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► To cite this version:

Prisca Bauer, Cécile Sabourdy, Benoît Chatard, Sylvain Rheims, Jean-Philippe Lachaux, et al.. Neural dynamics of mindfulness meditation and hypnosis explored with intracranial EEG: A feasibility study. *Neuroscience Letters*, 2022, 766, pp.136345. 10.1016/j.neulet.2021.136345 . hal-04808111

HAL Id: hal-04808111

<https://hal.science/hal-04808111v1>

Submitted on 29 Nov 2024

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Neural dynamics of mindfulness meditation and hypnosis explored with intracranial EEG: a feasibility study.

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Number of words in abstract: 182

Number of words in manuscript body: 4002

Number of display items: 6 figures, 1 table

Abstract

Purpose: Intracranial electroencephalography (iEEG) offers a unique window on brain dynamics with excellent temporal and spatial resolution and is less prone to recording artefacts than surface EEG. This study used a within-subject design to explore the feasibility to compare iEEG data during mind wandering, mindfulness meditation and hypnosis.

Results: Three patients who had iEEG for clinical monitoring and who were new to mindfulness meditation and hypnosis were able to enter these states. We found non-specific and wide-spread amplitude modulations. Data-driven connectivity analysis revealed widespread connectivity patterns that were common across the three conditions. These were predominant in the low frequencies (delta, theta and alpha) and characterised by positively correlated activity. Connectivity patterns that were unique to the three conditions predominated in the gamma band, one third of the correlations in these patterns were negative.

Conclusions: This study is the first to support the feasibility of a direct comparison of the neural correlates of mindfulness meditation and hypnosis using iEEG. These modulations may reflect the complex interplay between different known brain networks, and warrant further functional investigations in particular in the gamma band.

Keywords: *absorption, meta-awareness, plasticity, connectivity, stereo EEG, networks, mind wandering*

Highlights

- Three patients with iEEG participated in brief sessions of meditation and hypnosis
- Connectivity patterns in low frequencies were common to the three conditions.
- Connectivity patterns that were unique to a condition predominated in the gamma band
- This is the first iEEG study comparing mindfulness meditation and hypnosis

Introduction

Brief psychological interventions such as mindfulness meditation and hypnosis are increasingly popular in healthcare settings and the wider community to improve mental health and wellbeing [1–4]. Mindfulness meditation aims at strengthening non-judgemental awareness of the present moment often by paying attention to the breath or bodily sensations [5]. Hypnosis aims at modulating specific mental processes by turning the attention to a hypnotiser's suggestion. In clinical practice, this is often a pleasant autobiographic memory, or a fantasised journey to a pleasant place. The line between both types of exercises is hard to draw, partly due to the variety of hypnosis and mindfulness practices. Broadly, both mindfulness meditation and hypnosis require the stabilisation of attention, yet the focus of attention is different: In mindfulness meditation, the aim is to remain aware of where the attention is directed to and to come back to the focus of attention whenever it has been lost. Thus, the person has to be aware of their own attentional focus, a process called meta-awareness [6]. In hypnosis, the person is invited to fully immerse themselves in the suggestion that is offered (for example being on the beach). This leads to absorption: the complete involvement in a perceived or imagined experience and to dissociation: a detachment from reality [4].

Functional magnetic resonance imaging (fMRI) studies have revealed that meditative and hypnotic states, especially in trained or highly hypnotisable participants are associated with partly overlapping activation changes in brain areas involved large-scale brain networks such as the default-mode network, the saliency network and the frontal executive network [7,8]. These networks are linked structurally through anatomical connections [9]. Brain oscillations are thought to play a crucial role in functionally linking these different, often spatially distinct brain areas [10]. Mindfulness meditation was associated to changes in oscillatory power, measured with scalp electroencephalography (EEG) [11]. The most consistent finding across such studies is the increase in alpha frequency band power in mindfulness compared to a control state (usually mind wandering) [11]. Findings relating to other frequency bands are less conclusive. The hypnotic state was most consistently accompanied by changes in the theta band [12,13]. Changes in the gamma frequency band were also observed in meditation [14] and hypnosis [15,16]. These are difficult to interpret,

however, as the gamma band is prone to contamination with muscle artefacts. Compared to scalp EEG and fMRI, intracranial EEG (iEEG) is less prone to recording artefacts and offers a unique window on brain dynamics with excellent temporal and spatial resolution. Yet for obvious ethical reasons, iEEG is only done in people with underlying brain disorders, mainly epilepsy. A recent case report of iEEG recordings during meditation confirmed the finding of increased alpha power during meditation. Effects in theta, beta and gamma bands were inconclusive [17].

Few studies have thus far attempted to directly compare the neural correlates of mindfulness meditation and hypnosis. In this feasibility study, we used iEEG to explore the neural dynamics of a single session of mindfulness meditation and hypnosis induction compared to mind wandering in a within-subject design in three participants. We assessed changes in oscillatory power, and using a data-driven, assumption free approach we identified connectivity patterns that are unique and common to hypnosis and mindfulness meditation. To the best of our knowledge, this study is the first to provide a direct comparison of the neural correlates of mindfulness meditation and hypnosis.

Material and Methods

Participants

Participants with drug-resistant partial epilepsy who underwent stereotactic electrode implantation and monitoring were recruited at the Department of Functional Neurology and Epileptology of the Lyon University Hospital, France. Inclusion criteria were: >18yrs old, estimated IQ of >80, normal or corrected to normal vision, implantation in temporal and frontal, and/or parietal regions. People who had epileptic seizures < 1 hour before or during the experimental procedure or who were unable to follow the instructions were excluded from further participation and analysis. The experimental procedures were approved by national ethics committee Ile de France XI (protocol Nr. 17012, EudraCT number 2017-A00464-49) and conducted according to the international Declaration of Helsinki. All participants provided written informed consent prior to participation.

