Neural correlates of pure presence

Melanie Boly[1,2], Richard Smith[2], Giulietta Vigueras Borrego[1], Joan Paul Pozuelos[3], Tariq Alauddin[2], Peter Malinowski[4], Giulio Tononi[2]

[1] Department of Neurology, University of Wisconsin-Madison, USA
[2] Department of Psychiatry, University of Wisconsin-Madison, USA
[3] Neuromindset, University of Granada, Spain
[4] School of Psychology, Liverpool John Moores University, UK

*Corresponding authors: Melanie Boly, Giulio Tononi.

Email: boly@wisc.edu, gtononi@wisc.edu

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Abstract

Pure presence (PP) is described in several meditative traditions as an experience of a vast, vivid luminosity devoid of perceptual objects, thoughts, and self. Integrated information theory (IIT) predicts that such vivid experiences may occur when the substrate of consciousness in the cerebral cortex is virtually silent. To assess this prediction, we recorded 256-electrode high-density electroencephalography (hdEEG) in long-term meditators of Vajrayana and Zen traditions who were able to reach PP towards the end of a retreat. Because neural activity is typically associated with increased EEG gamma power, we predicted that PP should be characterized by widespread gamma decreases. For meditators of both traditions, PP was associated with decreased broadband hdEEG power compared to within-meditation mind-wandering, most consistent in the gamma range (30–45 Hz). Source reconstruction indicated that gamma decrease was widespread but especially pronounced in posteromedial cortex. PP broadband power also decreased compared to all other control conditions, such as watching or imagining a movie, active thinking, and open-monitoring. PP delta power (1–4Hz) was also markedly decreased compared to dreamless sleep. PP with minimal perceptual contents or accompanied by a feeling of bliss showed hdEEG signatures close to PP. In contrast, gamma activity increased during phases characterized by rich perceptual contents, such as visualization or mantra recitation. Overall, these results are consistent with PP being a state of vivid consciousness during which the cerebral cortex is highly awake (decreased delta activity) but neural activity is broadly reduced (decreased gamma activity), in line with IIT's predictions.

Significance Statement

Pure presence (PP) is described in several meditative traditions as an experience of a vast, vivid luminosity devoid of perceptual objects, thoughts, and self. Integrated information theory (IIT) predicts that such vivid experiences may occur when the substrate of consciousness in the cerebral cortex is virtually silent. We recorded 256-electrode high-density electroencephalography (hdEEG) in Vajrayana and Zen long-term meditators who could reach PP towards the end of a retreat. Compared to all control conditions, PP was characterized by decreased broadband hdEEG power, most consistent in the gamma range. These results are consistent with PP being a state of vivid consciousness during which the cerebral cortex is highly awake but neural activity is broadly reduced, in line with IIT's predictions.

Main Text

Introduction

It is generally assumed that consciousness requires neural activity. Neuronal firing would be needed to support specific computations, the "processing" of information, or the performance of certain cognitive functions. For example, consciousness might depend on recurrent processing within posterior cortex (1), on interactions between prefrontal and posterior cortex (2), on global information broadcasting (3), on top-down, predictive processing (4-6), and so on (7).

In contrast, integrated information theory (IIT, presented in detail in (8) and in an online wiki (9)) argues that an experience corresponds to a "cause–effect structure", rather than to a computation, a function, or a process. The cause–effect structure expresses the powers of the substrate's neurons to "take and make a difference" within it. According to the theory, the cause–effect structure specified by a substrate in its current state accounts in full for both the quality of the experience and its quantity, with no additional ingredients.

A counterintuitive prediction of the theory is that a substrate with the appropriate anatomical organization—a densely connected, hierarchical lattice as found primarily in posterior-central cortical areas—should support an experience even when its neurons are inactive (or nearly so). Moreover, as long as its causal powers are intact, a lattice-like substrate in a state of near-inactivity should specify a cause–effect structure corresponding to an experience of pure "extendedness" (10). On the other hand, if the substrate's causal powers are disrupted, notably by the bistability typical of early NREM sleep (11), consciousness will be lost despite ongoing neural activity (12).

While it is currently not feasible to test this prediction in the human brain at the single-neuron level, it is possible to assess its plausibility by recording gamma power with high-density electroencephalography (hdEEG), to the extent that gamma power can serve as a proxy for neuronal activation (13-15). To begin addressing these predictions experimentally, we focused on states of "pure presence" (PP), also known as "pure consciousness" (16, 17). Such states are acknowledged by several spiritual traditions (16, 17) and are described as experiences of vast, vivid luminosity, devoid of thoughts, objects, particular sensory features, the perception of a self, or any distinction between subject and object (non-duality). For example, the *Tibetan Book of the Dead* speaks of "a lucid clarity without anyone being there who is the observer…" where "only a naked manifest awareness is present" … "a vast luminous expanse, clarity inseparable from emptiness" (18). States of "pure being" with no self, no thoughts, and no perceptual contents have also been reported after severe trauma (19) and certain phases of sleep (20). It is also helpful to think of such states as an extreme on a continuum of cortical activation: different contents of experience—whether faces or objects (21, 22), simple sensations (23), thoughts (24), or self-related ideation (25, 26)—are typically accompanied by neuronal activations in specific neuronal populations, surrounded by widespread quiescence or deactivation. One would thus expect that during quiet, thoughtless, and selfless moments in the absence of exogenous or endogenous stimuli, the entire neural substrate of consciousness should be in a quiescent state.

In this work, we employed high-density electroencephalography (hdEEG, 256 channels) to record brain activity from experienced meditators who could reliably reach states of PP. Given that hdEEG gamma power (25–45 Hz) tracks locally increased neuronal activity when experiencing different conscious contents (21, 24), we predicted that PP states

should be associated with a widespread decrease in gamma power. By contrast, because increased delta activity (0.5–4 Hz) is a hallmark of a breakdown of causal interactions typically associated with states of unconsciousness (11, 21), we predicted that delta power should stay the same or even decrease.

This study sought to obtain a clear picture of the neural correlates of PP by minimizing potential confounding factors in several ways. First, we relied on long-term meditators because of their training in reaching such states, but we provided an explicit characterization of the target state for this study: no self, no thoughts, no perceptual objects or sensory features, non-duality, and instead a pure sense of spatial extendedness. Preliminary sessions were devoted to clarifying the phenomenal properties of the target PP state, disentangling them from the specific jargon or goals specific to a particular tradition. For example, some descriptions from LTMs may mention that "the visual perception of space disappears" during PP (17), but it turns out that it is the "external" space—the world—that vanishes, with the landmarks that delimit it, rather than the "internal" space—the feeling of extendedness of the experience as such. Second, we recruited long-term meditators from two different schools—the Vajrayana tradition, in which the "dissolving phase" corresponding to PP is a desired target, and the Zen tradition, in which PP-like states are encountered on the way to other target states. Third, we took advantage of week-long retreats to acclimate the subjects to the experimental setup and facilitate the attainment of PP. Fourth, we employed both a delayed-report paradigm and a no-report paradigm. As confirmed by individual interviews (see also (17)), PP is incompatible with immediate report. However, subjects can be trained to report its occurrence after a delay upon exiting the state (sometimes characterized as an "afterglow" (21)). Moreover, Vajrayana meditators were also recorded in a no-report paradigm while undergoing a prescribed sequence of meditation states (with instructions provided before each phase). Sixth, we employed a number of control conditions, both within meditation (mind-wandering and other meditative states with rich perceptual contents) and outside meditation (resting with eyes open or eyes closed, movie watching, imagining, performing a mental calculation). Seventh, we considered conditions of near-PP in which meditators reported minimal perceptual contents and PP accompanied by a feeling of bliss, to assess the robustness of the findings. Eight, we compared PP with dreamless sleep to assess the expected differences between PP and loss of consciousness.

As to the recordings, because PP states may be hard to maintain, we focused the analysis of hdEEG on a five-second epoch of recording occurring just before the report in the delayed-report paradigm or just after the start of the dissolving phase in the no-report paradigm. This approach maximized our chances of identifying the neural correlates of PP in both cases. Crucially, we employed a state-of-the-art procedure to remove any non-neural contaminant from the EEG signal (27). This is essential to ensure that any differences between PP and other states are due to neural changes rather than to changes in muscle activity, eye movements, sweat, or other factors (28). The use of 256 channels is especially important in this regard as it offers great sensitivity in revealing extraneous components (29, 30). Furthermore, we considered all frequency bands below 45Hz and all channels, in addition to preforming source localization, to avoid missing localized activations.

Results

LTM demographics and retreat procedure

Thirty-eight LTMs from the Vajrayana Karma Kagyu and Zen traditions of Buddhism were recorded during week-long retreats (Fig. 1; see Methods and Supplementary Material for details). During Vajrayana 8th Karmapa Guru Yoga or Zen Shikantaza practices, LTMs were instructed to signal with a mouse click when they had just emerged from a state of PP—defined as a "phenomenal state without thought, self, or perceptual contents." Additionally, they were asked to signal PP-like states with minimal perceptual content (PP-mpc), and states of mind-wandering (MW) occurring during their practice. Zen LTMs were also instructed to report tradition-specific states with "minimal thoughts" or "no thoughts" with preserved perceptual content, and non-dual states where "the self–other distinction disappears while the whole world is present". Vajrayana LTMs were also asked to report tradition-specific states of "bliss-awareness"—that is, PP-like states with "a feeling of bliss arising from mind itself" (PP-bliss). A range of other controls such as eyes open, eyes closed, watching then imagining a movie, active thinking (counting backwards), and open-monitoring were recorded each day. In Vajrayana LTMs, PP states were also acquired along with other content-rich meditative states by recording hdEEG during different phases of a pre-recorded, timed 16th Karmapa Guru Yoga practice. When feasible, LTMs who reported PP states during retreats were brought to the sleep laboratory for overnight hdEEG recordings.

[Insert Fig. 1 here]

HdEEG data from days 5–7 of the retreats was kept for analysis. Preprocessing included careful visual channel and epoch selection to reduce artifacts, followed by an iterative adaptive independent component analysis (EEGLab AMICA) procedure that has been optimized over the last 5 years (Suppl. Fig. 1). In brief, the time courses of the first 20 components of AMICA decomposition (containing most of the signal variance) were systematically inspected; artifact components were identified both through their focal aspect on 256-electrode topography (unlike brain components which are spatially filtered by the skull and are thus spatially smooth across >10 centimeters) and their time courses (prominent mix of low- and high-frequency signals rather than 1/f combined with oscillatory activities). Outlier epochs where ICA failed to separate brain from artifact components (reflected in mixed artifact and brain signals in several component time courses) were discarded; AMICA was then re-run on remaining time courses and component separation was re-evaluated. The only hdEEG datasets kept for further analysis were those in which a consistent separation of brain activity and artifacts within the first 20 components could be achieved (often requiring several AMICA iterations). Within these datasets, only brain activity components showing a spatially smooth topography and with consistently clean 1/f-oscillatory time courses (Suppl. Fig. 1) were kept for further analysis. After preprocessing, hdEEG data quality was once again verified through the assessment of individual hdEEG topographies. This allowed us to distinguish smooth brain activity from more discrete extra-cranial artifacts (see Suppl. Fig. 1) in the delta (1–4 Hz), theta (4–8 Hz), alpha (8–12 Hz), beta (15–30 Hz), and gamma frequency bands (30–50 Hz for the Zen cohort recorded in the USA, and 30–45 Hz for the Vajrayana cohort recorded both in the USA and Europe owing to differences in the frequency of line noise). Power band

topographies were also computed for source-reconstructed hdEEG time courses. This procedure yielded clean recordings of PP and related meditative states in 22 out of the 38 LTMs studied (14 Vajrayana LTMs and 8 Zen LTMs). Demographic data for the 14 Vajrayana LTMs included in the present analyses were as follows: avg 13 consecutive years of meditation (± sd 5): avg 6 practice days per week (± sd 1); avg 55 practice min/day (± sd 27); avg 5427 estimated total lifetime meditation hours (± sd 1900); avg 37.93 years old (± 6.16); 7 males and 7 females. Demographic data for the 8 Zen LTMs included in the present analyses were as follows: avg 14 consecutive years of meditation (± sd 6); avg 6 practice days per week (± sd 1); avg 48 practice min/day (± sd 14); avg 8004 estimated total lifetime meditation hours (± sd 4174); avg 41.3 years old (± sd 17.15); 5 males and 3 females. Clean sleep recordings with serial awakenings were also obtained in 2 Zen LTMs and a separate sample of 13 Vipassana LTMs (with avg 4310 practice hours [± sd 2481] and avg 49 min of daily practice [± sd 18]) for comparison with PP states.

PP compared to MW: delayed report within meditation practice

In order to minimize confounds, our main analysis consisted in comparing neural signatures of PP states to MW captured during the same meditation session. Statistical analysis was performed using a paired t-test between PP and MW at the within-subject level, and thresholded at cluster-based $p<0.05$ corrected for multiple comparisons using statistical nonparametric mapping (SNPM, see Methods). Figure 2 shows the result of this main analysis. Compared to MW, PP states were characterized by a broadband decrease in EEG power, most consistent and widespread in the gamma range. Similar results for signatures of PP states were obtained across the two different meditation traditions and at the single-subject level (Suppl. Figs. 2–5).

[Insert Fig. 2 here]

Next, we performed source reconstruction analysis of PP signatures (compared to MW), focusing on the gamma band (results for delta to beta bands are shown in Suppl. Fig. 6). Source reconstruction employed a template head model and minimum norm prior as implemented in Brainstorm (see Methods). Statistics were $p<0.05$ corrected for multiple comparisons across vertices using false-discovery rate (FDR). Fig. 3 displays the results of this analysis. In contrast to MW, PP was characterized by a widespread decrease in cortical gamma activity, most prominently in posteromedial areas.

[Insert Fig. 3 here]

PP vs. open-monitoring

Next, we compared PP to a different, well-characterized meditative state, open-monitoring (OM), which is characterized by refraining from engaging in thinking but preserved perceptual content. An OM meditation session was recorded each day before the PP meditation sessions. As shown in Fig. 4, (N = 15 LTMs), OM states were associated with an *increase* in delta to gamma activity compared to both MW and PP.

[Insert Fig. 4 here]

PP and control states outside of meditation practice

To further assess the specificity of the neural signatures of PP, we compared this state to a set of other control conditions collected outside of meditation. Such control conditions included eyes open, eyes closed, movie watching and re-imagining, and active thinking (counting backwards) for 2–3 minutes each (see Methods). These control conditions were recorded each day of the retreat before meditation sessions. Fig. 5 displays comparison between neural signatures of PP states and those of each of these controls recorded the same day. Results show a consistent broadband decrease in delta to gamma power during PP compared to other states, which survived SNPM correction for multiple comparisons in all states (except for active thinking, which showed significance at uncorrected $p<0.05$).

