in the signal that may artificially generate differences between conditions.

RESULTS

ACCURACY RESULTS (EXPERIMENT 1)

Since the number of subjects (6) was too low to perform a group analysis, significance was computed separately for each medium. Scoring data from the readings performed by Mediums 3 and 4 were not included in these analyses because two sitter ratings could not be obtained (see Methods). Two sets of ratings for each reading were examined: a set of target accuracy ratings provided by the blinded sitter for whom the unidentified reading was intended and a set of decoy ratings provided by a second control sitter not associated with the reading.

For each of the four mediums for which both sitters returned their scores, the target and decoy ratings were compared. Two methods were used to compute significance, one based on non-parametric surrogate data analysis and one based on a Wilcoxon signed rank test. For the surrogate data analysis method, under the null hypothesis of no difference between the target and decoy reading ratings, we randomly shuffled corresponding scores between the target and decoy ratings. For the Wilcoxon test, the average accuracy on each question was compared between the decoy and the target readings. All statistics are one-tailed with the null hypothesis (H0) that the accuracy would be identical for the decoy and for the target reading, and the alternative hypothesis (H1) that the accuracy would be higher for the target than for the decoy reading.

Three of the four mediums showed a significant bias toward reporting information scored as more accurate by sitters scoring target readings than by sitters scoring decoy readings. Medium 2's results were significant only when considering Wilcoxon statistics, so that outcome might not be as robust as the data from Medium 1 and Medium 5 (see **Table 1**).

CORRELATION BETWEEN ACCURACY AND ELECTROCORTICAL ACTIVITY (EXPERIMENT 1)

Exploratory analyses were performed in four frequency bands of interest: theta at 3–7Hz, alpha at 8–12 Hz, beta and high beta at 18–45 Hz, and gamma at 70–110 Hz. Two cases of significance within groups of electrodes were found: M1 in the theta frequency band and M3 in the alpha frequency band.

M1 demonstrated significant differences in frontal theta power between time periods rated as lower in accuracy (i.e., below 50%) compared to periods rated as higher in accuracy (i.e., equal to or above 50%). M3 showed similarly significant differences during low and high performance in the alpha frequency band. Results for M1 are shown in **Figure 2**.

For the significant electrodes, average power was computed in three quantiles containing about the same number of data segments (0–34% accuracy, 9 values; 40–80% accuracy, 9 values; 100% accuracy, 11 values). **Figure 2B** shows that the theta spectral power for the intermediate level of accuracy falls between the power for the low and the high accuracy segments. This reinforces the hypothesis that the effect we observe is linked to the medium's accuracy.

Table 1 | Percent accuracy and statistical significance for target vs. decoy ratings listed by medium.

	Accuracy target (%)	Accuracy decoy (%)	Accuracy difference (%)	Surrogate (*p*)	Wilcoxon (*p*)
M1	55.5	41.3	+14.2	0.008	0.029
M2	44.9	41.8	+3.1	ns	0.004
M5	63.3	16.5	+46.8	<0.00005	0.00005
M6	45.1	39.5	+5.6	ns	ns

It should be noted that absolute accuracy values for target and decoy ratings are subjective and depend on the judgment of the sitters. Some sitters may give generally higher scores to all items and some may give generally lower scores to all items. Calculating the differences between decoy and target reading scores ("Accuracy difference" column), rather than examining absolute target accuracy scores, addresses this bias.