Electrode implantation and iEEG recordings

All participants were stereotactically implanted with multi-lead EEG depth electrodes (DIXI Medical, Besançon, France). The recording sites were selected solely according to clinical indications, without reference to the current experiment. Each individual was implanted with 11 to 15 semi-rigid electrodes. Each electrode had a diameter of 0.8 mm and was comprised of 10 or 15 contacts of 2 mm length, depending on the target region, 1.5 mm apart. After a linear scale adjustment to correct for differences between individual brain size and the Talairach model, the coordinates of each electrode contact with their stereotactic scheme were used to anatomically localise the contacts using the proportional atlas of Talairach and Tournoux. These locations were further confirmed by overlaying a post-implantation MRI scan showing contact sites with a pre-implantation structural MRI with VOXIM® (IVS Solutions, Chemnitz, Germany), allowing direct visualisation of contact sites relative to brain anatomy. iEEG data were recorded using approximately 128 implanted depth electrode contacts per individual using the SD LTM Express, Micromed system for signal acquisition with a sampling rate of 512 Hz, high-pass filter 0.15 Hz, low-pass filter 500 Hz, using a reference electrode located in the white matter. Each electrode trace was subsequently referenced with respect to its direct neighbour (bipolar derivations with a spatial resolution of 3.5 mm) to cancel out effects of distant sources that spread equally to both adjacent sites through volume conduction.

Audio instructions

At least one day after the implantation of the electrodes, participants were asked to take part in the study. After a brief explanation of the procedure and time to answer questions, three different audio instructions were played through a windows laptop with external sound boxes to guide participants into mind wandering, meditation and hypnosis. Due to the implanted electrodes the use of noise-cancelling headphones was not possible. The instructions (recorded by CS, a neurologist trained in hypnosis and mindfulness meditation) consisted of an introduction part in which the instructions were dense (2'30 - 7 minutes), and a practice part, which consisted of three silent periods of 160-180 seconds (3') interspersed with reminders of the instructions (see figure 1). The instruction scripts and timings are shown in Appendix I. The instructions were tested in a sample of 100 healthy volunteers prior to being used in this context (results will be published separately).

In the control condition (duration 11 minutes) participants were asked to relax while letting their mind wander wherever it wanted. The mindfulness instructions (total length 17 minutes) asked participants to focus their attention on their body and bodily sensations, progressively bringing the attention to the breath, to which they were instructed to come back whenever they noticed that they had been distracted. Toward the end of the instruction they were instructed to open their awareness to all sensations present in their body. The hypnosis condition (total length 17 minutes) started with attention on the body and bodily sensations, after which people were invited to bring to mind a real or imagined pleasant place. They were then asked to recall all sensations and feelings associated with this place, with emphasis on all sensory experiences (sight, sound, smell, taste and touch).

In all three conditions, people were asked to find a comfortable supine position, with their eyes closed, and to lie as still as possible. To avoid novelty effects, the control condition was presented first, the mindfulness and hypnosis instructions were randomised. The experimenter (PRB) stayed present in the room during the entire experiment and silently followed the audio-instructions with the participant. At the end of the experimental session, a brief, semi-structured interview was conducted to assess compliance with the instructions and what participants experienced during the instruction. Participants were asked about how they were feeling, their ability to concentrate, their point of view in the visualisation (first or third person), and awareness of their body. They were also asked about the differences and similarities they had observed between the three instructions. The interviews were video recorded.

Data analysis

Data analysis was conducted in Matlab® (version 2018). We analysed and compared the spectral components of intracranial data obtained during three different condition-epochs: mind wandering, mindfulness meditation and hypnosis. Only the data obtained during the silent periods lasting a total of ~9 minutes in each condition were included in the analyses. Continuous iEEG signals were first bandpass filtered in successive frequency intervals: 2-4Hz for the delta band (2Hz width), 4-8Hz for the theta band (2Hz width), 8-12Hz for the alpha band (2Hz width) and 50-150Hz for high-gamma band (10Hz width). It has been shown that high frequency activity between 50Hz and 150-200 Hz reflects local output (population spiking) and is a

reliable indicator of local neural processing [18–20] while activity around 40Hz is thought to be linked to dendritic input and local transmission [19,20]. High gamma band responses between 50-150 Hz have successfully been used in previous studies to characterise functional cortical responses [21–26]. We then extracted the envelope of each bandpass-filtered signal using a standard Hilbert transform. The signal envelope for each frequency band had a time resolution of 64Hz and was divided by its mean across the entire recording session and then multiplied by 100, yielding the instantaneous envelope values as percentage of the mean. All envelope signals within a frequency interval were then averaged [26,27]. For each condition, we split the condition-epochs in consecutive time windows of 1000ms. Epileptic spikes have a much larger amplitude than the physiological signal. To exclude potential epileptic spikes and artefacts from analysis, all temporal samples across all electrodes contacts that exceeded an amplitude threshold of 5 times the standard deviation of the epoch's mean were removed.

To study the spontaneous variations in spectral amplitude at each recording site in each condition, we baseline-corrected amplitude values by subtracting the mean amplitude recorded in the first ten seconds. To evaluate functional differences in amplitude between the three conditions we used a one-way ANOVA with a post-hoc Tukey-Kramer test, all p-values were Bonferroni-corrected for the number of recording sites.

We assessed the functional connectivity patterns between all recording sites by computing the time-resolved amplitude correlation in each frequency band for each condition. The significance level of each correlated pair was Bonferroni-corrected using the number of pairs. Unique connectivity patterns consist of all pairs of recording sites that showed significant correlation in only one of the three conditions. Common connectivity patterns consist of all electrode pairs showing significant correlation across the three conditions. To estimate the difference in global connectivity strength between conditions in the common connectivity pattern we used a one-way ANOVA on all correlation Rho values from the common connectivity pattern.

Results

Participants

We recruited five consecutive participants, four men, one woman. The woman was excluded from analysis as she indicated during the experiment that she could not comply with the instructions because of her clinical condition (post-operative tiredness). One man had to be excluded from further participation as he had a seizure during the control condition. Thus, three male participants (aged between 36 and 57 years old) completed the study and were included in the analysis. S1 and S2 were right handed, S3 was left handed. S1 had left mesial temporal lobe epilepsy and hippocampal sclerosis, S2 had left frontotemporobasal epilepsy, S3 had right temporal lobe epilepsy with heterotopia. The implantation of the electrodes in each patient is shown in figure 2 . In the debriefing interviews, the three participants reported that they complied with the different instructions. They were able to invoke a pleasant environment for the hypnosis instruction. For all three, the visual sense was dominant in this condition. S1 reported that the control condition felt the longest, and that he completely lost the sense of time during the hypnosis instructions. All three described a greater sense of wellbeing and relaxation after the end of the experiment.