[Insert Fig. 5 here]

PP vs. dreamless sleep

Finally, we compared neural signatures of PP in the same 15 LTMs described above to those of epochs of dreamless non-rapid eye movement (NREM) sleep obtained in 15 LTMs (2 Zen LTMs and 13 other age-matched LTMs from the separate Vipassana cohort), in which serial awakenings with experience sampling were performed (see Methods). Group results (displayed in Fig. 6) revealed that PP was characterized by a broadband decrease in delta to gamma power compared to epochs of dreamless sleep.

[Insert Fig. 6 here]

We also confirmed these results at the individual level in 2 Zen subjects in whom overnight sleep recordings could be performed at the end of their retreats (see Methods). Suppl. Fig. 7–8 show topographies of PP states vs. dreamless and dreaming epochs obtained from serial awakening from either NREM sleep (stages 1–3) or REM sleep.

PP variants with minimal perceptual content or bliss

We further assessed the neural signatures of a state described by both Vajrayana and Zen LTMs as PP-like but with minimal perceptual content (PP-mpc), typically faint feelings of a somatosensory or visual nature. The comparison of PP-mpc to MW (Fig. 7, upper panels, 15 LTMs) shows widespread decreases in delta and gamma power, similar to PP states, with most consistent gamma decreases in posteromedial cortices. However, these changes were not as pronounced as for PP (uncorrected $p<0.05$). Moreover, gamma activity was preserved in both central and posterior occipital cortices. Direct statistical comparison revealed decreased gamma activity in central, posteromedial and occipital cortices during PP compared to PP-mpc at uncorrected $p<0.05$ (Suppl. Fig. 11, upper row).

[Insert Fig. 7 here]

We also investigated another PP variant traditionally described in Vajrayana as "bliss-awareness"—a PP-like state with "a feeling of bliss arising from mind itself". The results of a group analysis in 9 Vajrayana LTMs with clean recordings during both PP-bliss and MW states (captured during 8th Karmapa Guru Yoga practice) are shown in Fig. 7, lower panel. The neural signatures of PP-bliss are again similar to those of PP—with maximum decrease in both delta and gamma band activity in posterior cortex, although less pronounced than during typical PP (uncorrected $p<0.05$). Unlike PP-mpc, we did not find significant gamma-band activity differences between PP-bliss and PP within the same participants at uncorrected $p<0.05$ values (Suppl. Fig 11, lower row).

In 8 Zen practitioners, we also captured a state characterized by decreased thoughts but preserved perceptual contents during Shikantaza practice (Suppl. Fig. 12, upper panel). In line with OM findings described above, this state showed increased gamma power compared to MW. When transitioning to deeper absorption states, where thoughts stopped completely (with perceptual contents still preserved, then only minimally present (PP-mpc), then totally absent (PP)), gamma activity decreased progressively, at first in posteromedial areas, then in a more widespread pattern (Suppl. Fig. 12, three lower panels).

PP: no-report paradigm

In a further set of experiments, we took advantage of a highly rehearsed, precisely timed practice that allowed us to assess the neural correlates of PP in a no-report paradigm and compare PP to other meditative states with richer thought-like and perceptual contents. The pre-timed 16th Karmapa Guru Yoga practice in Vajrayana LTMs starts with a visualization-rich generation phase, then transitions to a mantra recitation phase, then to a dissolving (completion) PP phase. For the dissolving phase, LTMs are instructed to visualize that "all form disappears; there is now only awareness without center or limit" (see Supplementary Methods for a more detailed description). As the timing of the various phases was pre-determined, no report was needed. The results obtained in 11 LTMs by subtracting the average hdEEG topography from a pre-meditation baseline are shown in Fig. 8 (with bar graphs representing the whole-scalp average of gamma activity as the group mean +/- s.e.m. for each meditation phase).

[Insert Fig. 8 here]

As shown in the figure, the 16th Karmapa dissolving phase (meditation phase 3) obtained through a no-report paradigm showed a similar neural signature as the 8th Karmapa PP state obtained by delayed report. At the single-subject level, the neural signatures of PP were even more consistent during the 16th Karmapa than the 8th Karmapa meditation in the same cohort (Suppl. Figs. 9 and 10), possibly owing to the no-report paradigm. The generation phase (meditation phase 1), which requires intense visualization, and the mantra recitation phase (phase 2) were instead dominated by a whole-brain increase in gamma activity. Increased gamma activity was also seen at the end of the meditation session (phase 4), when LTMs are instructed to "let the world reappear".

Discussion

We used hdEEG to investigate the neural correlates of PP, a state in which expert LTMs experience a vivid sense of spatial extendedness in the absence of any contents related to self, thought, or perceptual objects. We found that, compared to several other conditions both within and outside of meditation sessions, PP states are characterized by a distinct hdEEG signature: a pronounced and widespread decrease in gamma power, maximal in posteromedial cortex, consistent with reduced cortical activity, on a background of low delta power, consistent with high cortical arousal. In short, PP states seem to be associated with a cerebral cortex that is widely awake but minimally active. Similar findings were observed in PP variants accompanied either by minimal perceptual contents (PP-mpc) or with a feeling of bliss (PP-bliss). These results were confirmed during PP states captured using a no-report paradigm (pre-timed Guru Yoga meditation).

Low or decreased delta activity during PP, compared to both within-meditation MW and other control conditions, is consistent with a state of aroused wakefulness. The high cortical arousal of PP states was confirmed by the direct comparison between the hdEEG of PP states and that of epochs preceding awakenings from dreamless sleep in the same LTMs. It is also in line with the description of PP provided by all subjects, as well as by their traditions (18). Far from being a state of dozing off or disconnection, PP is a state of intense, vivid, heightened consciousness. The signatures of PP states also differ from those of “mind-blanking” reported in meditation-naïve subjects, which seem to correspond to short bouts of drowsiness (31, 32). The phenomenology and neural signatures are thus remarkably different between “contentless” states such as PP that are meditation-induced (“cultivated”) and drowsy states that occur “in the wild” (33).

Source reconstruction revealed that the decrease in delta and gamma power was widespread and maximal in posteromedial areas. Previous work has suggested that special states of absorption or states of “thoughtless emptiness” may be accompanied by a broadband decrease in EEG power (34). Other work has shown a decreased high-frequency power in posteromedial areas as a signature of ego-dissolution achieved by LTMs (26). In our case, the decrease in gamma-band cortical activity during PP was significant not only over the precuneus and middle-posterior cingulate cortex, which are known to be involved in self-related experiential contents (25, 35, 36) and thinking (24), respectively, but also over the frontal poles, which are involved in metacognition (37), and over the temporo-parietal junctions, involved in agency (38). Gamma activity was also decreased over the right temporal lobe and sensory areas, as well as in other parts of the prefrontal cortex. These findings are in line with the phenomenology of meditative PP states—the absence of a sense of self, of thought, and of perceptual contents—and with the associated suspension of cognitive functions such as reflection, control, and working memory (16, 17).

The neural signatures of a variant PP state with minimal perceptual content (PP-mpc) were overall similar those of “contentless” PP states, with most consistent decreases in gamma power over posteromedial and right temporo-parietal cortex. However, the decrease in gamma power was less marked, and some gamma activity was preserved over medial occipital areas and somatosensory cortices. These results are compatible with reports from meditators suggesting that simple bodily sensations were last to disappear in the transition from MW to full PP experiences (see also results in Suppl. Fig 12 obtained in Zen). Another variant of PP, accompanied by “a feeling of bliss coming from mind itself” (PP-bliss), was also associated with a widespread decrease in gamma

power, albeit again less marked than in PP. This finding is aligned with the Vajrayana teachings emphasizing the inseparability of bliss and emptiness (Tib. *detong*), which is core to the Guru Yoga practice (39, 40).

The hdEEG correlates of PP were markedly different not only from those of MW episodes within the meditation session, but also from those of a variety of states outside the session. These included resting wakefulness with eyes open and eye closed, watching a movie, imagining the movie, and active thinking. Just as important, the hdEEG correlates of PP were also specific, being markedly different with respect to other meditative states achieved by LTMs. These included various meditative states during which perceptual content was not abolished, such as OM, Zen Shikantaza states with decreased thoughts but preserved percepts, and Vajrayana visualization and mantra recitation phases. For example, previous studies have reported that a variety of other meditation states, such as OM or non-dual compassion states, can be accompanied by increased gamma activity (41, 42). Overall, our findings emphasize the importance of characterizing the phenomenology of various meditative states to identify their specific and reproducible neural signatures (33).

This study was undertaken to assess a counterintuitive prediction of integrated information theory (IIT): that the neural substrate of consciousness can support a vivid experience even when it is minimally active, as long as its causal powers are preserved. The results are consistent with this prediction, showing that vivid states of pure consciousness—devoid of self, thoughts, and perceptual objects—are associated with a hdEEG background of low gamma power and low delta power. Widespread low gamma power is suggestive of low neural activity throughout the cortex. Low delta power—much lower than in dreamless sleep and as low or lower than in MW, movie imagining, and movie watching—indicates that causal links within the cortex are in working order, rather than interrupted by the bistability that characterizes slow wave sleep (43). By the same token, the present results pose a challenge to current computational/functionalist or dynamical system accounts, according to which being conscious requires some kind of “computation” or “information processing” (7).

Besides stipulating the necessary and sufficient conditions for being conscious, IIT also aims at accounting for the quality of an experience, which it identifies with the cause–effect structure specified by its neural substrate in its current state (8, 10). In particular, previous work has shown that lattice-like substrates, such as those found in posterior cortex, specify cause–effect structures that capture the feeling of “extendedness”. This kind of structure, called an “extension”, is composed of a set of distinctions (‘spots’) bound by causal relations of reflexivity, inclusion, fusion, and connection. As shown by computer models, an extension can account for the corresponding phenomenal properties of spatial extendedness, as well as for derived spatial properties such as regions, locations, and distances (10). Notably, a grid-like lattice in a state where all units are inactive (but not ‘inactivated’ by bistability) specifies such a structure just as much as in other states, where some units are active. The only difference is that the extension is completely homogenous in the case of inactivity, while it is warped by inhomogeneities when some units are active and others inactive (10). Remarkably, LTMs of various traditions, including our subjects, describe PP states as a vast, homogeneous expanse, sometimes qualifying the experience as “mirror-like”, “panoramic”, or “luminous”.

While this work demonstrates that a vivid experience of PP is accompanied by a widespread reduction of EEG power, especially in the gamma range, it cannot demonstrate directly that neuronal activity in the underlying cortex is in fact reduced or

minimal. In both monkeys and humans, increases and decreases in gamma power are tightly correlated with local increases and decreases in neuronal population firing (13-15). However, it is certainly possible that, at the level of individual neurons or small local populations, activity may not decrease during PP—in fact, it might even increase—without being detected by the hdEEG. Moreover, neuronal activity in subcortical regions, as well as in some cortical regions located far from the scalp, are often invisible to the EEG. Ongoing work aims to induce PP-like states in meditation-naïve subjects using paradigms inspired by millennia-old traditions, such as a fading meditation bell. In this way, it may be possible to explore the neural correlates of PP-like states using intracranial electrodes and single-unit recordings in subjects with epilepsy (44). Despite these caveats, given the substantial evidence that cortical areas are necessary for consciousness and the overall correlations between gamma activity and neuronal firing, the current findings lend some plausibility to the notion that consciousness may be vividly present in states of low or minimal cortical activity.

In future work, it will also be worth comparing the neural signatures of meditative PP with those achieved by LTMs during "clear light" practices in lucid dreams (45) and with certain states induced by psychedelics such as 5-MEO-DMT, which are occasionally described as being phenomenologically similar (46). The correlation between the occurrence and depth of PP states and measures of mindfulness, decentering (47), fear of death (48), and hedonic and eudaimonic well-being should also be explored. Finally, it will be important to investigate the neural mechanisms underlying LTMs' ability to reach states of PP, including the role of attentional training.

Materials and Methods

Participant selection

We recruited Vajrayana and Zen participants for the present study. Inclusion criteria consisted in at least 3000 hours of lifetime meditation experience, current meditation practice of several times a week, and previous meditation experience in a retreat setting. Study procedures were approved both by UW–Madison Health Sciences' and University of Granada's Institutional Review Boards.

Vajrayana practitioners were recruited from the Tibetan Karma Kagyu lineage (Diamond Way Buddhism organization) because their Guru Yoga practice explicitly targets the achievement of PP states during the "dissolving phase" of the meditation. Recruited participants had all completed a series of intensive practices called the *Ngöndro* (Tib.) at least once and performed both 8th and 16th Karmapa Guru Yoga as their main practices (see Supplementary Material: Vajrayana practice details).

Because PP states are not an explicit target of Zen practice, Zen participants were recruited if they indicated they had had at least one PP experience and thought it was possible to replicate this in an experimental setting during a seven-day meditation retreat. They also all had experience with Shikantaza or equivalent meditation practice.

Retreat and hdEEG acquisition schedule

All retreat experiments took place in naturalistic settings, in meditation centers belonging to the LTMs' respective spiritual schools. Up to three LTMs were recorded during the same

week. A member of the research team stayed on-site with the LTMs and ensured that their subsistence needs were met so that they could fully focus on the practice. Retreat schedules and rating scales were adapted for Zen and Vajrayana traditions (see Supplementary Methods). After informed consent was obtained, questionnaires were administered to quantify the participant's total hours of experience for each type of practice, including in retreats. LTMs were then fitted with a 256-channel hdEEG net and given control tasks, including resting with eyes open and eyes closed (2 min.), a series of video clips (1 min) that were then followed by an imagination task where they closed their eyes and imagined the same video they had just watched (1 min); this sequence was repeated three times and the videos were randomized from a pool of six videos each session. Additionally, subjects performed an active thinking task where they were instructed to count backwards starting at 300 by sevens (3 min), and a short open-monitoring meditation session where they wore an eyeshade and earplugs to reduce ambient stimulation and were told to just allow thoughts to come and go without paying any attention to them but also not trying to reduce them (3 min). After the control tasks, subjects were then trained to meditate while rating their experiences using a mouse click, after emerging from various absorption states. At the end of each meditation session, participants reported on their sleepiness (0–4 scale) and were invited to provide open-ended reports about their meditative states. To ensure accurate understanding and communication of the target phenomenal states to be signaled within each meditation practice, LTMs of the two traditions who were members of the research team assisted with pre-briefing, de-briefing, and assistance throughout the retreats.

