BIAL FOUNDATION FINAL REPORT

PROJECT TITLE: Finding the light: Neural and pharmacological evidence of pure consciousness (357/2020)

PRINCIPLE RESEARCH CENTRE: Vrije Universiteit Amsterdam, Faculty of Behavioral and Movement Sciences, Amsterdam, Netherlands

PRINCIPLE RESEARCHER: Professor Heleen A. Slagter

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SUMMARY OF PROGRESS: The aim of the BIAL project was to test whether it is possible to find objective evidence of 'pure consciousness' in advanced meditators using a combination of neuroimaging, machine learning, and psychopharmacology.

AIMS We proposed two research questions:

1. Testing the extent to which the linguistic hierarchy, and thus conceptual processing itself, is broken down during the deep meditative state of pure consciousness.
2. Testing the hypothesis that accessing pure consciousness, which involves "surrendering the conceptual mind" subsequently permits volitional control over levels of wakefulness.

As communicated previously, we conducted two experiments as part of research question 1. Two part-time RAs assisted with data collection. In the below, we provide a brief summary of Experiment 1 and Experiment 2 and their preliminary findings.
For reasons communicated previously, including the postdoc hired on the project leaving to take up an Assistant Professor position in Australia, it was no longer feasible to also conduct the final experiment involving a pharmacological manipulation. The remaining budget will be returned to BIAL upon this final report.

OUTPUTS
We have presented the results of Experiment 2 at the following conferences: "Phenomenological Methods in Neuroscience and Consciousness Research" at the University of Zurich, 29–30 April 2022, as well as "The Nothingness Conference" hosted by the University of Sydney at Lilianfels, Blue Mountains, Australia.

The preliminary results have also been included in several other invited presentations, including: Murdoch University in Perth (12th of May, 2023); The University of Queensland (21st October, 2023); Monash University in Melbourne (24th of March, 2022); The Theosophical Society (14th March, 2022).

Two master students conducted their master thesis project within the BIAL project.

We anticipate two peer-reviewed publications in well regarded scientific journals upon completion of data analysis of Experiments 1 and 2 in which we will acknowledge BIAL funding.

OVERVIEW OF EXPERIMENT 1

AIMS and METHODS In the first experiment, and as proposed in our grant application, we recruited meditators and measured linguistic conceptual processing (using EEG) under different states of meditative absorption. We collected data from 49 meditators (25 experienced and 24 advanced meditators) and have analysed the results using machine learning (multivariate pattern analysis, Chan et al., 2011). Table 1 below shows the characteristics of our sample:

Table 1

Characteristics of the sample

Factor			Total sample (n = 49)	Less advanced (n = 25)	Highly advanced (n = 24)
Sex	Male		23	10	13
	Female		26	15	11
Age	Mean		50	48.5	53
	Standard deviation		9	9.6	8.8
Education	University		21	11	10
	Hbo		20	11	10
	Mbo		7	2	4
	High school		1	1	0
Experience	Hours	Mean	4987	2036	8060
		Median	3000	2000	5750
	Retreat	Mean	271	103	447
		Median	72	42	133
Tradition/style	Theravada		11	4	7
	Tibetan		14	5	9
	Zen		20	13	7
	Mindfulness		4	3	1
Predominant style	FA		14	10	4
	OM		20	10	10
	ND		15	4	10