Amplitude modulations

Across the three participants an average of 23% of the signal was rejected to avoid any possible contamination by epileptic activity. The Bonferroni-corrected significance threshold (0.05 divided by the number of electrodes included in the analysis) for subject 1 was $p < 0.00044$, for subject 2 $p < 0.00038$ and for subject 3 $p < 0.00039$. Compared to mind wandering (control condition) >80% of all recording sites showed statistically significant amplitude differences during mindfulness meditation and hypnosis across participants. These changes in amplitude (increases and decreases), were found across all frequency bands and regions of interest (Table 1 and figure 3). An interesting observation in figure 3 is that in the lower frequency bands (especially delta), the frontal electrodes show higher amplitudes in meditation and hypnosis than in control. In the gamma band, this pattern is reversed, with higher amplitudes in those electrodes in the control condition compared to meditation and hypnosis. In the temporal regions, there are higher amplitudes in the lower frequency bands (especially alpha) in the control condition than in hypnosis and meditation. In

the gamma band, however, there are higher amplitudes in meditation and hypnosis compared to the control condition.

Table 1. Changes in spectral amplitude responses. The percentage of recording sites that show a significant difference (increase and decrease) in spectral amplitude response between conditions in the three participants is shown. The significance threshold was Bonferroni corrected by the number of recording sites included in analysis and was $p < 0.00044$ for subject 1, $p < 0.00038$ for subject 2 and $p < 0.00039$ for subject 3 C: Control (Mind wandering) M: Mindfulness meditation. H: Hypnosis.

Modulation of spectral amplitude responses									
% Recording sites	C > M	M > C	C = M	C > H	H > C	C = H	M > H	H > M	M = H
DELTA (2-4 Hz)									
S1	65.18	18.75	17.86	66.96	18.75	16.07	47.32	33.04	21.43
S2	31.25	46.88	23.44	14.06	73.44	14.06	13.28	77.34	10.94
S3	40.31	31.78	29.46	37.98	37.98	25.58	28.68	42.64	30.23
THETA (4-8 Hz)									
S1	54.46	17.86	29.46	74.11	14.29	13.39	65.18	15.18	21.43
S2	42.19	39.84	19.53	23.44	55.47	22.66	17.19	62.50	21.88
S3	33.33	44.96	23.26	25.58	53.49	22.48	18.60	62.02	20.93
ALPHA (8-12 Hz)									
S1	59.82	19.64	22.32	75.89	13.39	12.50	55.36	18.75	27.68
S2	43.75	35.94	21.88	36.72	49.22	15.63	28.13	51.56	21.88
S3	41.09	35.66	24.81	41.86	39.53	20.16	30.23	47.29	24.03
HGAMMA (50-150 Hz)									
S1	41.96	42.86	16.96	45.54	37.50	18.75	41.07	42.86	17.86
S2	43.75	35.94	21.88	49.22	37.50	14.84	42.97	33.59	25.00
S3	28.68	58.14	14.73	19.38	66.67	15.50	31.01	51.94	18.60

Connectivity

Global connectivity analysis in the delta band across participants revealed that 70.3% (5.4 SEM) of all pairs with significantly correlated activity were part of a common connectivity patterns while 5.2% (1.5 SEM) belonged to unique connectivity patterns

shown in figure 4. In all three participants, common connectivity patterns correlated more strongly during mindfulness meditation as compared to mind wandering ($p < 0.001$, Bonferroni-corrected across all pairs). In two participants, correlations were stronger in mindfulness meditation as compared to hypnosis ($p < 0.0001$, Bonferroni-corrected across all pairs).

In the theta band 67.8% (2.6 SEM) of all significantly correlated pairs were part of common connectivity patterns while 6.2% (1.9 SEM) belonged to unique connectivity patterns (figure 4). In all three participants common connectivity patterns were more strongly correlated during mindfulness meditation and hypnosis than during mind wandering ($p < 0.0001$, Bonferroni-corrected across all pairs). In two participants, there were stronger correlations during hypnosis than during mindfulness meditation ($p < 0.05$, Bonferroni-corrected across all pairs).

In the alpha band 64.7% (4.9 SEM) of all pairs with significant correlation belonged to common connectivity patterns while 14.1% (2.7 SEM) belonged to unique connectivity patterns. The correlation was stronger in the common connectivity patterns during hypnosis than during mind wandering ($p < 0.0001$, Bonferroni-corrected across all pairs). Hypnosis was accompanied by stronger correlations than mindfulness in two participants ($p < 0.05$, Bonferroni-corrected across all pairs).

In the high-gamma band 34% (2 SEM) of all pairs with significant correlation belonged to common connectivity patterns while 38.9% (0.9 SEM) belonged to unique connectivity patterns (figure 4). In all three participants the common connectivity patterns correlated more strongly during hypnosis than during mind wandering ($p < 0.05$, Bonferroni-corrected across all pairs).

Across all participants and frequency bands, common connectivity patterns consisted in 97.3% (0.62 SEM) of positive rho values, and 2.7% of negative rho values. Unique connectivity patterns consisted in 66.81% (2.17 SEM) of positive rho values, and in 33.19% (2.17 SEM) of negative rho values. This heterogenous distribution of positive and negative connectivity between common and unique networks is shown for subject 2 in figures 5 and 6.

Discussion

We explored the amplitude and connectivity patterns of brief hypnosis and mindfulness sessions and compared them with a control condition consisting of mind wandering. We found non-specific and wide-spread amplitude modulations. Our data-

driven approach to connectivity analysis revealed widespread patterns, likely involving multiple networks, that were common to the three conditions, and smaller patterns that were specifically activated by one of the conditions. These common connectivity patterns may reflect general mechanisms such as attention and memory, whereas the unique connectivity patterns may reflect specific changes in mindfulness and hypnosis. Our most striking finding is the fact that the common connectivity patterns are large, predominate in the low frequencies, and consist mostly of positively correlated activity, while the unique connectivity patterns are found more in the gamma band and one third of the correlations in these patterns is negative. This finding is in line with previous studies showing that suppression of gamma band activity correlates with task complexity [21].