For Vajrayana participants, the hdEEG net was applied on the day of arrival to familiarize participants with the controls and the rating procedure, then for 4 hours per day every day of the 5-day retreat, while the rest of the time was spent meditating without the hdEEG net. After net application, control conditions were performed, then a pre-timed 16th Karmapa Guru Yoga session (no-report paradigm). Then, participants were instructed to perform 8th Karmapa Guru Yoga, during which they signaled target phenomenal states with mouse clicks.

For Zen participants, the hdEEG net was applied on the first day and during the last three days of the week-long retreats. Participants used mouse clicks to signal target phenomenal states during meditation sessions. Control conditions were repeated at the beginning and the end of each recording day (for analysis, the cleanest session of the two was kept for analysis in each LTM; yielding 6 morning and 2 evening sessions). The meditation rounds were all 50 min long followed by 10 min of walking meditation. All meditation rounds were timed by the researcher(s) running the study. These 50 min rounds were repeated throughout the day for an average of 8–9 rounds totaling 6~7hrs of formal meditation each day.

Two LTMs (2952.83 $\pm$ 468.34 lifetime hours of practice; age, 41.87 + 6.95; age range, 38–52; 1M 1F) in the Zen tradition that had reported a PP state by the end of day 6 were recorded at WI Sleep for an overnight Serial Awakening (SA) recording. Once they arrived at the sleep lab, we applied a 256 HdEEG net (Electrical Geodesics, Inc., Eugene, Ore.) for sleep recordings and additional submental electromyogram and electrooculogram to perform sleep staging using Alice® Sleepware (Philips Respironics, Murrysville, PA) Throughout the night, they were awakened repeatedly (49) and asked to report whether, just before the awakening, they had been experiencing anything (DE), had been experiencing something but could not remember the content [DE without recall of content (DEWR)] or had not been experiencing anything [no experience (NE); (49)]. The serial

awakening protocol has previously been reported in detail (49). The group from the Vipassana tradition underwent the same protocol. To summarize, participants were awakened periodically throughout the night using a computerized tone delivered through headphones lasting 1.5s. They were then asked to report, “what was the last thing going through your mind before the alarm?”. If they reported something (DE), they then underwent a structured interview through an intercom where they were asked to describe details of the report followed by a series of questions probing the duration, complexity, whether the experience was self-centered vs environment centered, how much they were perceiving, thinking, or imagining, the degree of positive or negative affect, and a few other questions regarding control of dream content and specific contents of the dream. Awakenings were performed at intervals of at least 20 min, in N2 or REM sleep. Participants were required to have been asleep for a minimum of 10 min and must have been in a stable sleep stage for a minimum of 5 min for an awakening to occur. At the conclusion of the awakenings, subjects were allowed to sleep adlib.

High-density EEG preprocessing

Data from days 5–7 of retreats were kept in the analysis. We applied a 0.1–Hz first-order high-pass filter and focused our analysis on 185 channels with highest signal-to-noise ratio, excluding the neck and face. We then applied a linear finite impulse response bandpass filter between 1–50 Hz (using EEGLab pop_eegfiltnew FIR filter algorithm), removed the noisiest sections and bad channels visually, and then ran adaptive mixture independent component analysis (AMICA) (27). We inspected the AMICA decomposition and removed segments with artifacts in which ICA decomposition failed to separate brain activity from physiological noise time courses (Supplementary Fig. 1, upper panel) and then re-ran the AMICA algorithm without remove components. Once the AMICA decomposition showed a clear separation between the first twenty brain and artifactual components (comprising most of the signal variance; see Supplementary Fig. 1, lower panel), ICA components contaminated by artifacts were removed. We then interpolated bad channels using spline interpolation in EEGLAB and average-referenced the signal. We then extracted epochs preceding by 8 to 3-seconds prior to the reports of events of interest (e.g. reports of PP, PP-mpc, PP-bliss and MW during meditative states. For the 16th Karmapa Guru Yoga sessions, we extracted epochs 5–10 seconds after the end of each instruction (these time points corresponded to our best guess for timing of target states in the report vs no-report cases). For the OM and all other controls tasks, we extracted epochs of 5 seconds of continuous clean data starting at least 5 seconds after beginning the task and no more than 5 seconds before the end of tasks. For both the 2 Zen meditators and the 13 Vipassana LTMs that had serial awakenings (Fig. 5), we extracted 5 second epochs immediately before each serial awakening from N2–N3 sleep that was reported as dreamless. Data were similarly extracted in 1 Zen participant who also had serial awakenings with reports of dreams from both NREM sleep and REM sleep (Suppl. Fig. 7). We extracted epochs -5–0 seconds before each serial awakening. In one Zen, we also extracted 5 seconds of continuous clean data from stages N1, N2, N3, and REM sleep and displayed them on the same power scale for comparison to PP and MW. Topographies of delta (1–4 Hz), theta (4–8 Hz), alpha (8–12 Hz), beta (15–25 Hz) and gamma (30–50 Hz for Zen data, 30–45 Hz for Vajrayana data) were computed in each condition for statistical analysis. Of note, the gamma frequency range was kept below 45/50 Hz to stay away from line noise artifacts (60 Hz for USA data, 50 Hz for Spain data)

while applying FIR filters. We did not analyze higher EEG frequency data because of expected lower signal-to-noise ratio for high-gamma.

Source-reconstruction was performed for MW and PP conditions in the 15 LTMs who reported both states. Forward model used a realistic head template with boundary element methods (BEM) and sLORETA priors, as implemented in Brainstorm (www.neuroimage.usc.edu/brainstorm). We created separate source-space topographies for EEG gamma to delta frequency bands for PP and MW.

Statistical analysis

Except when specified below, hdEEG topographical statistics were performed using a within-subject design, using paired t-tests testing for within-subject differences across conditions in each frequency band of interest. As in previous work, scalp-level statistics were corrected for multiple comparisons using statistical non-parametric mapping (SNPM), and source-space statistics using false-discovery rate (21).

Because the comparison between PP and dreamless sleep involved different subjects, unpaired t-tests were performed testing for between-group differences in hdEEG power (with one group of LTMs in PP states, and one group of LTMs in unconscious sleep states. Because only one Zen LTM experienced a NDA state with rich content (Fig. 8, lower panel), and this LTM did not report a PP state, case-report statistics (50) were employed to compare the NDA experienced by this subject to PP states obtained in other LTMs. First, NDA or PP was normalized by MW by performing subtraction between those states within each individual. Then, a t-test was implemented to assess for systematic difference between [NDA vs MW] in the one LTM and [PP vs MW] in each of the other individuals. Again, all scalp-level statistics were corrected for multiple comparisons using SNPM.

Acknowledgments

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Figures

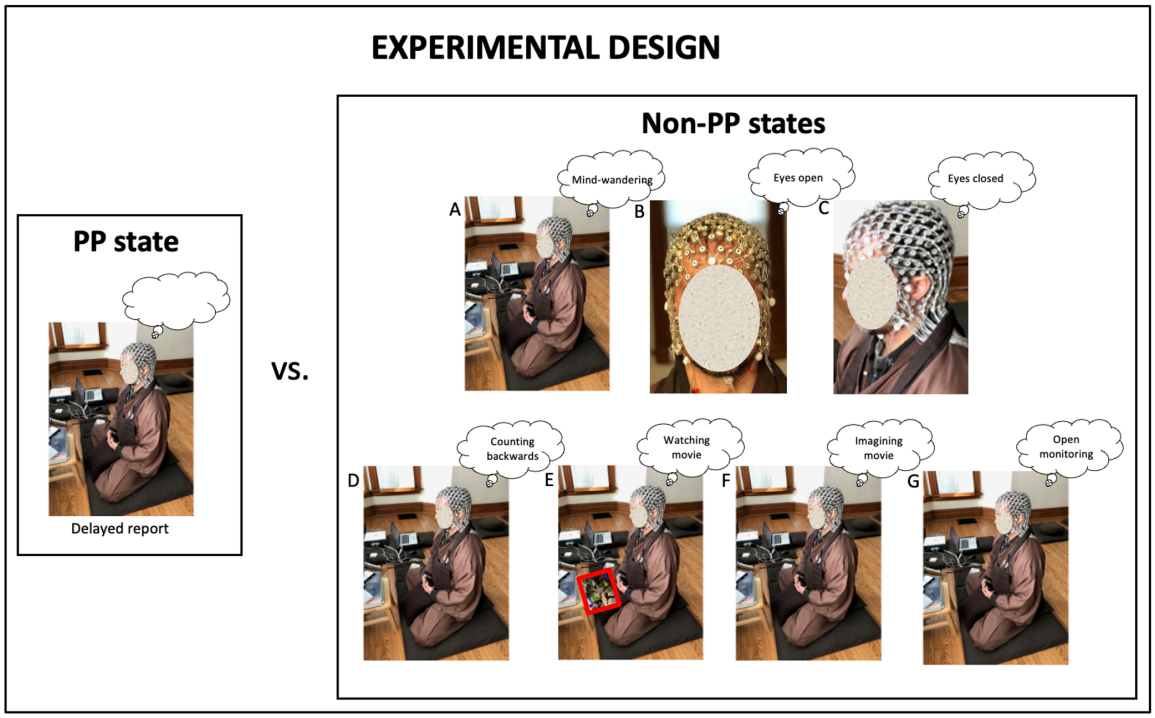


Fig.1. Experimental design. 256-electrode HDEEG was recorded during PP and compared to a variety of non-PP states: within-meditation mind-wandering (A), resting eyes open (B) and eyes closed (C), watching a movie (D), imagining the same movie (E), active thinking (counting backwards, F), open-monitoring (G).

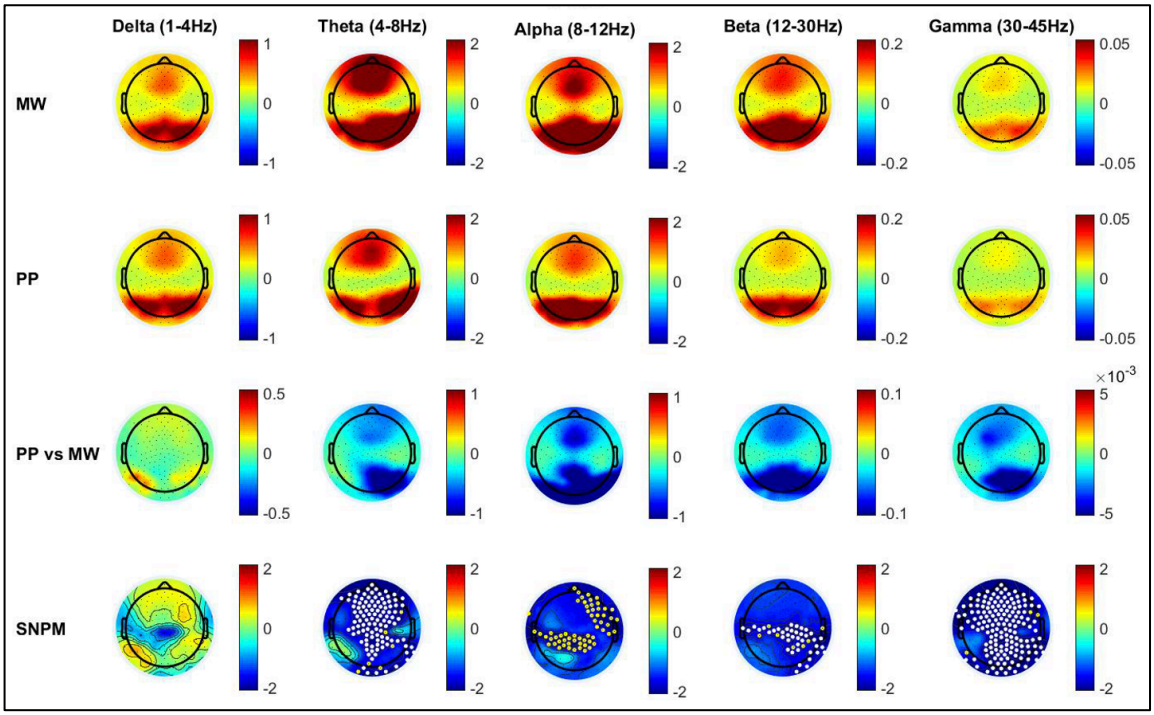


Fig. 2. Neural correlates of pure presence (PP) compared to within-meditation mind-wandering MW in 15 long-term meditators (LTMs; 7 Vajrayana and 8 Zen) in the delta to gamma frequency ranges. Data obtained during Vajrayana 8th Karmapa Guru Yoga and Zen Shikantaza practices. First row: average group topography for MW. Second row: average group topography for PP. Third row: average group difference for PP compared to MW (within-subject subtraction of MW from PP). Last row: statistical non-parametric mapping (SNPM) statistics for group difference between PP and MW. Colors represent EEG power (first to third rows) and T values (last row). White dots represent channels surviving $p<0.05$ corrected for multiple comparisons using SNPM; yellow dots represent channels surviving uncorrected $p<0.05$ values.