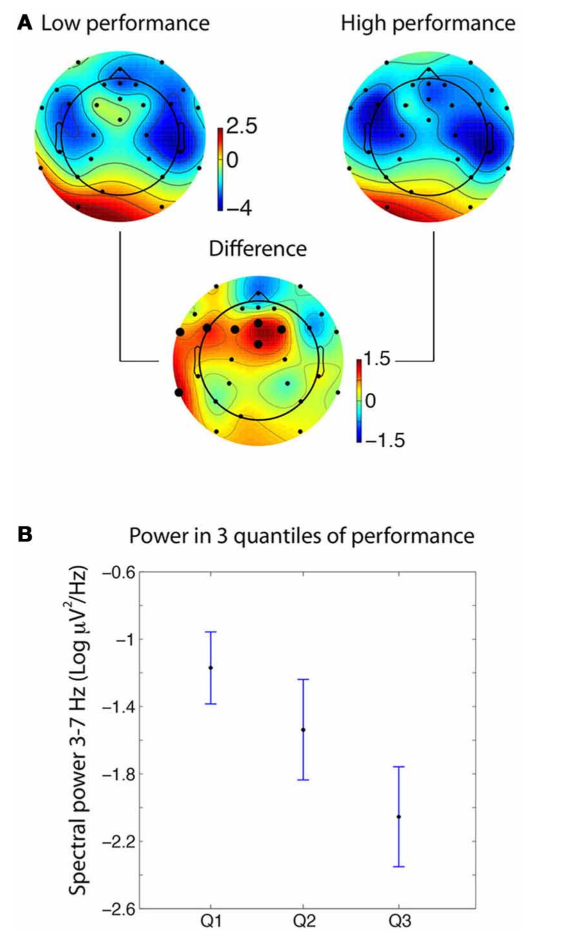

FIGURE 2 | Spectral differences in the theta frequency band for medium M1. (A) Scalp topography of theta power during the mental experiences of information later rated as low (<50%) or high (≥50%) in accuracy [the unit being $10*\log_{10}(\mu V^2)$]. The large dots on the differential scalp topography indicate significance at $p < 0.005$. **(B)** When splitting the data into three quantiles of increasing accuracy (i.e., 0–34; 40–80; and 100% accuracy), theta power for the intermediate accuracy level fell in between the high and low accuracy levels. Error bars indicate 95% confidence intervals.

One explanation for this effect is that it is due to artifacts in the data. To test this hypothesis, the same analysis was run on the data artifacts instead of the cleaned data. Instead of considering the clean channel data with the ICA artifacts removed, only the artifactual data were considered, removing all non-artifactual ICA components from the raw data. Session 1 for Medium 1 had four artifactual ICA components and Session 2 for Medium 1 had three such artifacts. When processing artifactual data, no significant difference was observed between the low and high accuracy conditions. When looking at the three quantiles as in **Figure 2B**, the gradual decrease in power with theta accuracy was not observed.

Supplementary Figure 1 shows significant differences for M3 in the alpha 8–12 frequency band. M3 is one of the two mediums where only one reading was available instead of two, so this plot uses only about half of the data compared to the plot for M1. In contrast to M1 where theta power was negatively correlated with the medium accuracy, for M3 alpha power is positively correlated with accuracy. This result is consistent with the literature showing that alpha and theta power often tend to covary in opposite directions (Laufs et al., 2003; Braboszcz and Delorme, 2011). Since M3 only had one scored reading, there was not enough data to perform a quantile analysis as was done for Medium 1.

ANALYSIS OF MENTAL STATES (EXPERIMENT 2)

In **Figure 3**, EEG in the gamma frequency band for the four different mental states (Recollection, Fabrication, Perception, and Communication) for all six mediums is compared. We observed