Activity in the theta band has been linked to processes of navigation, memory, learning and plasticity [13,28]. A previous study found changes in resting state EEG theta networks after just one week of meditation training [29]. It was suggested that mindfulness meditation induces white matter changes through increasing frontal midline theta activity [30]. A speculative hypothesis is that the widespread changes in the theta band seen in our participants, who were new to these exercises, may reflect first stages of plasticity.

Mindfulness and hypnosis are complex cognitive processes. It is increasingly clear that human cognition is linked to complex interactions between different brain areas that form networks that dynamically interact with each other [9]. Converging evidence from fMRI studies has identified three functional networks [9]: 1) the salience network, which involves the anterior insular (AI) and dorsal anterior cingulate cortices (dACC), and has extensive connectivity with subcortical and limbic structures involved in reward and motivation. It is involved in monitoring the salience of external and internal inputs. 2) the central-executive network connects the dorsolateral prefrontal and posterior parietal cortices, and has subcortical coupling that is distinct from that of the salience network. It is engaged in higher-order cognitive and attentional control. 3) the default mode network includes midline and posterior inferior parietal regions and is associated with spontaneous and self-generated thought. In many cognitive tasks, the default mode network shows an antagonistic relation with the other two networks [29]. In creative thinking, however, there appears to be cooperation of these three networks [30]. Previous studies have

shown that mindfulness and hypnosis also involve these three major brain networks, and consistently report a reduction of the activity in the default mode network [8,31]. We hypothesise that the changes in connectivity patterns observed in our study are linked to similar mechanisms and reflect the complex orchestration of these different brain networks [32]. This is in line with a previous fMRI study on mindfulness meditation showing a state-specific reduction in connectivity between salience/emotion and central executive networks [33].

Breath cycles and heart rhythm have been shown to directly modulate neuronal activity [34,35]. Interoception and awareness of the heartbeat [36,37] or breath [38] appear to modulate this activity. One study for example found increased coherence in the anterior cingulate, premotor, insular and hippocampal cortices during attention to breathing [38]. As our mindfulness meditation instruction consisted of focusing the attention on the sensations of the body, including the breath, it is possible that the changes we found during the mindfulness condition are partly due to such interoceptive processes. Our study has several limitations. The number of participants is small, which is explained by the difficulty in finding suitable participants with depth electrodes who are able to participate in such a study. The implantation sites for the electrodes is decided solely based on clinical purposes and needs, making it challenging to recruit participants with similar or overlapping regions of interest. The implantation procedure and clinical monitoring for their drug-resistant epilepsy is hugely demanding. Often, people are tired or have frequent seizures. Although we recruited five participants, only three could be included in the analysis of this exploratory study. Our study protocol may have been challenging for the participants who were unfamiliar with the exercises. Both mindfulness meditation and hypnosis become easier with practice, and require a peaceful environment and some time to enter the state. We standardised and pre-recorded our instructions for reproducibility, which may have reduced the compliance. Although we tried to keep the instructions as short as possible, we felt that it was important to give people enough time to enter the different states and to try and stabilise them, as the three participants were novices. This is also the reason why we decided against a cross-over design (C-M-H-M-H-C or similar), as this would have substantially lengthened the study protocol, which would have been unfeasible in the clinical context of the participants. Such a cross-over design can be done in participants with prior training [39]. In people

without training, it carries the risk that participants mix up the instructions. In our current design (C-M-H / C-H-M), we cannot exclude additive effects of the states, or contamination by other task-unrelated mental processes such as mind wandering during meditation or hypnosis. To increase the specificity of our finding we alternated the order of the hypnosis and mindfulness condition to try and minimise these effects and used the mind wandering control condition as a baseline. As the patients with implanted electrodes were in high demand for other research protocols, and were tired due to the operation, seizures and changes in medication, it was not possible to repeat the protocol on a different day.

Intracranial EEG has the advantage that there is little artefact contamination. One potential issue is inter-ictal epileptic activity in the form of spikes, which we tried to circumvent in several ways: We did not include participants if they had a seizure <1hr before the start of the experiment, avoiding the post-ictal phase, and excluded participants who had a seizure during the experiment. Using a rigorous automatic rejection rule, we rejected 23% of time-windows with potential artefacts and epileptic spikes from analysis, making us confident that our final analysis is conducted on signal that is both artefact free and free of epileptic activity.

Several reports have suggested that mindfulness may trigger seizures in people with epilepsy. Randomised controlled trials of mindfulness interventions instead show a trend towards seizure reduction. In our small sample, the only seizure that occurred during the experiment occurred during the control condition.

Despite these limitations, this pilot study shows that brief psychological interventions are feasible and beneficial for patients requiring epilepsy surgery, and induce widespread changes in neural patterns. We hope that future studies with more participants, who ideally are familiar with the exercises, will be conducted to further advance our understanding of the dynamics of the different networks involved in hypnosis and mindfulness meditation more precisely. Other measures of connectivity involving phase information, such as phase coherence or synchrony, would be interesting areas of exploration in further studies involving larger cohorts.

Conclusion

We found non-specific and wide-spread amplitude modulations in three people using iEEG during mindfulness meditation and hypnosis compared to mind wandering. Connectivity analysis revealed widespread common connectivity patterns, predominately in the low frequencies (delta, theta and alpha), mostly with positively correlated activity. Unique connectivity patterns predominated in the gamma band and one third of the correlations in these patterns were negative. These modulations may reflect the complex interplay between different known brain networks, and possibly first stages of plasticity.

Acknowledgements

We thank the participants for their participation, and the anonymous reviewers for their suggestions to improve the manuscript.

Funding

This work was supported by the BIAL Foundation (Grant No 260/16 to PRB and AL), the European Union's Horizon 2020 research and innovation program under the Marie Skłodowska-Curie grant agreement No 749582 (Neural Correlates of Self /NeuCoSe to PRB), by the LABEX CORTEX of Université de Lyon (ANR-11-LABX-0042) within the "Investissements d'Avenir" program (ANR-11-IDEX-0007) (AL, BC, JPL), and by a European Research Council grant (ERC-Consolidator 617739-BRAINandMINDFULNESS) (AL).