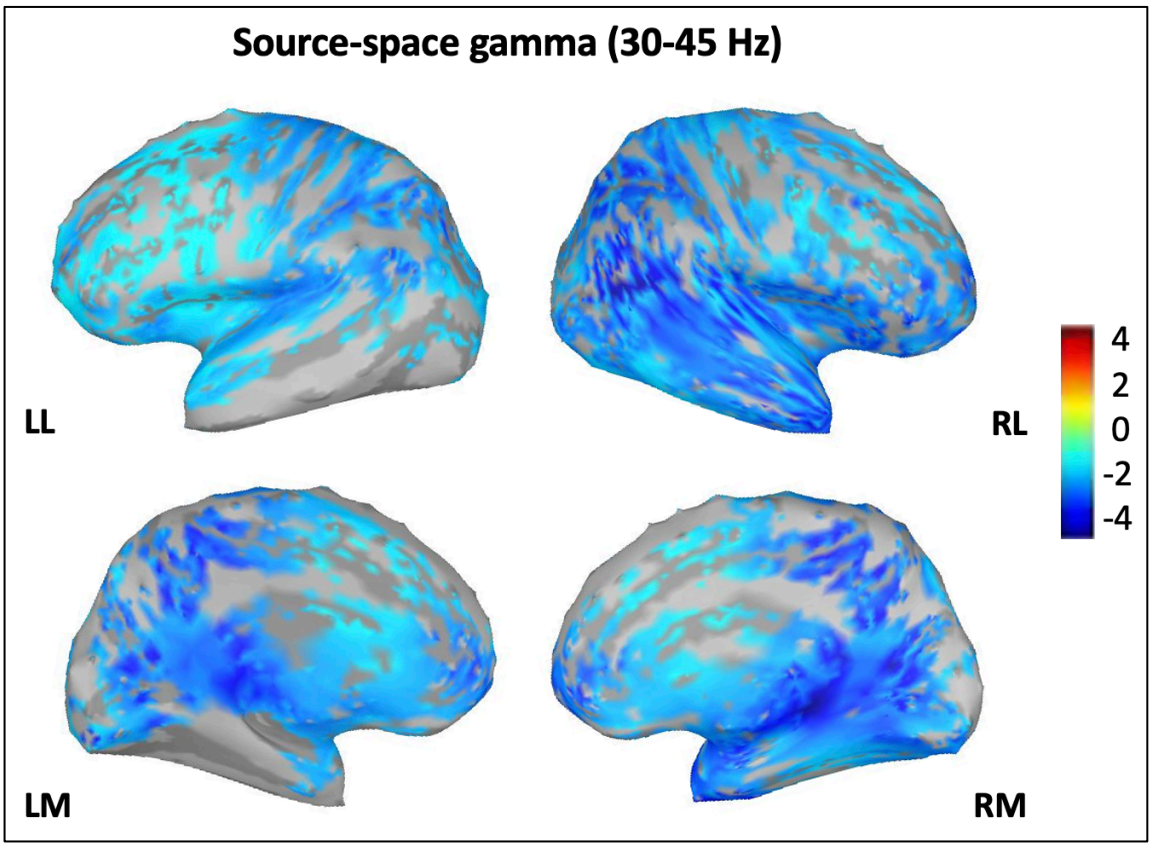


Fig 3. Source reconstruction results for gamma decrease in PP vs MW, corrected at FDR p<0.05. LL: left lateral; RL: right lateral; LM: left medial; RM: right medial. Colors represent T value for changes in source-level gamma power during PP compared to MW in the same 15 LTMs displayed in Figure 1. Darker blue colors, representing stronger decreases, most prominently in posteromedial areas.

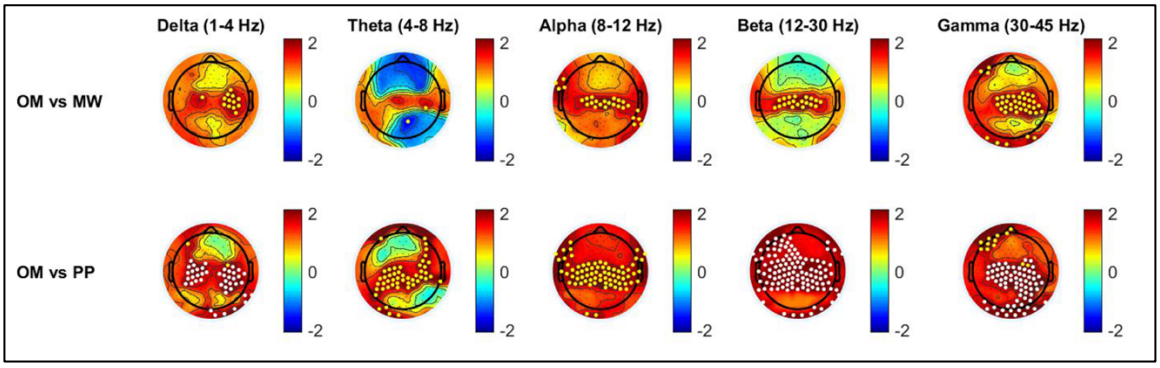


Fig. 4. Comparison of open-monitoring (OM) to MW (first row) and PP (second row) in the same 15 LTMs displayed in Figs. 2–3. Colors represent EEG power T value); white dots represent channels surviving SNPM-corrected p values<0.05; yellow dots represent channels surviving uncorrected p<0.05.

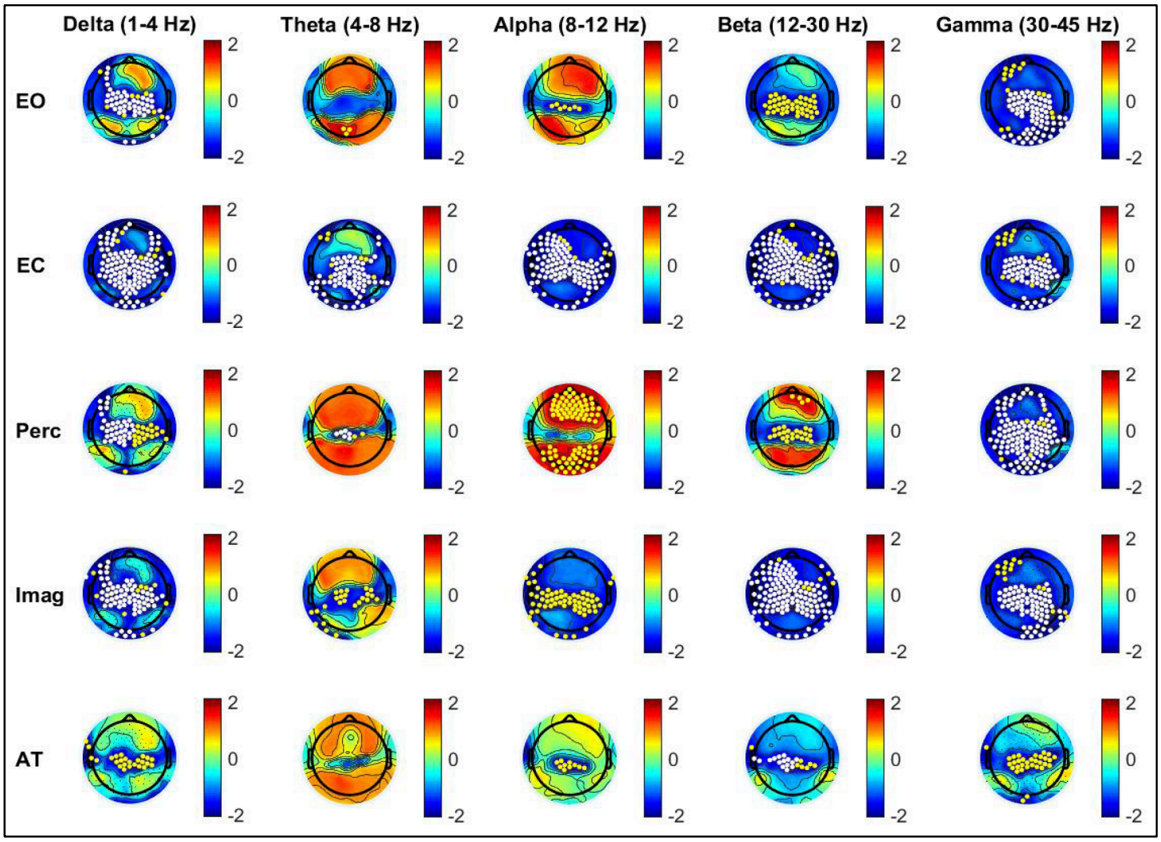


Fig. 5. PP shows consistent delta to gamma power decreases compared to other control states outside of meditation (data from the same 15 LTMs displayed in Figs. 2–4). EO: resting with eyes open; EC: resting with eyes closed; Perc: watching a movie; Imag: imagining the same movie; AT: active thinking (counting backwards). Colors represent T values; white dots represent channels surviving SNPM-corrected p values<0.05; yellow dots represent channels surviving uncorrected p<0.05.

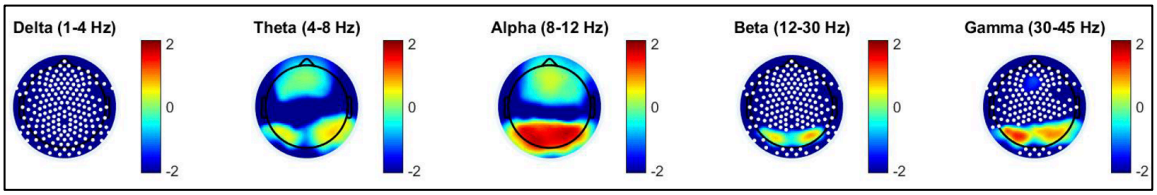


Fig. 6. Compared to dreamless sleep, PP shows widespread decreases in EEG power, most consistent in delta, beta, and gamma ranges (PP data from the same 15 LTMs displayed in Figs. 2–4; sleep data from 2 Zen and 13 age-matched Vipassana LTMs). Colors represent T values; white dots represent channels surviving SNPM-corrected p values<0.05.

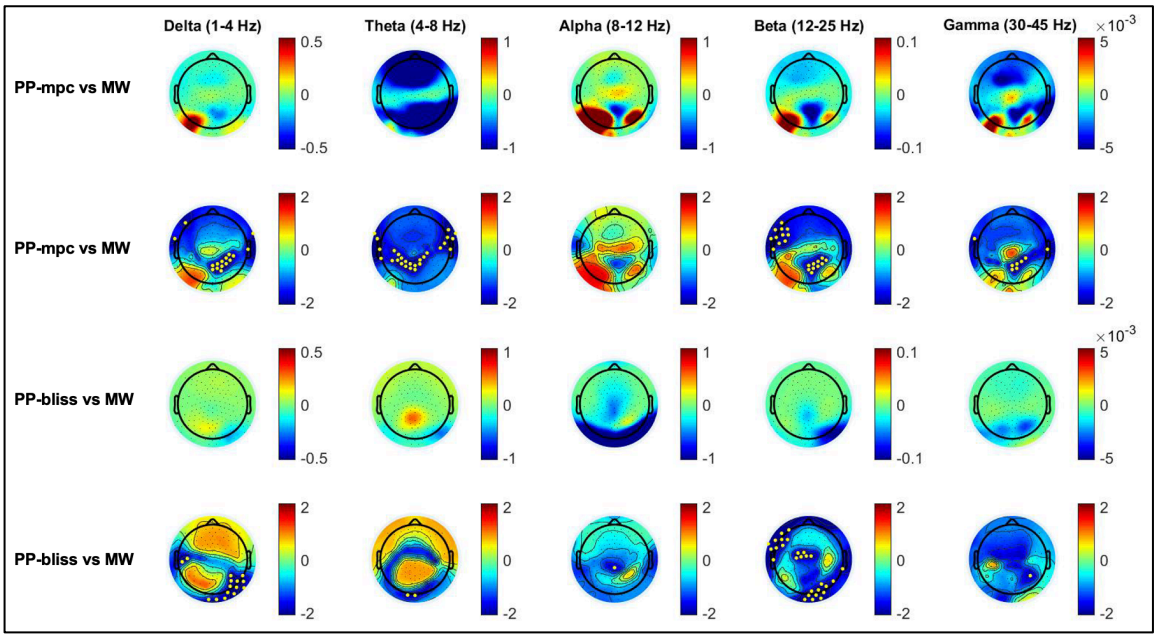


Fig. 7. PP variants display similar signatures compared to PP states. First two rows: comparison of PP-mpc (PP with minimal perceptual contents) to MW in the same 15 LTMs who also reported PP states. Lower two rows: comparison of PP-bliss (PP with "a feeling of bliss arising from mind itself") to MW in 9 Vajrayana LTMs who reported both states. Colors represent EEG power (first and third rows) and T values (second and fourth rows); yellow dots represent channels surviving uncorrected $p<0.05$.

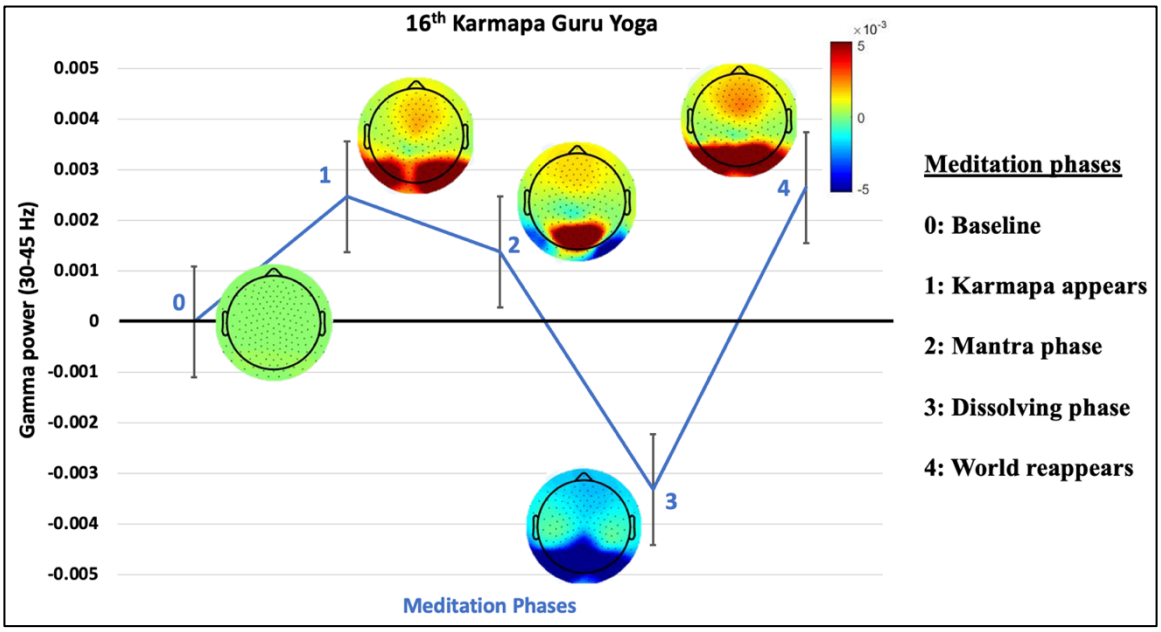
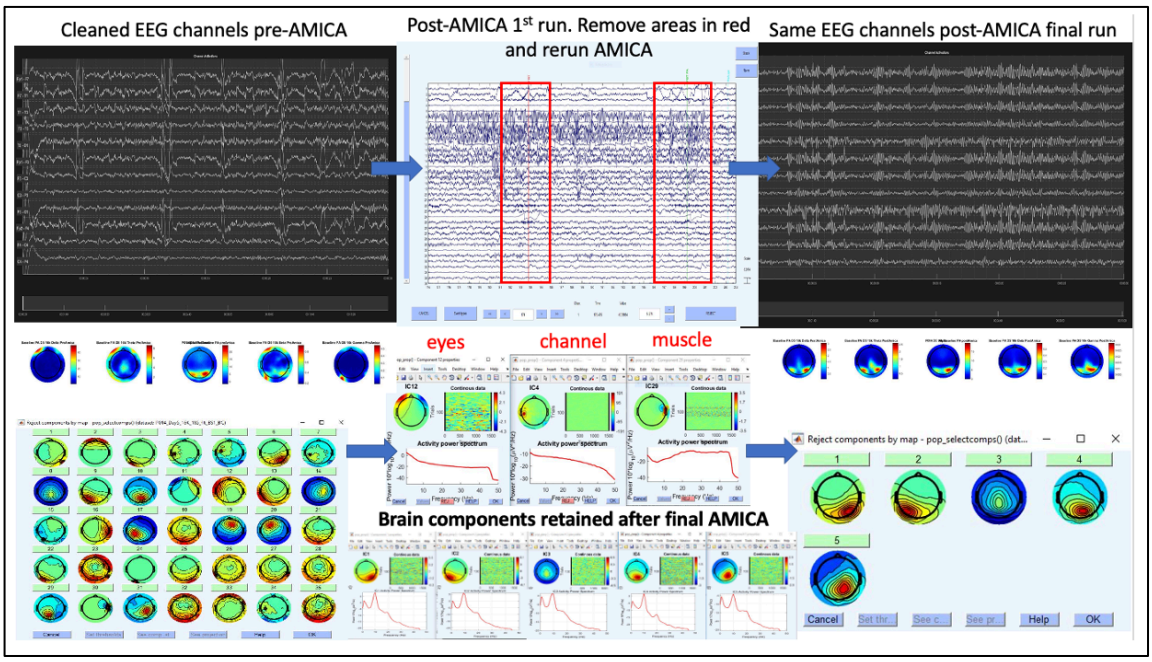