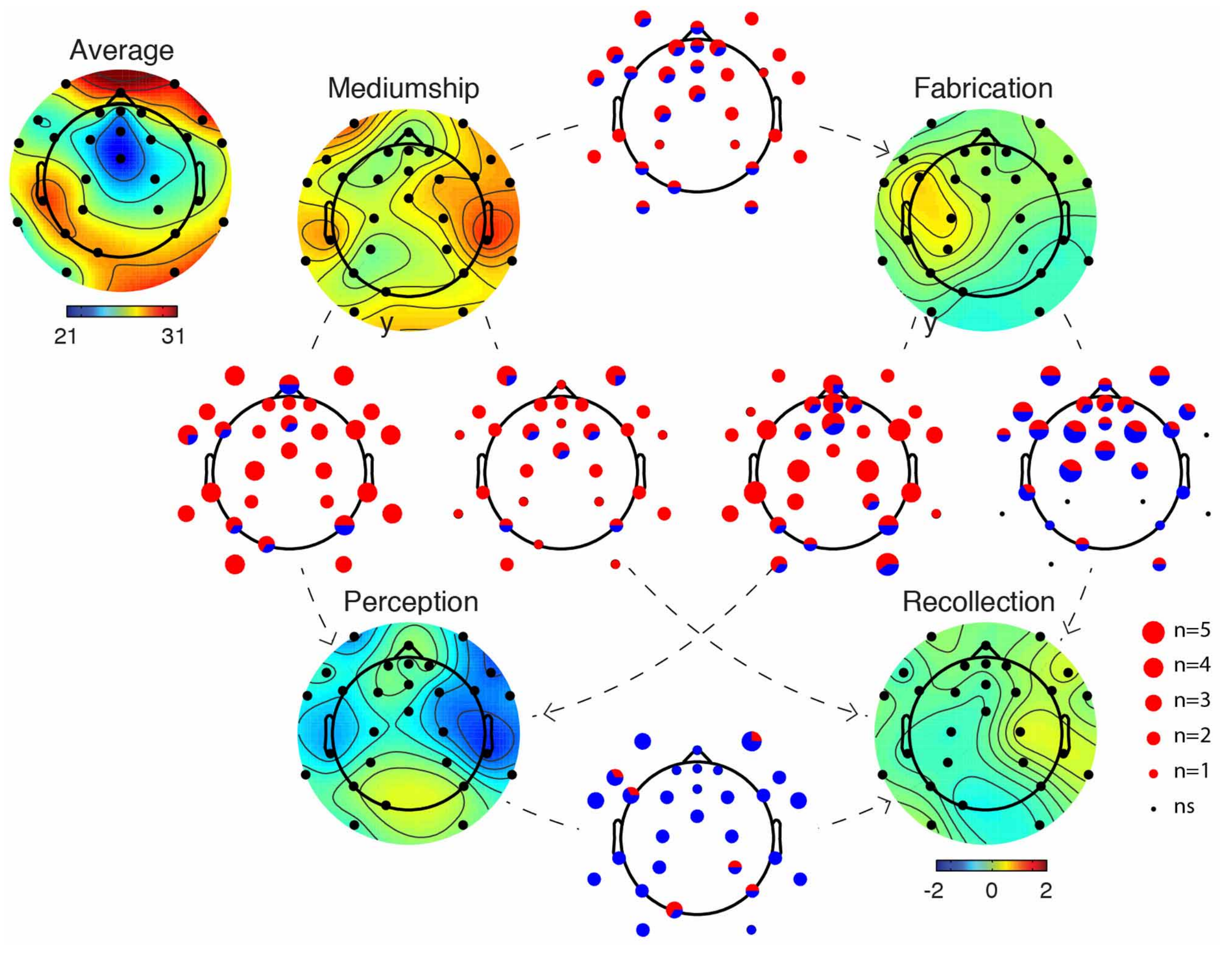

FIGURE 3 | Summary figures depicting differences between mental states in the high gamma frequency band (75–110 Hz). The scalp topography image in the left upper corner indicates the average gamma power for all mental states and all subjects [the unit being 10*$\log_{10}(\mu V^2)$]. Scalp topographies for each mental state indicate deviation from the average scalp power (same units). In between each pair of mental states A and B, a plot indicates the number of significant participants for each electrode ($p < 0.01$ after cluster correction for multiple comparisons). The size of the dot represents the number of participants for which a given electrode is significant [from $n = 0$ (ns) to $n = 5$; significance in all six participants was never attained]. The pie chart within each dot represents the proportion of participants who demonstrated significant differences in one direction (red corresponds to A > B and blue corresponds to A < B). The direction of the comparison is indicated by a directional dashed line from A to B. For example, between the Mediumship Communication mental state and the Perception mental state, most electrodes are significant for three or four participants and the color (red) indicates that gamma power is of larger amplitude during the Communication mental state compared to the Perception mental state.