Conflict of interest statement

PRB receives speaker fees from NovoCure. SR received consultant and/or speaker fees from EISAI, UCB Pharma, Livanova, GW Pharma, Arvelles therapeutics, Idiorsia. The other authors have no conflicts of interest to declare.

Author contributions

PRB, AL and CS designed the study. JPL and SR were responsible for the iEEG recordings. PRB and BC collected the data. JRV analysed the data and prepared the figures in close interaction with PRB. PRB and JRV wrote the first draft of the manuscript. All authors contributed substantially to the manuscript and read and approved the final version.

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Figure 1. Experimental protocol. *The three instructions consisted of an introduction/induction part with dense instructions, and a silent part (“state”) which consisted of three sections of ~3 minutes interspersed with reminders of the instructions. The control condition consisted of mind wandering.*

Figure 2. Implantation scheme. *Glass brain showing all intracranial recording sites for the three participants (green: subject 1, black: subject 2, red: subject 3). For subject 2 each electrode is labelled with a letter, to facilitate the interpretation of results shown in figures 4-6.*

Figure 3. Topographic distribution of condition effects for local amplitude responses. *Glass brains showing all intracranial recording sites for the three participants for the four frequency bands and the different conditions: red: control (mind wandering) vs mindfulness meditation, blue: mindfulness meditation vs control, pink: control vs hypnosis, black: hypnosis vs control.*

Figure 4. Connectivity analyses. *Theta and High gamma band correlation matrices of subject 2. Upper row, connectivity patterns common to the three conditions. Lower row, unique connectivity patterns per condition.*

Figure 5. Common and unique connectivity patterns with frontopolar electrodes in subject 2. A) recording sites in subject 2, frontopolar electrodes in red. B) Circular connectivity representation of common and unique networks between two most frontopolar electrodes (shown by white dots in circle perimeter) and all other recording sites. The green lines show all significant correlations between these frontopolar recording sites and all other recording sites, which are then split into positive correlations (red lines) and negative correlations (purple lines) to form common (top) and unique connectivity patterns (bottom). C: Control (Mind wandering); M: Mindfulness meditation; H: Hypnosis.

Figure 6. Common and unique connectivity patterns in inferior frontal electrodes in subject 2. A) recording sites in subject 2, inferior frontal electrodes in red. B) Circular connectivity representation of common and unique networks between three electrodes in inferior frontal cortex (shown by white dots in circle perimeter) and all other recording sites. The green lines show all significant correlations between these inferior frontal recording sites and all other recording sites, which are then split into positive correlations (red lines) and negative correlations (purple lines) to form common (top) and unique connectivity patterns (bottom). C: Control (Mind wandering); M: Mindfulness meditation; H: Hypnosis.

Appendix 1

Instructions (translated from French)

Control condition:

I now provide you a new instruction.

First of all, close your eyes, then simply lie down with your eyes closed and listen to the instructions. You may hear the noises surrounding you. Keep your eyes closed, while staying awake, still, you may let your mind wander. For example, you could think about what you are going to do when the experiment is over.

...

The monotonous noises can sometimes induce drowsiness, especially if you try to lie awake, without moving. Continue letting your mind go where it wants to go.

...

Try to stay awake, with your eyes closed, without moving, this part of the experiment will soon be over.

You can now open your eyes. You will see images on the screen. Please look at them carefully.

Hypnosis

I will now offer you a new instruction that will likely connect you with your ability to relax, to recharge your batteries, in a pleasant, comfortable, quiet way, like a beautiful interlude that you offer yourself.

To start, I suggest you let your eyes close because it is often more pleasant.

Let the rhythm of your breath establish a state of ease and relaxation, conducive to beneficial changes, in complete calm.

Then, with each breath becoming deeper and deeper, I invite you to focus on the sensations that appear as you let your body fully inhabit this position; in the feet, legs, thighs, back, hands, arms, shoulders, neck, back of the head ...

And in front of you, now, under your closed eyelids, I invite you to observe the flight of two butterflies or dragonflies... observe their movement, from right to left, from left to right, their colour, their grace, the variations of light on their wings... perhaps they cross each other, in a complex and mysterious ballet, rising above your head until you can no longer see them. And in this modified state of consciousness, this waking daydream, I invite you to let emerge the real or imaginary image, it doesn't matter, on the contrary, of a place, in which you felt particularly well, maybe in resourcing contact with the elements of nature.

Take the necessary time to let this pleasant place come to you.

And as soon as it comes into contact with you, I suggest you observe it and detail the different elements... allow your eyes to see what there is to see, the light, on the objects, the vegetation maybe..., the shades depending on the time of day.

Let your hands, your feet touch what there is to touch... The feeling of support according to the ground, the sensations on your skin, ... The smells, the place, the vegetation, maybe food,

Noises, voices, everything your ears have heard, the tastes, what your mouth may have tasted...

I let you soak up all these sensations for a few moments, reconnect with them, knowing that you will be able to integrate the sounds around you into this pleasant memory.

➤ [silence lasting about 2 minutes 40]

Now that you've been around this place and what contributes to its beneficial effect, I suggest that you let all these pleasant sensations (landscape, physical sensations, noises, tastes and smells) intensify as if you were wrapping yourself up in them, like in a duvet or a comfortable blanket when you feel like dozing off...

➤ [silence lasting about 2 minutes 30]

And always, as much as it seems necessary and useful to you, try to keep in touch with all these sensations, these perceptions, these sounds, these smells, these tastes, and maybe you can feel how pleasant and enjoyable the contact with all these sensations can be.

➤ [silence lasting about 2 minutes 30]

Now I invite you to slowly let your eyes open again... You will see images on the screen. I invite you to look at them attentively, letting all the sensations they provoke come to you.

Mindfulness meditation

I now propose a new exercise for which I invite you to close your eyes.

Try to focus your attention on your body, in a light and caring way.

Pay attention to the upper part of your body ... the face ... the neck, the basis of the neck ...

Become aware of the sensations that are present ...

Likewise, give caring attention to your lower body ... your stomach ... lower back ... legs ... feet ... and become aware of the sensations that are present ... Allow your body and mind to relax and just be present ...