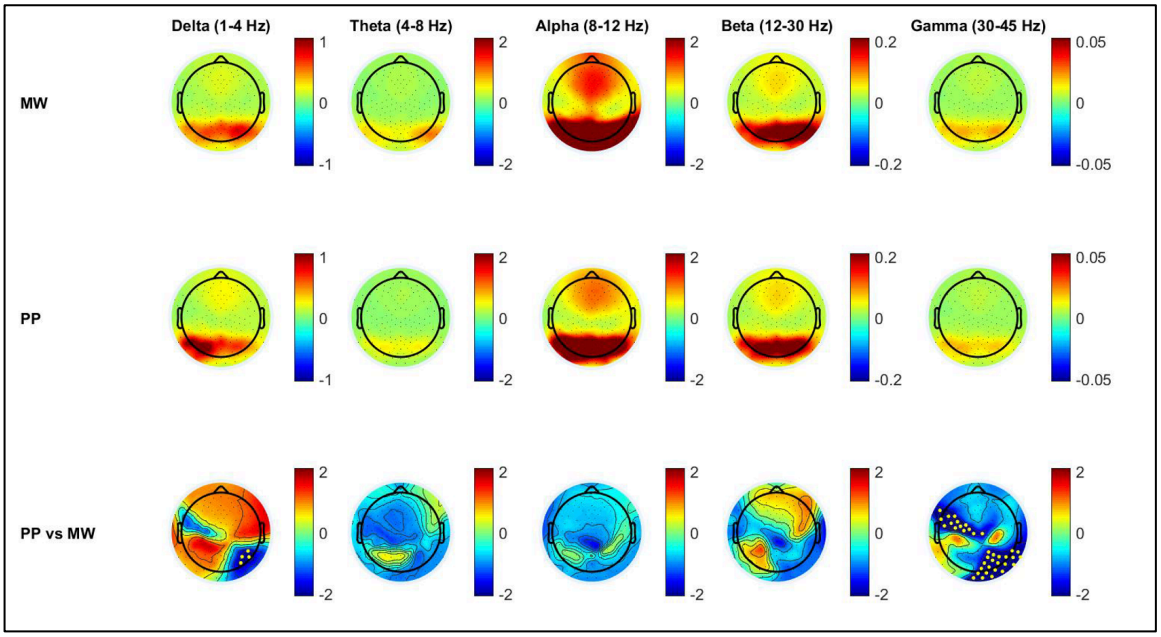
Fig. 8. HdEEG results obtained during a highly rehearsed, pre-timed version of 16th Karmapa Guru Yoga meditation (no-report paradigm). While other meditation phases were characterized by increased gamma activity compared to pre-meditation baseline (e.g., during phase 1, when Karmapa appears; during phase 2, with the mantra recitation; or during phase 4, when the world reappears), PP signatures with decreased gamma power were selectively found during the dissolving phase of the meditation (phase 3), when "all form disappears; there is now only awareness without center or limit". Color-coded results show the group-average gamma-power topography for each phase (baseline-subtracted); bar graphs represent the whole-scalp average of gamma activity as group mean +/- sem. A detailed description of each meditation phase is presented in Supplementary Material.

Supplementary material

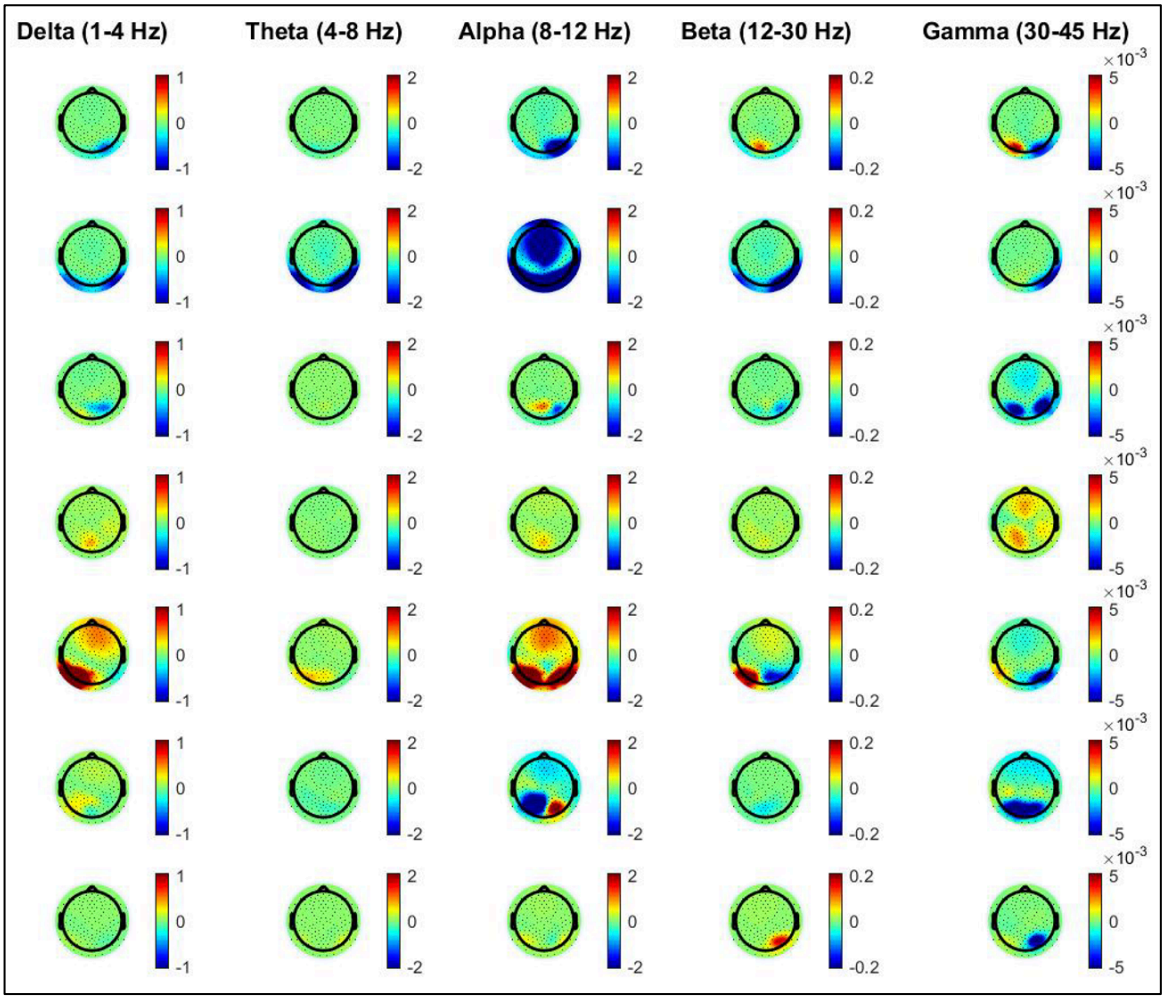
Supplementary Figures



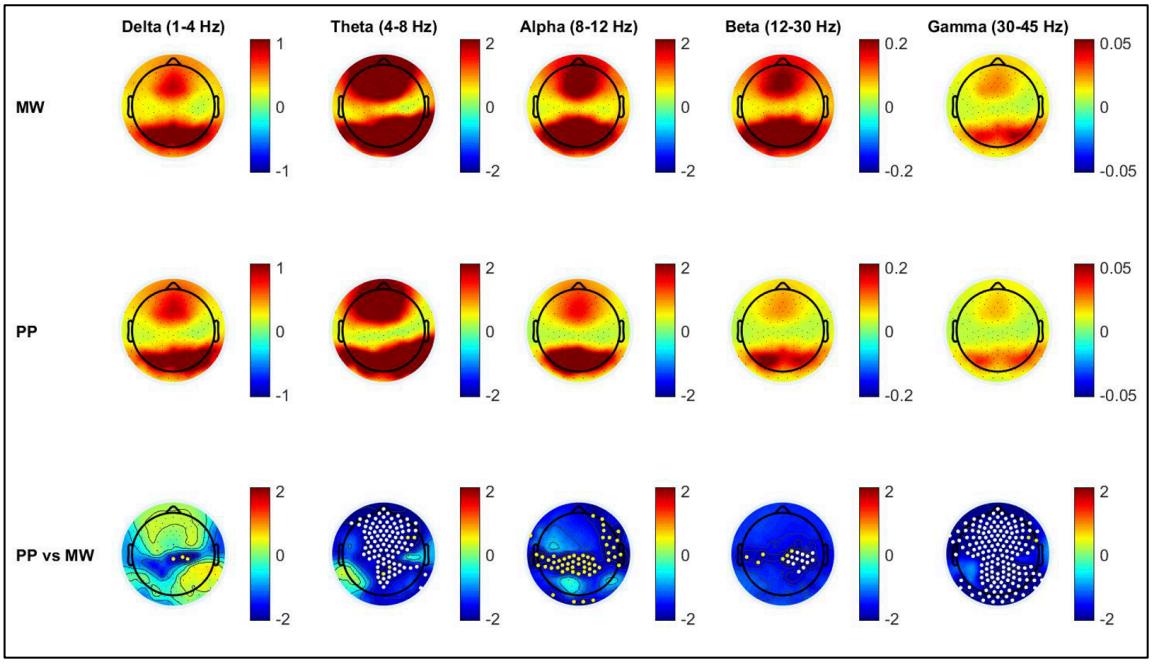
Suppl. Fig 1. Clean epoch selection was aided by inspection of AMICA component time courses. Epochs where AMICA decomposition failed (i.e. when artifacts were found to contaminate many ICA components rather than remain contained in their respective muscle, eye or EKG components) were removed from data and AMICA was ran again. This allowed to obtained (right panel) smooth brain activity topographies, as expected by spatial filtering from the skill, and well separated from sparse and focal extracranial noise sources such as eye movements or muscle, with data quality assessment greatly favored by high spatial resolution of 256-electrode high density EEG.



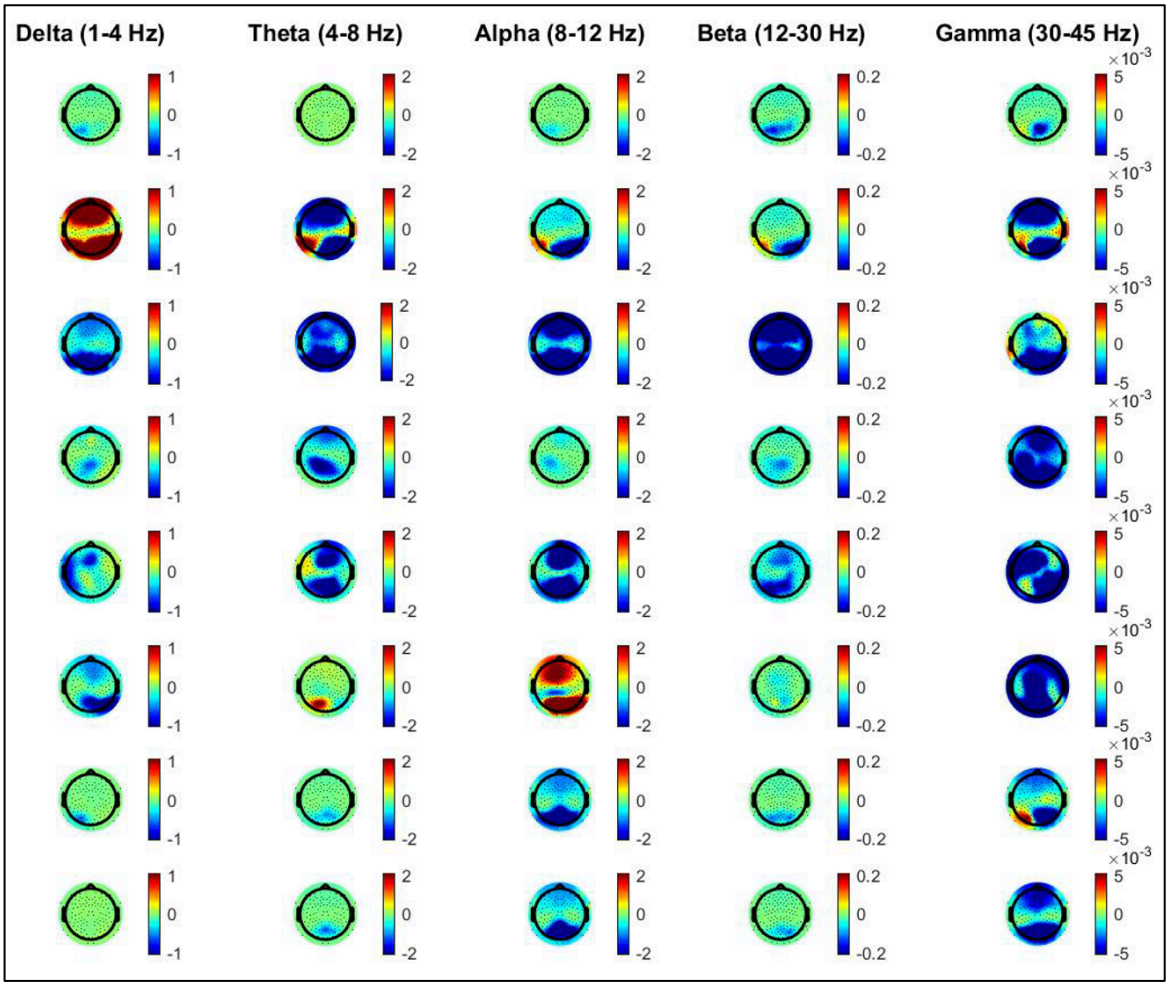
Suppl. Fig 2. Neural correlates of pure presence (PP) compared to within-meditation mind-wandering (MW) – subgroup analysis in 7 Vajrayana LTMs in delta to gamma frequency ranges. First row: average group topography for MW. Second row: average group topography for PP. Third row: average group difference for PP compared to MW (within-subject subtraction of MW from PP). Last row: statistical non parametric mapping (SNPM) statistics for group difference between PP and MW. Colors represent EEG power (first to third rows) and T values (last row). Yellow dots represent channels surviving uncorrected $p<0.05$ values.