the largest number of significant electrode differences in the gamma frequency band (75–110 Hz). **Figure 3** illustrates that the EEG is different in all conditions. Red dots on scalp maps indicate which electrodes are significant; Monte-Carlo surrogate statistics with cluster method were used to correct for multiple comparisons. The Mediumship Communication mental state differed more from the Perception mental state than from other mental states. For four of the mediums, larger amplitude high gamma power was observed during the Communication mental state as compared to the Perception mental state at nine electrode sites. The least consistent difference across mediums was the state of Fabrication compared to Recollection (**Figure 3**). For this pair of mental states, although most participants demonstrated a significant difference, about half of the mediums had higher gamma power in the Fabrication condition while the other half had higher power in the Recollection condition.

Gamma and high gamma activity in EEG is often questioned because muscle activity can contaminate this frequency band. Therefore, the same type of analysis was rerun but instead of processing the clean EEG data, only the ICA artifactual components were processed (**Supplementary Figure 2**). We found a pattern of gamma activity that was similar to **Figure 3** in terms of the number of participants who showed significant differences and also in terms of the polarity of the difference. It was concluded that eye and muscle artifacts that were not successfully removed by ICA might dominate the difference observed in **Figure 3**. At this point, it cannot be concluded that the differences observed in **Figure 3**—albeit most likely genuine—originated from brain activity.

A number of significant effects in the beta and high beta frequency band (18–45 Hz) were also observed. These differences were similar to the differences observed in the gamma frequency band in terms of the polarity of the differences although fewer electrodes were significant. **Table A2** summarizes the number of significant electrodes between each state for all mediums.

Differences were also found in the theta and alpha frequency bands although these differences were only present for three mediums (M1, M3, and M6) and only at specific locations on the scalp. In **Supplementary Figure 3**, details regarding which electrodes differed across the mental states in these frequency bands are illustrated. Few electrodes were significant in these frequency bands and the results were idiosyncratic across subjects.

DISCUSSION

A few prior electrophysiological (Solfvin et al., 1977; Mesulan, 1981; Hughes and Melville, 1990; Oohashi et al., 2002; Hageman et al., 2010) and neuroimaging (Peres et al., 2012) studies examined mediums or shamans in trance states. However, to the best of our knowledge, this experiment was the first EEG study of mental mediums who do not experience mediumship communication as a trance mental state. We observed decreased theta power in the frontal area during high accuracy segments of one medium's readings.

INTERPRETATION OF THE BRAIN/ACCURACY CORRELATION

Previous research with mediums has resulted in positive (e.g., Schwartz et al., 2002; Roy and Robertson, 2004; Beischel and Schwartz, 2007; Kelly and Arcangel, 2011) and negative (Schwartz et al., 2003; O'Keefe and Wiseman, 2005; Jensen and Cardeña, 2009) outcomes. Beischel and Schwartz (2007) performed an experiment similar in blinding to Experiment 1 with eight mediums and an experimenter serving as a proxy sitter in which blinded absent sitters scored target and decoy readings. Sitters provided significantly higher global scores for target readings than for decoy readings ($p = 0.007$) and sitters chose their target reading over a decoy reading 81% of the time when faced with a forced-choice task ($p = 0.01$). Kelly and Arcangel (2011) also performed an experiment employing a proxy sitter although they used a photograph of the deceased person instead of his first name and the proxy often knew personally or had information about the sitters and deceased individuals. In that study, each blinded sitter rated six transcripts. In the most successful experiment, sitters rated their reading in the top half (3 out of 6) in 30 cases out of 38 ($p < 0.0001$). Our significant accuracy results for mediums M1, M2, M5 and M6 are consistent with the results obtained in these studies.