After a slightly deeper inbreath, you also breath out more deeply as you relax...

You can quietly expand your awareness to all the sensations that are present in this moment in your body.

Allow your mind to be open, relaxed and present...

Don't try to stop the feelings...sounds...or thoughts that appear. Don't get distracted...

Just let them pass...

Let your mind rest ... open and spacious ... perfectly at ease in the present moment ...

To help you anchor yourself in the present moment, try and become aware of the sensations linked to your breathing, as they occur naturally, without wanting to modify them.

Sometimes the mind gets carried away by thoughts and emotions...

If you notice that you have been carried away, gently bring your mind back to the sensations of the breath... moment after moment.

Let emotions or thoughts that pass naturally through the mind come and go as mere mental productions.

Just be aware that you are breathing moment after moment, ... throughout this experiment. ...

➤ [silence lasting about 2 minutes 40]

It is normal for the mind to get carried away by thoughts and emotions. If this is the case, simply go back to the sensations of breathing ... Let your mind relax in the present moment ...

➤ [silence lasting about 2 minutes 30]

Let your mind rest...perfectly at ease in the present moment... Be aware of the sensations of your breath moment by moment...

➤ [silence lasting about 2 minutes 30]

I now invite you to quietly open your eyes... You will see images on the screen. I invite you to look at them attentively, while remaining present, open and relaxed.

Counterbalanced order

Control

Introduction

State

~2'30

3x~3

Meditation

Introduction

State

~7'

3x~3

Hypnosis

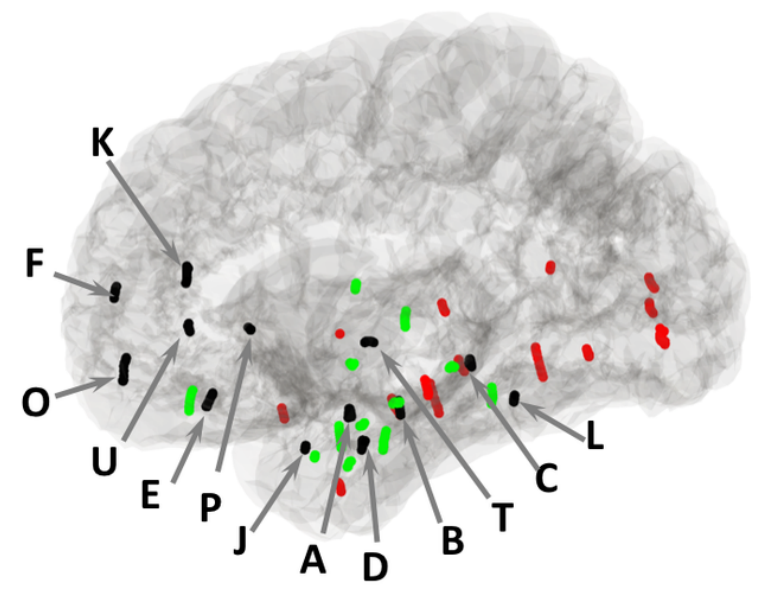
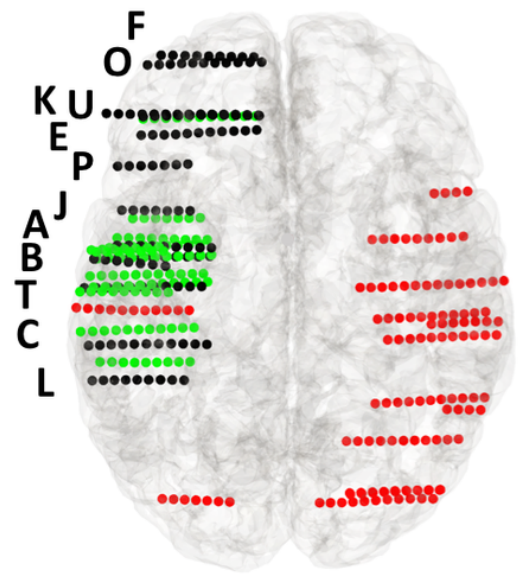
Induction

State

~7'

3x~3

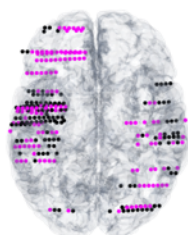
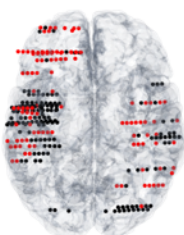
Inter
view



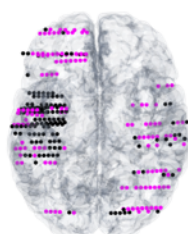
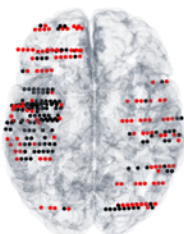
**Meditation
vs
Control**

**Hypnosis
vs
Control**

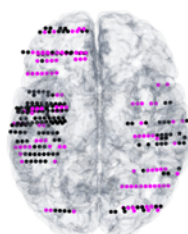
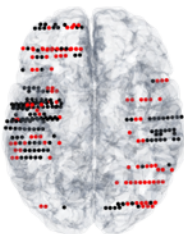
Delta
2-4Hz



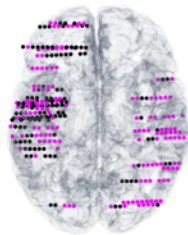
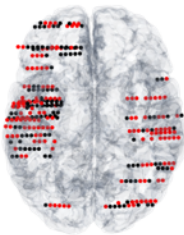
Theta
4-8Hz