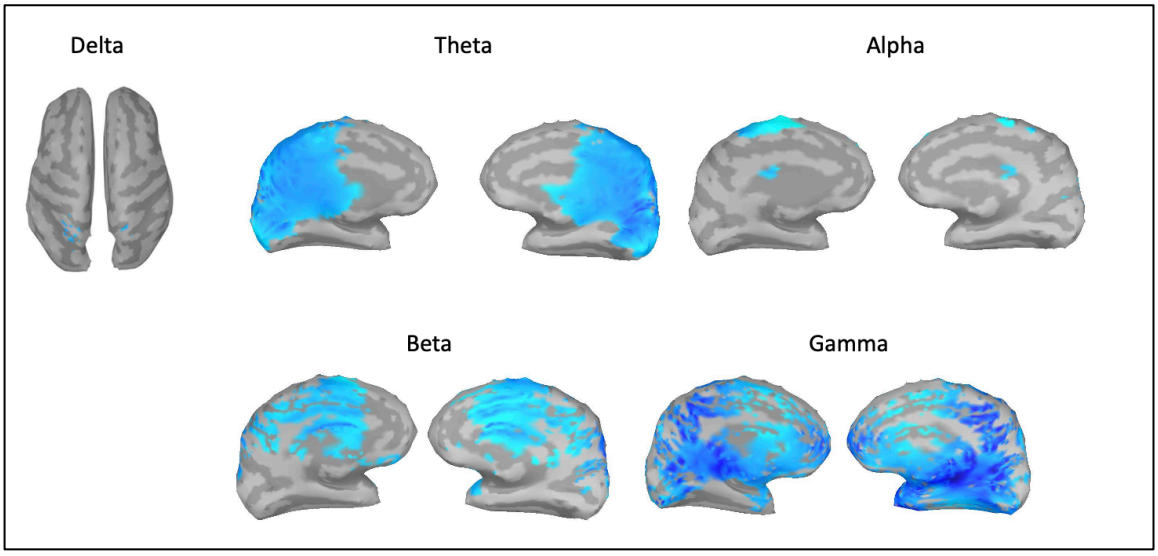
Suppl. Fig 3. Neural correlates of pure presence (PP) compared to within-meditation mind-wandering (MW) – individual analysis in 7 Vajrayana LTMs in delta to gamma frequency ranges. Colors represent EEG power.



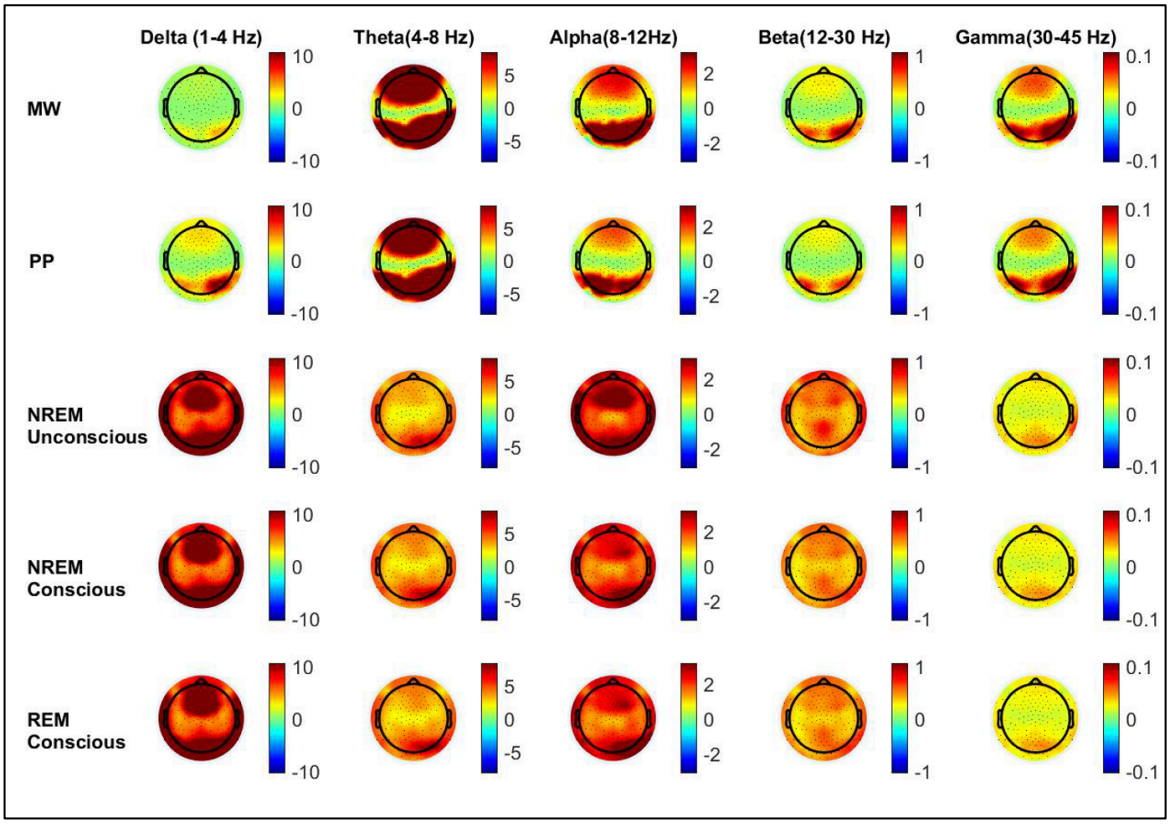
Suppl. Fig 4. Neural correlates of pure presence (PP) compared to within-meditation mind-wandering (MW) – subgroup analysis in 8 Zen LTMs in delta to gamma frequency ranges. First row: average group topography for MW. Second row: average group topography for PP. Third row: average group difference for PP compared to MW (within-subject subtraction of MW from PP). Last row: statistical nonparametric mapping (SNPM) statistics for group difference between PP and MW. Colors represent EEG power (first to third rows) and T values (last row). Yellow dots represent channels surviving uncorrected $p<0.05$ values.



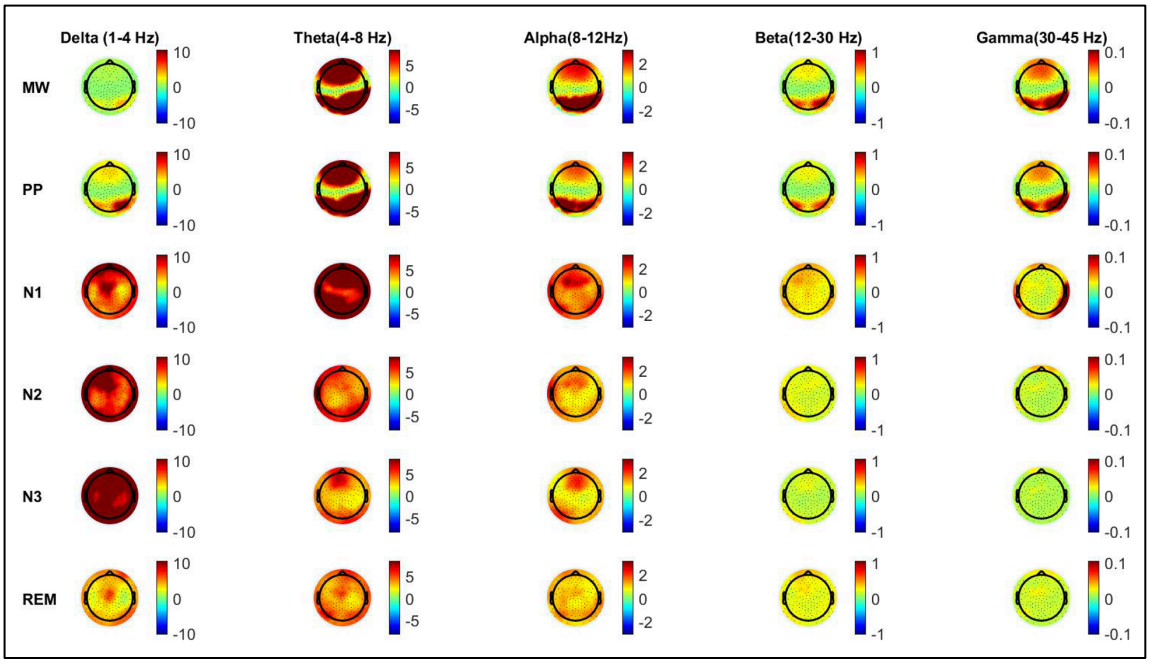
Suppl. Fig 5. Neural correlates of pure presence (PP) compared to within-meditation mind-wandering (MW) – individual analysis in 8 Zen LTMs in delta to gamma frequency ranges. Colors represent EEG power.



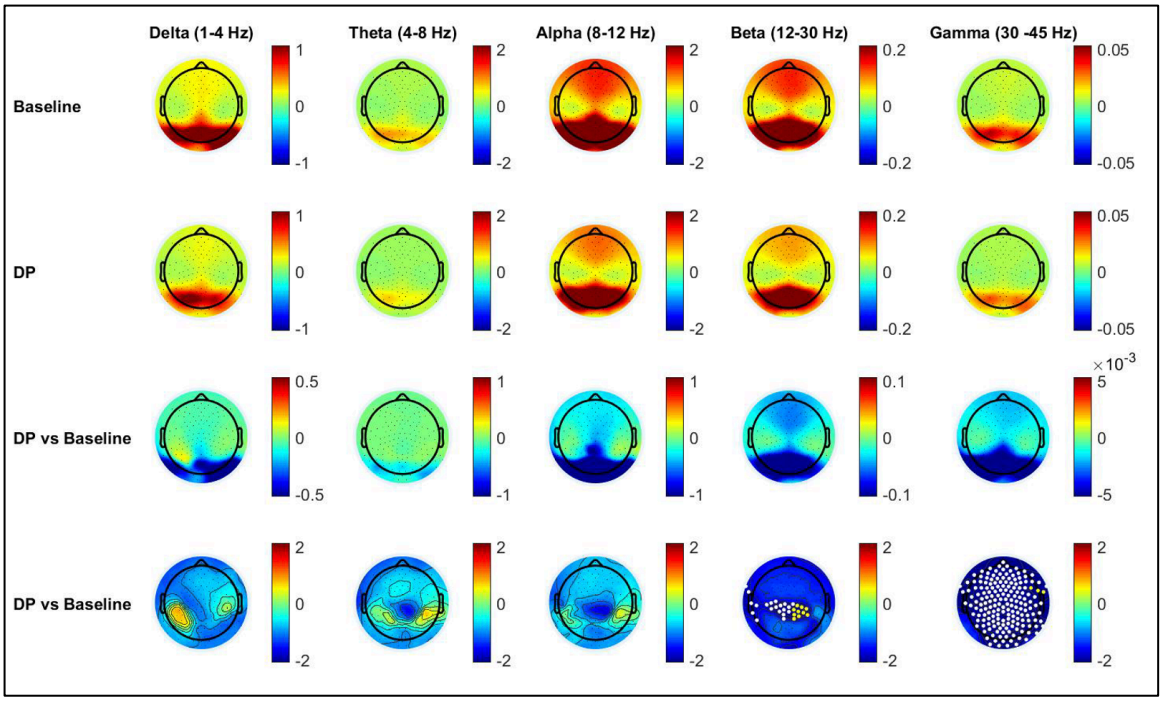
Suppl. Fig 6. Source reconstruction results for gamma decrease in PP vs MW, uncorrected $p<0.05$. LL: left lateral; RL: right lateral; LM: left medial; RM: right medial. Colors represent T value for changes in source-level in delta (1-4 Hz), theta (4-8 Hz), alpha (8-12 Hz), beta (15-30 Hz) and gamma (30-45 Hz) power during PP compared to MW in the same 15 LTMs displayed in Figure 1. Darker blue colors represent stronger decreases.