As for the brain imaging data, our results from Medium 1 are also consistent with the previous literature. Activity in frontal areas demonstrated with fMRI has been associated with trance spiritual states (Jevning et al., 1996; Beauregard and Paquette, 2006). Decreased frontal midline theta rhythm might index decreased involvement of working memory neural circuits (Onton et al., 2005), which in turn might be consistent with a medium accessing a receptive mental state. We thus argue that these results could reflect genuine anomalous information transfer and would justify replication attempts with this medium.

CORRELATION IN THE GAMMA FREQUENCY BAND

Findings in the EEG gamma frequency band have been associated with meditative trance states (Lutz et al., 2004; Cahn et al., 2010) and conscious thinking (Rieder et al., 2011). However, microsaccades seem to induce gamma in some EEG recordings (Yuval-Greenberg et al., 2008), which has raised doubts about all scalp EEG gamma findings. When observing potential gamma power chances, our approach in the past (Cahn et al., 2010) and in the present study was to perform the same analysis that was run on clean data on the artifacts. The fact that we found gamma power changes in the artifacts that resembled the findings in the clean data suggests that the results we observed are most likely not of brain origin. It could be, for example that the artifact extraction method failed to remove all eye movements and the origin of the gamma power changes we observed were movement artifacts.

The gamma differences between mental states seem to be similar in both data channels and artifacts. The artifacts we removed were most often eye-related activity and did not necessarily capture high frequency activity. We searched for common sources of noise that could contaminate brain activity in this frequency range. In particular we looked at galvanic skin response (GSR) and attempted to correlate GSR with gamma activity. The average GSR value was computed for each time window used to compute gamma power and the correlation was performed over all time windows irrespective of the mental state being experienced by the medium. Two participants showed significant correlation with GSR at five electrode sites at the $p < 0.01$ threshold after correction for multiple comparisons. However, given that this effect was not observed in all participants, it is unlikely that changes in GSR at the scalp level would be responsible for the changes in the gamma frequency band observed in most participants (**Supplementary Figure 2**).

STUDY LIMITATIONS

The design of this study, while necessary for the collection of clean EEG data in quantities large enough for analysis, was not conducive to the testing of hypotheses about mediums' ability to gain accurate information about deceased persons. First, these research mediums are not used to responding to multiple specific questions; in standard research protocols (Beischel, 2007), four to six questions are asked by the experimenter and each answer is then divided into items for rating purposes. In the current protocol, we asked a total of 25 questions. The periods of silence and stillness after questions were asked that were required to limit artifacts in the EEG recordings may also have been disruptive to the mediumship process. That is, after hearing a question, mediums were asked to experience information related to that questions silently for 20 s while EEG data were recorded. The items verbalized by the mediums at the end of those periods may not have reflected the full information they experienced during the collection of EEG data. In standard mediumship research readings, mediums are instructed to immediately "say what you see" and then provide an interpretation of the content if applicable. Although the speed with which each medium experiences and conveys information differs, generally speaking several items are experienced and spoken within any 20-s period. In the current study, information experienced during the 20-s pauses may have been forgotten or altered by the time it was verbalized. Thus, the correlation between cortical activity during the silent 20-s periods and the accuracy of the statements verbalized by the mediums after those periods is indirect at best.

CONCLUSION

To conclude, we believe the results for Medium 1, correlating accuracy with electrocortical activity, qualify as a robust finding. The results regarding differences in gamma power bands between different mental states remains puzzling as the gamma difference we observed seems to arise, at least in part, from eye or muscular activity. The characterization of the exact nature of this difference in the gamma frequency band, and assessing whether any of this activity originates from the brain, calls for additional research. Taken together, the study's findings suggest that the experience of communicating with the deceased may be a distinct mental state that is not consistent with brain activity during ordinary thinking or imagination.