Alpha
8-12Hz

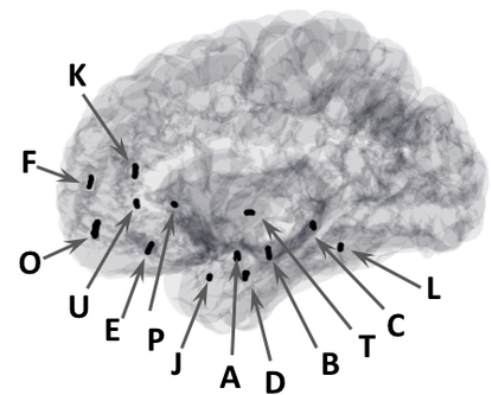


HGamma
50-150Hz



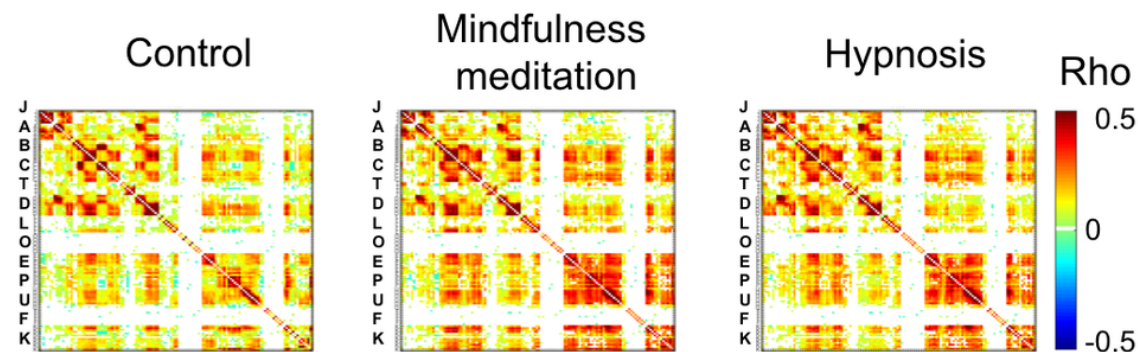
M > C
C > M

H > C
C > H

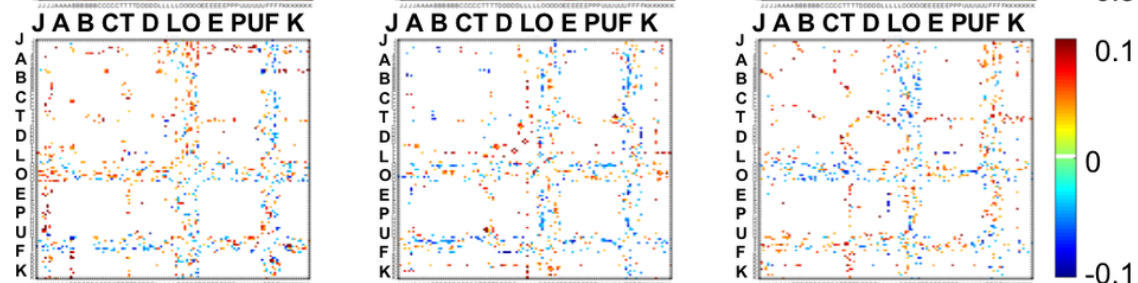


Theta

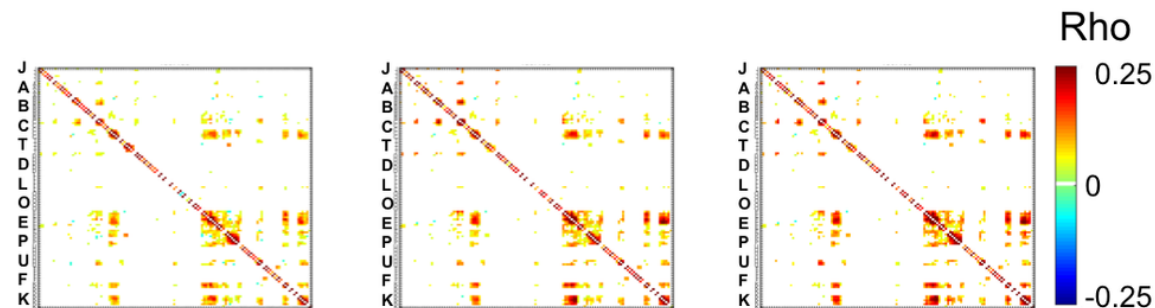
Common
Connectivity
Patterns



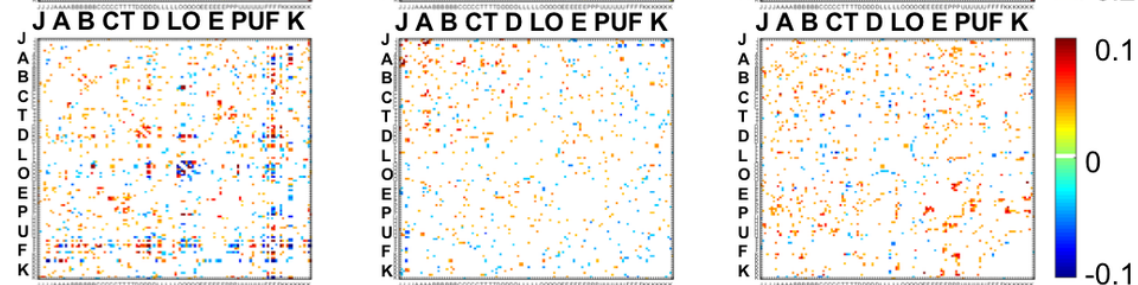
Unique
Connectivity
Patterns



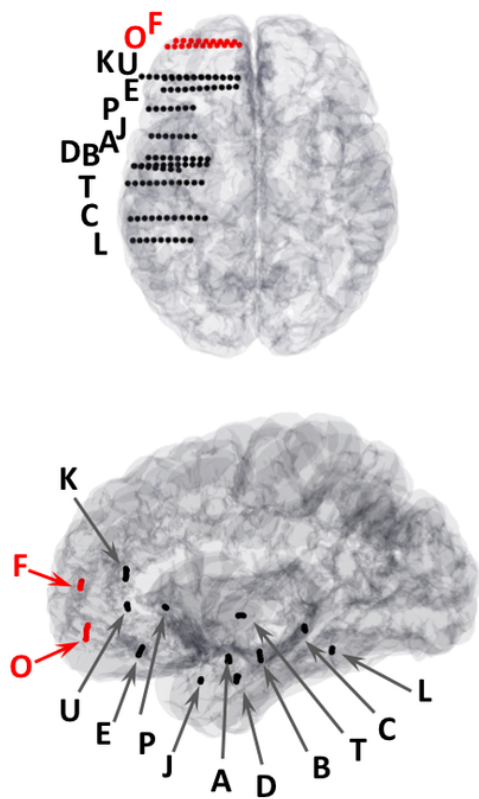
Common
Connectivity
Patterns



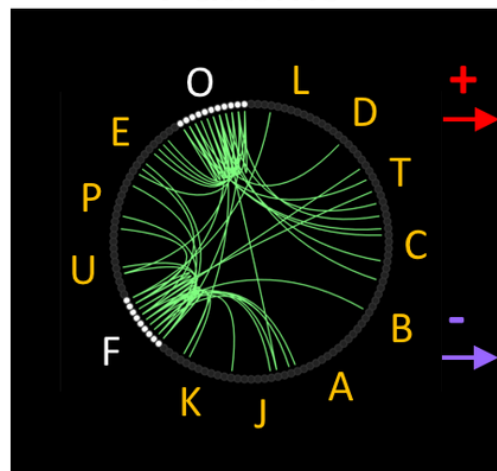
Unique
Connectivity
Patterns



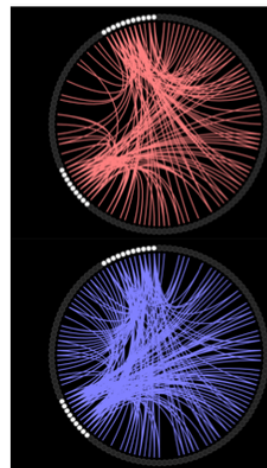
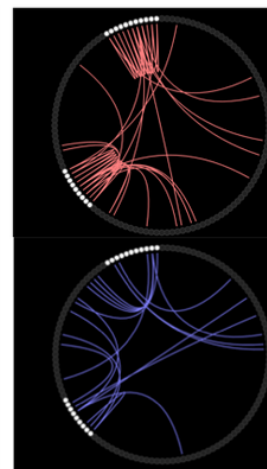