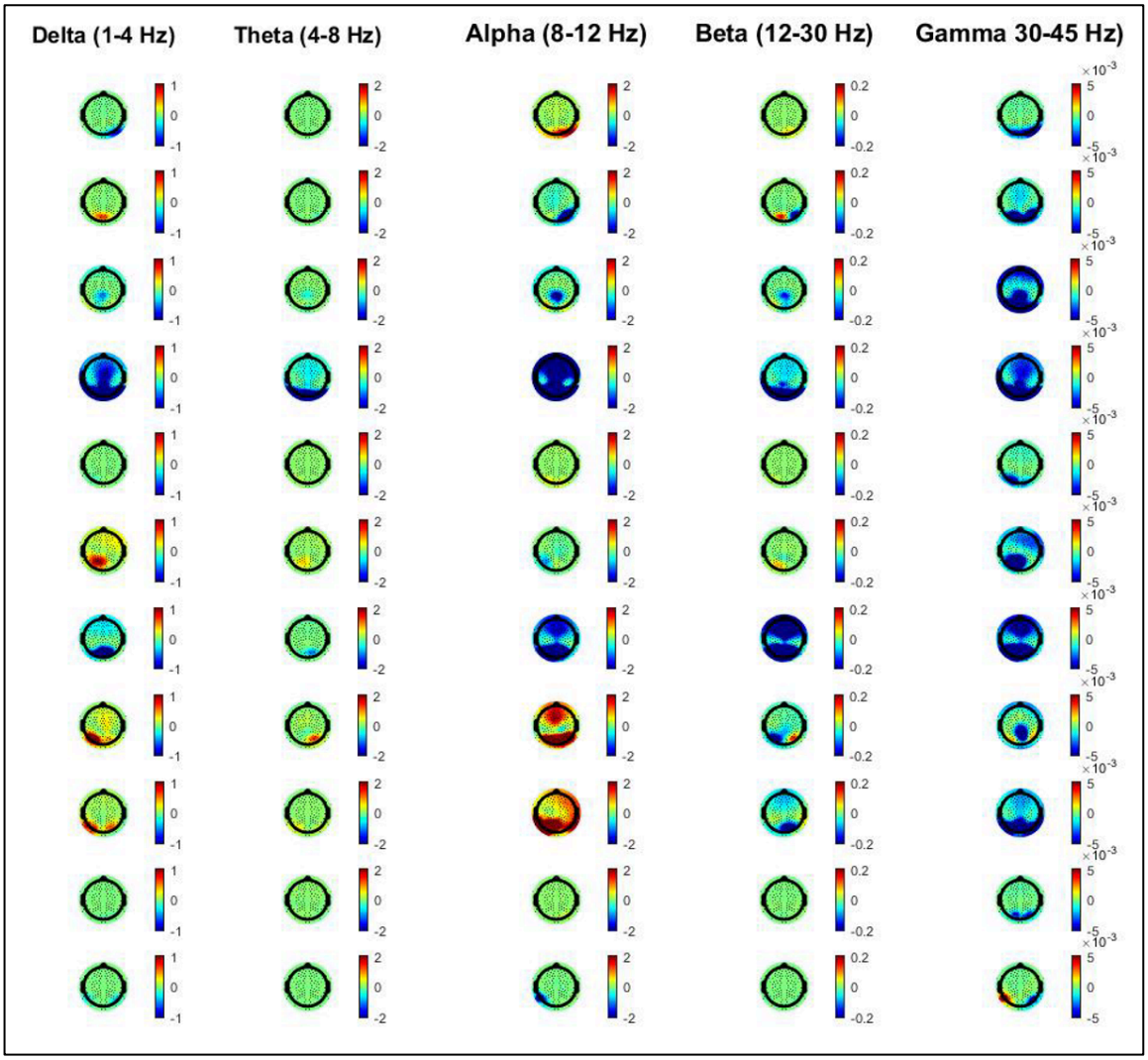
Suppl. Fig 7. Individual analysis of a Zen LTM during MW, PP vs serial awakenings from NREM (either conscious or unconscious) and REM sleep (conscious). Colors represent EEG power.



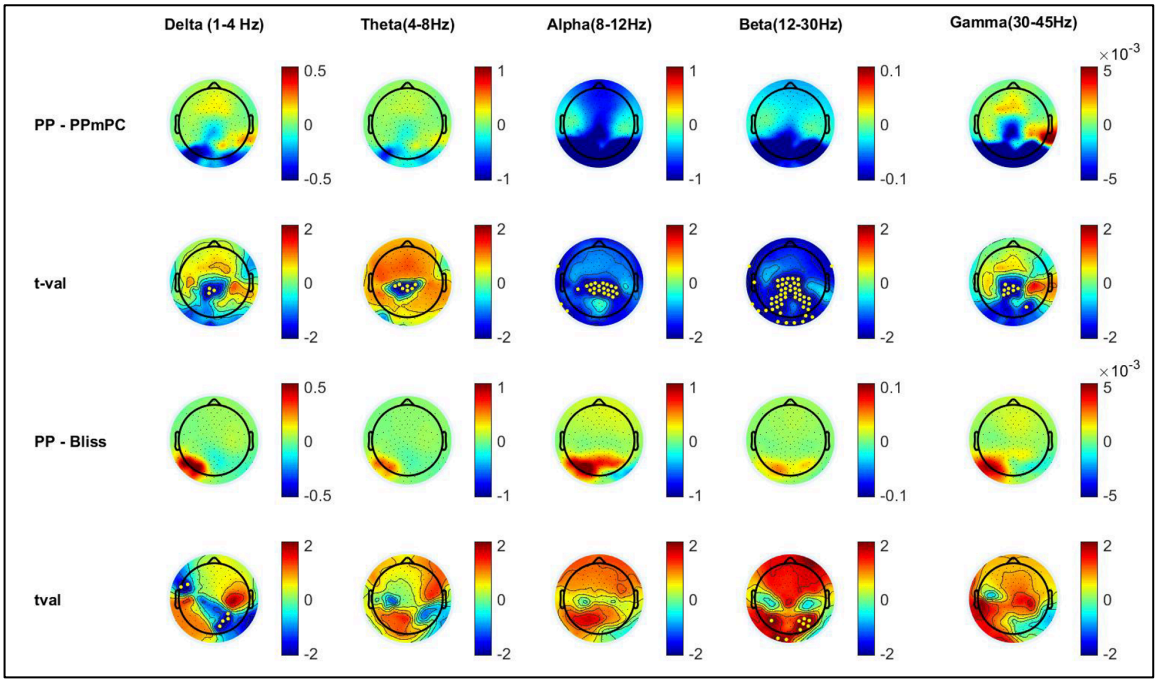
Suppl. Fig 8. Individual analysis of a Zen LTM during MW, PP, NREM sleep stages 1, 2 and 3, and REM sleep. Colors represent EEG power.



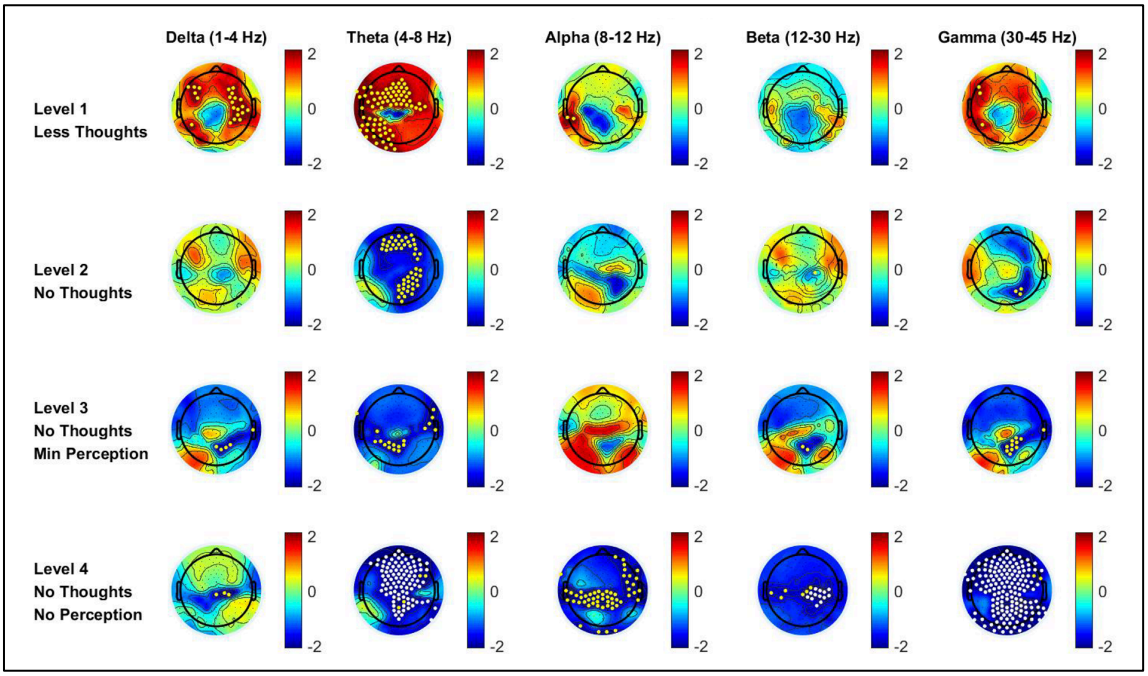
Suppl. Fig 9. Neural correlates of pure presence (PP) using a no-report paradigm during the Dissolving phase (DP) of 16th Karmapa Guru Yoga compared to baseline (11 Vajrayana LTMs). First row: average group topography for baseline. Second row: average group topography for DP. Third row: average group difference for DP compared to baseline (within-subject subtraction of baseline from DP). Last row: statistical non-parametric mapping (SNPM) statistics for group difference between DP and baseline. Colors represent EEG power (first to third rows) and T values (last row). White dots represent channels surviving $p<0.05$ corrected for multiple comparisons using SNPM; yellow dots represent channels surviving uncorrected $p<0.05$ values.



Suppl. Fig 10. Neural correlates of dissolving phase (PP) compared to [re-meditation baseline – individual analysis in 11 Vajrayana LTMs in delta to gamma frequency ranges. Colors represent EEG power.



Suppl. Fig. 11. Upper two rows: comparison of PP vs PP-mPC in 15 subjects (uncorrected p<0.05). PP displays decreased delta and decreased gamma in central, posteromedial and occipital cortices. Lower two rows: comparison of PP vs PP-bliss in 9 subjects (uncorrected p<0.05). PP displays slightly less delta than PP-bliss, but no significant changes in gamma are seen. Colors represent EEG power (first and third rows) and T values (second and fourth rows). Yellow dots represent channels surviving uncorrected p<0.05 values.



Suppl. Fig 12. Progressive decrease in gamma with levels of absorption in 8 Zen LTMs (no thoughts, less thoughts, PP-mC then PP). Colors represent T values. Yellow dots represent channels surviving uncorrected $p<0.05$ values. White dots represent channels surviving $p<0.05$ corrected for multiple comparisons using SNPM; yellow dots represent channels surviving uncorrected $p<0.05$ values.

Zen Science–Meditation Retreat Schedule

Sunday	
Evening	
3:00-5:00 pm	Arrive at MZC/paperwork/study prep
5:00-5:30	Dinner
5:30	Net setup/control tasks
7:00–7:50	Zazen: 50-minute round
7:50–8:00	Kinhin: Walking meditation
8:00–8:50	Zazen: 30-minute round
9:00	Net removal/Bed

Monday	
Morning/afternoon	
5:45 am	Wake up
6:00-6:50	Zazen: 50-minute round
6:50-7:00	Kinhin: Walking meditation
7:00-7:50	Zazen: 50-minute round
7:50–8:20	Breakfast
8:20–9:45	Work/rest period
9:45–10:35	Zazen: 50-minute round
10:35-10:45	Kinhin: Walking meditation
10:45–11:35	Zazen: 50-minute round (w/recorded talk option)
11:35-11:45	Kinhin: Walking meditation
11:45-12:15	Zazen
Afternoon/evening	
12:15–1:30 pm	Lunch/clean-up/break
1:30–2:20	Zazen: 50-minute round
2:20–2:30	Kinhin: Walking meditation
2:30–3:20	Zazen: 50-minute round
3:20–4:45	Exercise/break
4:45–5:15	Zazen: 30-minute round
5:15–7:00	Dinner/break
7:00–8:30	Regular weekly meditation (3-25min rounds with kinhin)
8:30	Yaza (optional sitting)

Tuesday	
Morning	
5:45 am	Wake up
6:00–7:00	Regular weekly meditation (posture change at halfway)
7:00–7:10	Kinhin: Walking meditation
7:10–8:00	Zazen: 50-minute round
8:00–8:20	Breakfast
8:20–9:45	Work/rest period
9:45–10:35	Zazen: 50-minute round
10:35-10:45	Kinhin: Walking meditation

10:45–11:35	Zazen: 50-minute round (w/recorded talk option)
11:35-11:45	Kinhin: Walking meditation
11:45-12:15	Zazen
Afternoon/evening	
12:15–1:30 pm	Lunch/clean-up/break
1:30–2:20	Zazen: 50-minute round
2:20–2:30	Kinhin: Walking meditation
2:30–3:20	Zazen: 50-minute round
3:20–4:45	Exercise/break
4:45–5:15	Zazen: 30-minute round
5:15–7:00	Dinner/break
7:00–7:50	Zazen: 50-minute round
7:50-8:00	Kinhin: Walking meditation
8:00-8:50	Zazen: 50-minute round
9:00	Yaza (optional sitting)

Wednesday

Morning	
5:45 am	Wake up
6:00–6:50	Zazen: 50-minute round
6:50-7:00	Kinhin: Walking meditation
7:00–7:50	Zazen: 50-minute round
7:50–8:20	Breakfast
8:20–9:45	Work/rest period
9:45–10:35	Zazen: 50-minute round
10:35-10:45	Kinhin: Walking meditation
10:45–11:35	Zazen: 50-minute round (w/recorded talk option)
11:35-11:45	Kinhin: Walking meditation
11:45-12:15	Zazen
Afternoon/evening	
12:15–1:30 pm	Lunch/clean-up/break
2:20-2:30	Kinhin: Walking meditation
2:30-3:20	Zazen: 50-minute round
3:20-4:25	Exercise/break
4:25-5:15	Zazen: 50-minute round
5:15-7:00	Dinner/break
7:00-9:00	MZC Wednesday night meditation schedule
9:00	Yaza (optional sitting)

Thursday

Morning	
5:45 am	Wake up
6:00–7:00	Regular weekly meditation (posture change at halfway)
7:00–7:10	Kinhin: Walking meditation
7:10–8:00	Zazen: 50-minute round

8:00–8:20	Breakfast
8:20–9:30	Work/rest period
9:30–10:00	Zazen: 40-minute round
10:00-12:15	Net Setup/control tasks
Afternoon/evening	
12:15–1:30 pm	Lunch/clean-up/break
1:30–2:20	Zazen: 50-minute round
2:20–2:30	Kinhin: Walking meditation
2:30–3:20	Zazen: 50-minute round
3:20–4:25	Exercise/break
4:25–5:15	Zazen: 50-minute round
5:15–7:00	Dinner/break
7:00–7:50	Zazen: 50-minute round
7:50-8:00	Kinhin: Walking meditation
8:00-8:30	Zazen: 30-minute round
8:30-9:15	Control tasks/net removal
9:15	Yaza (optional sitting)

Friday

Morning	
5:45 am	Wake up
6:00–7:00	Regular weekly meditation (Posture change at halfway)
7:00-7:20	Chanting
7:20–7:30	Kinhin: Walking meditation
8:00-12:15	Same as Thursday
Afternoon/evening	
12:15–8:50 pm	Repeat Thursday afternoon/evening schedule
9:00	Yaza (optional sitting)