AUTHOR CONTRIBUTIONS

Arnaud Delorme, Julie Beischel, Dean Radin, and Paul J. Mills designed the study. Julie Beischel recruited and trained the medium participants. Mark Boccuzzi recruited and trained the sitter participants. Julie Beischel, Leena Michel, Dean Radin, and Arnaud Delorme collected the EEG data and psychometric data. Julie Beischel, Mark Boccuzzi, and Arnaud Delorme analyzed the psychometric data. Julie Beischel and Arnaud Delorme analyzed the accuracy data. Arnaud Delorme analyzed the EEG data. Arnaud Delorme and Julie Beischel wrote the manuscript. Dean Radin and Paul J. Mills edited the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: http://www.frontiersin.org/journal/10.3389/fpsyg.2013.00834/abstract

Figure S1 | Correlation between alpha power (8–10 Hz) and for the accuracy of statements reported by Medium 3. Legend same as for **Figure 2A**.

Figure S2 | This figure is similar to Figure 3 but instead of processing the data, we processed artifacts as isolated by independent component analysis.

Figure S3 | Grand average spectrum for three participants that showed significant differences between mental states [the unit being $10*\log_{10}(\mu V^2)$]. The ANOVA method was used to compute significance. Electrodes in white indicate those deemed significant after correction for multiple comparison and across all mental conditions.

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APPENDIX

Table A1 | Questions asked of each medium during each reading.

Questions regarding the discarnate's appearance during his/her physical life:

1. Describe the discarnate's hair.
2. Describe the discarnate's eyes.
3. Describe the discarnate's build.
4. Describe the discarnate's height.
5. About how old was the discarnate when s/he passed away?
6. Is there anything else you can tell me about the discarnate's physical appearance?

Questions regarding the discarnate's personality:

7. Was the discarnate more shy or more outgoing?
8. Was the discarnate more serious or more playful?
9. Was the discarnate more rational or more emotional?
10. Is there anything else you can tell me about the discarnate's personality?

Questions regarding the discarnate's hobbies/activities/interests:

11. Did s/he spend more of his/her free time indoors or outdoors?
12. Were most of his/her activities solitary or were most social?
13. Were most of his/her activities physical or were most not physical?
14. Is there anything else you can tell me about the discarnate's hobbies/activities/interests?

Questions regarding the discarnate's cause of death:

15. Did the death occur quickly or slowly?
16. Was the cause of death natural or unnatural?
17. What body parts were affected at the death?
18. Is there anything else you can tell me about the discarnate's cause of death?

19. **What were the discarnate's favorite foods?**
20. **What was the discarnate's occupation? What did s/he do for a living?**
21. **Provide dates or times of year important to the discarnate**.
22. **Provide names of people who were close or important to the discarnate**.
23. **Describe any animals that were close or important to the discarnate**.
24. **Does the discarnate have any messages specifically for the sitter?**
25. **Is there anything else you can tell me about the discarnate?**

Categories are listed in bolded text. For each reading, categories and sub-questions within each category (where applicable) were randomized, However, the final sub-question in a category (i.e., questions 6, 10, 14, and 18) and the final question overall (i.e., question 25) were asked last for each category and overall, respectively. Questions were worded to reflect the deceased person's gender (e.g., 'What did she do for a living?' or 'Were most of his activities solitary or were most social?'). In this questionnaire, the deceased person is designated by the label "discarnate," a common term used in mediumship research.

Table A2 | Comparison of the cumulative number of significant electrodes across the six participants between mental states in the gamma and beta frequency bands.

	Mediumship	Fabrication	Perception	Recollection
GAMMA (75–110 Hz) FREQUENCY BAND				
Mediumship	–	66	93	56
Fabrication	–	–	93	70
Perception	–	–	–	59
BETA (18–45 Hz) FREQUENCY BAND				
Mediumship	–	59	60	53
Fabrication	–	–	53	44
Perception	–	–	–	53

The maximum for each table is highlighted using a green background.

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