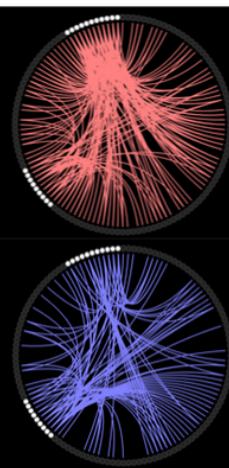
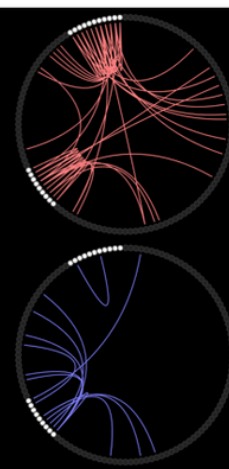
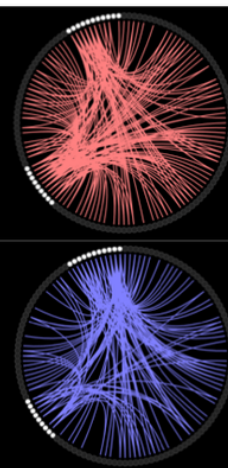
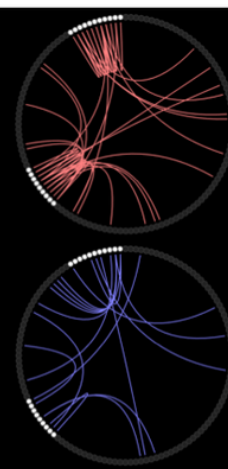
Hgamma

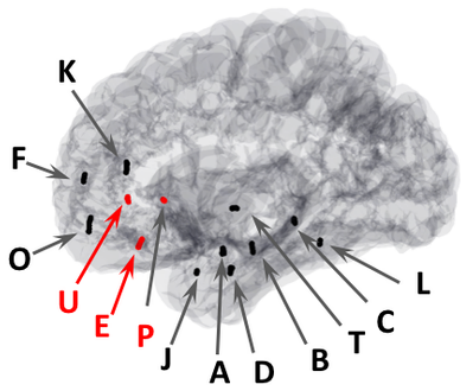
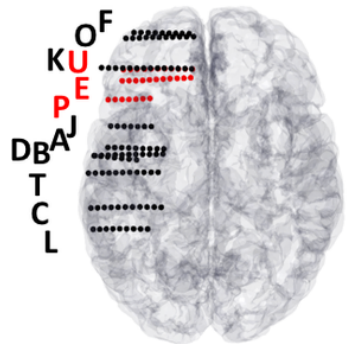
A**B**

Common Connectivity
Patterns

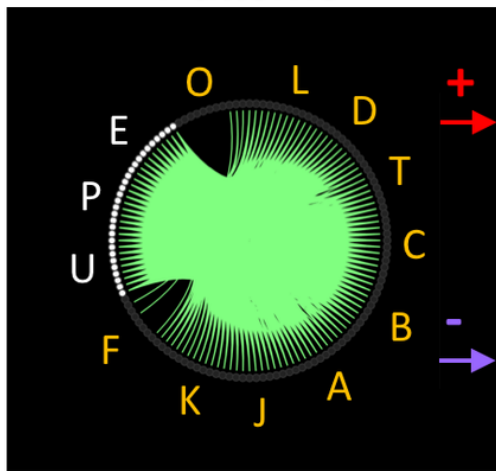


Unique Connectivity
Patterns

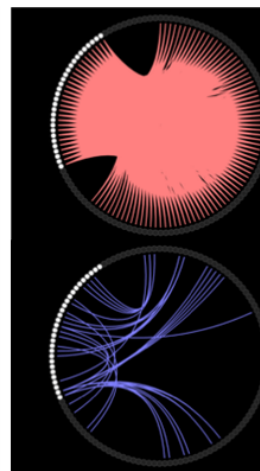
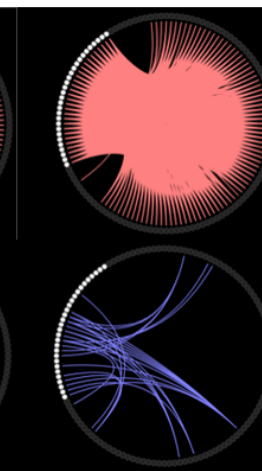
C**M****H**

A**B**

Common Connectivity
Patterns



Unique Connectivity
Patterns

C**M****H**