Saturday

Morning	
5:45 am	Wake up
6:00-6:50	Zazen: 50-minute round
6:50-7:00	Kinhin: Walking meditation
7:00–7:50	Zazen: 50-minute round
7:50–8:20	Breakfast
8:20-12:15	Same as Thursday
Afternoon/evening	
12:15–8:50 pm	Repeat Thursday afternoon/evening schedule
9:00	Yaza (optional sitting)

Sunday

Morning	
6:00 - 8:30 am	Wake up
8:30–9:20	Zazen: 50-minute round
9:20-departure	End study/shower/lunch/airport shuttle

Vajrayana Science–Meditation Retreat Schedule

Tuesday

Afternoon/evening

3:00-6:00 pm	Travel and arrive at retreat center. Settle in.
6:00 pm	Main explanations
7:00 pm	Paperwork
7:30 pm	Dinner
8:15 pm	Meditation/Familiarization with Mouse responses

Wednesday

Morning

7:00 am	Wake Up
7:30 am	Breakfast
8:00 am	Net Set Up
9:00 am	Control Tasks Morning
9:40 am	16th Karmapa Meditation
10:20 am	8th Karmapa Meditation

Afternoon/evening

1:00 pm	Net Removal
1:30 -2:00 pm	Lunch/Break
3:00- 5:00 pm	Meditation
5:00-7:00 pm	Rest
7:00 pm	Dinner/Break
8:30 – 10:00 pm	Meditation

Thursday

Morning

7:00 am	Wake Up
7:30 am	Breakfast
8:00 am	Net Set Up
9:00 am	Control Tasks Morning
9:40 am	16th Karmapa Meditation
10:20 am	8th Karmapa Meditation

Afternoon/evening

1:00 pm	(Net Removal)
1:30 -2:00 pm	Lunch/Break
3:00- 5:00 pm	Meditation
5:00-7:00 pm	Rest
7:00 pm	Dinner/Break
8:30 – 10:00 pm	Meditation

Friday

Morning

7:00 am	Wake Up
7:30 am	Breakfast
8:00 am	Net Set Up
9:00 am	Control Tasks Morning

9:40 am	16th Karmapa Meditation
10:20 am	8th Karmapa Meditation
Afternoon/evening	
1:00 pm	Net Removal
1:30 -2:00 pm	Lunch/Break
3:00- 5:00 pm	Meditation
5:00-7:00 pm	Rest
7:00 pm	Dinner/Break
8:30 – 10:00 pm	Meditation

Saturday

Morning	
7:00 am	Wake Up
7:30 am	Breakfast
8:00 am	Net Set Up
9:00 am	Control Tasks Morning
9:40 am	16th Karmapa Meditation
10:20 am	8th Karmapa Meditation
Afternoon/evening	
1:00 pm	Net Removal
1:30 -2:00 pm	Lunch/Break
3:00- 5:00 pm	Meditation
5:00-7:00 pm	Rest
7:00 pm	Dinner/Break
8:30 – 10:00 pm	Meditation

Sunday

Morning	
7:00 am	Wake Up
7:30 am	Breakfast
8:00 am	Net Set Up
9:00 am	Control Tasks Morning
9:40 am	16th Karmapa Meditation
10:20 am	8th Karmapa Meditation
Afternoon/evening	
1:00 pm	Net Removal
1:30 -2:00 pm	Lunch/Break
3:00- 5:00 pm	Meditation
5:00 pm	Dinner
5:30 pm	End of study

Supplementary Methods

Questionnaires administered to Zen and Vajrayana (Diamond Way Buddhism, DWB) LTMs

Zen

If you become aware that you were in any of the following states below for ~30sec or more, make the appropriate number clicks on the mouse that correspond to the state that you just exited.

Mind Wandering, Enlightenment, and Black Out, **Left Mouse** Button:

1. **Mind Wandering:** Lost in thinking, thoughts or images. You may not know how long you were mind wandering for, but you suddenly have awareness that you were lost and not focused on your meditation practice. **One click**, **left** mouse button.
2. **Enlightenment:** You experience what is traditionally called an enlightenment experience where your sense of self becomes merged with everything you are aware of, and there is no distinction between this and that, subject and object, observer and observed. This could be as short as 30sec or last for an extended period of time. **Two clicks**, **left** mouse button.
3. **Black Out:** No thoughts, no sense perceptions, no awareness at all. One would come out of this not knowing how much time had passed or where they were. It would feel as if waking up from deep sleep and time had passed, but you feel as if you had just closed your eyes. **Three clicks**, **left** mouse button.

Mind Blanking, **Right Mouse** Button:

1. **Minimal Thoughts:** Thoughts are still present, but the time between them has greatly reduced. When they do arise, you are aware of them and not being carried away by them as you are during mind wandering. **One click**, **right** mouse button.

2. **No Thoughts:** No thoughts, but you are fully aware of sense perceptions such as seeing, hearing, feeling body sensations, sense of time, and sense of self. **Two clicks**, **right** mouse button.

3. **No Thoughts and Minimal Perceptions:** No thoughts, very few sense perceptions, absorbed more completely in pure awareness or the object of practice. **Three clicks**, **right** mouse button.

4. **Pure Presence:** No thoughts, no sense perceptions, no sense of individual self, but only awareness remains. **Four clicks**, **right** mouse button.

DWB

If you become aware that you were in any of the following states below for ~20-30sec or more, make the appropriate number clicks on the mouse that correspond to the state that you just exited.

Mind Wandering and Mostly Clear Awareness, **Left Mouse** Button:

1. **Mind Wandering:** Lost in thinking, thoughts or images. You may not know how long you were mind wandering for, but you suddenly have awareness that you were lost and not focused on your meditation practice. **One click**, **left** mouse button.

2. **Mostly clear awareness**: Resting in mind with nearly no thoughts or sensations. **Two clicks**, **left** mouse button.

Bliss and Pure Awareness, **Right Mouse** Button:

1. **Bliss:** You experienced a state of bliss that emerged from the mind itself and filled your experience. **One click, right** mouse button.

2. **Pure awareness:** Resting in mind with no thoughts or sensations. **Two clicks**, **right** mouse button.

Make sure that you are really in the state before pressing the button. You will have 5 sec to respond with the button press once you come out of the state. We want you to be as precise as possible. Please describe any additional information if you indicated that you entered a blank mind state, such as emotional or bodily feelings that arose. Write down your descriptions after the block of sitting has ended.

Supplementary discussion

Zen practice details

All Zen participants practiced Shikantaza meditation during the retreat. Although the participants had various Zen background and teachers, all but one had over 10 years of continuous meditation practice and a history of multiple in-person retreats. They also all indicated they had at least one prior experience of pure presence and thought there was a good chance they could replicate it during our study. Shikantaza is a Japanese term often translated as "just sitting" described here:

> Shikantaza, or "just sitting," is meditation without a goal. It is boundless—a process that is continually unfolding… One way to categorize the meditation practice of Shikantaza, or "just sitting," is as an objectless meditation. This is a definition in terms of what it is not. One just sits, not concentrating on any particular object of awareness, unlike most traditional meditation practices, Buddhist and non-Buddhist, that involve intent focus on a particular object…But objectless meditation focuses on clear, nonjudgmental, panoramic attention to all of the myriad arising phenomena in the present experience (Loori, 2012)

The word Shikantaza is similar in meaning as the Chinese word for "just sitting" translated in English as "silent illumination". The equivalent in the Chinese school of meditation practice known as Chan (Zen originally came from the word Chan both meaning meditation) of "silent illumination" is best described here by Chan Master Sheng-yen:

> The style of meditation called "silent illumination" is one of the great practices of the Chan (Zen) tradition. Silent illumination originated around the eleventh century, and its greatest advocate was Master Hung-chih Cheng-chueh (Hongzhi Zhengjue) of the Ts'ao-tung (Caodong) sect, which became the Soto sect in Japan. In Tibet, the mahamudra practice is very similar. The practice originated in India, where it was called shamatha-vipashyana, or serenity-insight. The aim of this practice is a mind unburdened with thoughts. This leads the mind to profound awareness about its own state (Loori, 2012).

But this is not a "dead" sitting where one is unalert. This alert awareness is described in James Austin's book, Zen and the Brain as an alert condition, performed erect, with no trace of sluggishness or drowsiness. During retreats in particular, Shikantaza can be shifted, or shifts itself, into long moments of extra-attentiveness. This means a kind of listening as though one were blind, of looking as though one were deaf, of feeling as though all one's pores were open and receptive. The senses seem to stretch out to close the gap between stimulus and perception, that interval which had once been occupied by the old judgmental barriers of interpretation. At such times, the meditator enters a state of high perceptual expectancy. It is the way one listens, knowing that a tiger lurks in the jungle nearby (Austin, 1998). This extra-attentive state, as Austin describes it, leads one into a type of samadhi (VI-B Absorption with Senate Loss: Internal Absorption. Table 10 pg 302 (Austin, 1998) where eventually the meditative absorption leads one's experience of body and mind to drop away leaving just the experience of pure presence with no objects remaining, including the self.

Even during long retreats this can be a fairly rare experience and is not sought after but arises through deep meditative absorption (samadhi) as the practice progresses. Half of those recruited (8) reported this state at least once during the retreat by pressing a silent mouse button when they came out of the state and found themselves returning to perceptual/thought like awareness. In all cases, this only occurred during the last 2-3 days of the retreat. They were initially trained over the first 3-4 days of the retreat to report when they came out of various states of emptiness as indicated on the Zen Pure presence rating scale in the supplemental. There was also an opportunity to speak with an experienced, long-term meditator who is familiar with such states in order to clarify any confusion that may have arisen during the retreat.

References

Austin, J. (1998). *Zen and the Brain: Toward an Understanding of Meditation and Consciousness.* Second Edition, Wisdom Publications.

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Vajrayana practice details

All Vajrayana Buddhist participants were practitioners of the Tibetan Buddhist Karma Kagyu lineage (Diamond Way Buddhism organization) and followed the same system of meditation practices. For all of them, the Guru Yoga meditation on the 16th Karmapa had been the general meditation they had been practicing regularly for years—many of them daily. They had also all completed a series of practices called the *Chag Chen Ngöndro* (Tib.; Eng. “Preparation for Mahamudra Practice,”)—known in English as the “Four Foundational Practices” (Nydahl, 2019), the “Four Uncommon Preliminaries” (Karmapa Wangchug Dorje, 2009), or the “Four Special Foundations” (Kongtrul, 1977)—and were all currently practicing the advanced Guru Yoga meditation of the 8th Karmapa Mikyö Dorje (Tib. *Tun Shi Lame Naljor*; Eng. “Meditation on the Lama in Four Sessions”). Following the established path of the Karma Kagyu lineage towards the ultimate Mahamudra practice, they had all adopted this Guru Yoga of the 8th Karmapa as their main, regular meditation practice.

Generally speaking, Guru Yoga meditations focus on awakening the qualities of an enlightened mind, as they are represented or expressed by one’s teacher (Magnussen, 2003; Malinowski, 2013). Within Tibetan Buddhist traditions, the Guru Yoga is hailed as the most effective meditation method to achieve full realization of these qualities (Sobisch, 2006). For example, the contemporary Buddhist master Dzongsar Jamyang Khyentse Rinpoche summarizes the practice in his preface to the book *Guru Yoga* (Dilgo Khyentse, 1999, p. 18): “Guru Yoga is the quickest, most effective method for attaining enlightenment and is the one path in which all other paths are complete. Guru Yoga includes renunciation, bodhicitta, development (*Kyérim*) and completion (*Dzogrim*) meditation, and mind training (*Lojong*), which is why we can say Guru Yoga is the embodiment, or the essence, of all paths.”

Given the centrality of the Guru Yoga for Vajrayana practitioners, our research focused on their two main Guru Yoga meditations: the Guru Yoga of the 8th Karmapa (Mikyö Dorje; see Rheingans, 2012, 2017) and of the 16th Karmapa (Rangjung Rigpe Dorje; see Bausch, 2018, 2021). With growing meditation expertise, all practitioners increasingly emphasize the dissolving or completion phase of these meditations (Tib. *dzog rim*). This phase was the perfect target for our study because practitioners aim to rest mind in a state of pure presence.

The 8th Karmapa Guru Yoga was the main practice all participants engaged with during their week-long retreats. They practiced it in a flexible, self-directed manner with no restrictions in terms of timing or progression through the various stages of the practice. They were instructed to report specific states of awareness during the dissolving (or completion) phase of this practice (see Methods).

In addition, we used the 16th Karmapa Guru Yoga meditation to quantify the neural signatures of pure presence using a no-report paradigm. Rather than engaging in self-paced meditation practices, here the participants followed a scripted, pre-recorded and precisely timed guided meditation. Compared to the 8th Karmapa Guru Yoga, this practice has a relatively condensed and simple structure. It was composed by Karmapa Rangjung Rigpe Dorje to be easily accessible and easy to practice. It emphasizes the key points of Guru Yoga in a compact fashion, making the fixed timing we employed feasible. The fixed timing allowed us to know when exactly the practitioner enters the dissolving phase, without relying on self-report. To reduce the impact of the auditory instructions and to ensure that the different phases of the meditation are of equal length, we recorded an abridged version of the guided meditation instructions, which had been approved by Lama Ole Nydahl (for the full text of the meditation, see p. 147ff in Nydahl, 2009). Here our main question was whether neural signatures of PP can also be detected when externally instigated, and whether the neural signature is similar to self-reported states of PP as detected during the 8th Karmapa Guru Yoga.

	16th Karmapa Guru Yoga key meditation phases	**Brief description and representative quotes (original quotes are indicated)**
0	Pre-meditation baseline	Resting with eyes open until meditation starts
1	The form of the 16th Karmapa appears	The meditation starts by contemplating the four basic thoughts, taking refuge and awakening *bodhicitta* (Skt.), the altruistic motivation for one's practice. Then, the meditator calls the form of Karmapa to mind, who appears in front of them in space, and focuses on awakening the enlightened qualities of body, speech, and mind: "In front of us appears the golden, transparent form of the 16th Karmapa, a radiant field of energy and light."
2	Mantra phase	Participants are instructed to repeat the mantra only internally / in their mind (i.e., without verbalization): "We now use the mantra *karmapa chenno*. It means, 'Power of all buddhas, work through us.'"
3	Dissolving phase	"All form disappears; there is now only awareness without center or limit."
4	World reappears	"Our surroundings, this world and all worlds appear, perfect and pure."

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