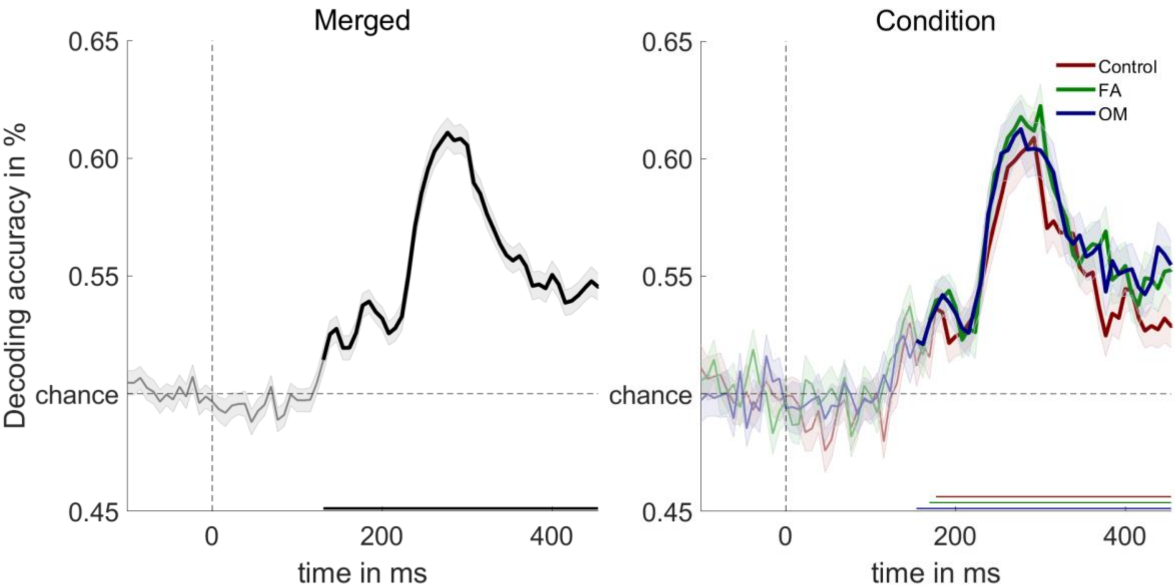
Note. To separate the sample into less advanced and highly advanced meditators, we performed a median split based on the number of days spent on retreat. This is a deviation from our planned analyses (for more detail, see results)

In Experiment 1, each participant entered into three different states of meditation, categorized as control, focused attention (FA), open monitoring (OM). After each session participants were asked if they entered a state of pure consciousness or non-dual awareness. We aimed to test how these different states of meditation affect the processing of linguistic concepts as measured by event-related potentials and multivariate pattern analysis of EEG. We present two figures illustrative of our “decoding” results below:

PRELIMINARY RESULTS

Figure 1.

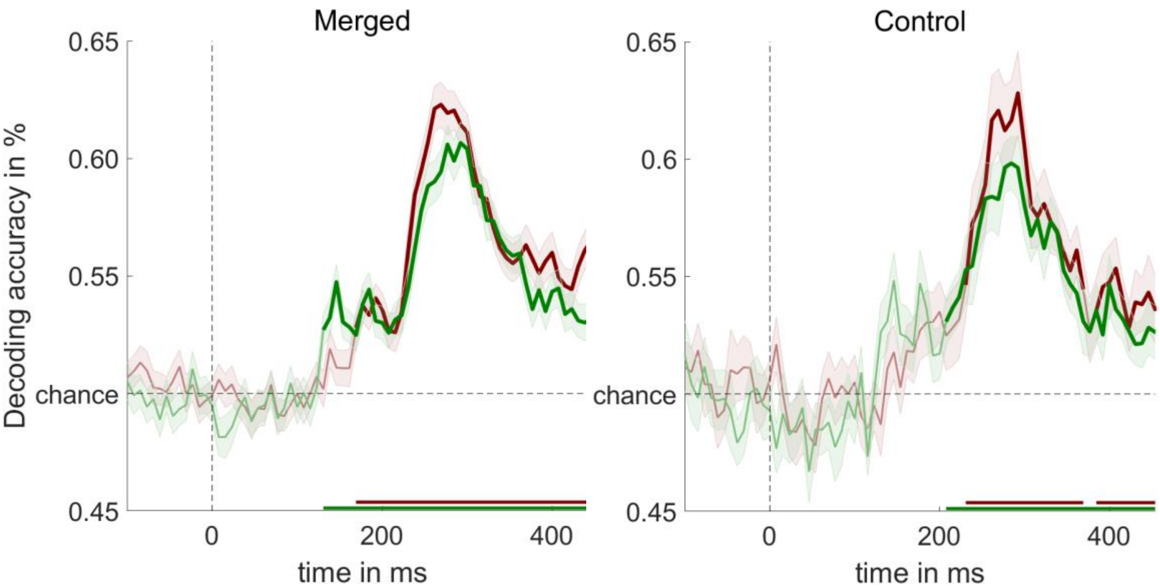
Multivariate pattern analysis "decoding" words from pure sound across conditions (left) and under different conditions of meditation (right).

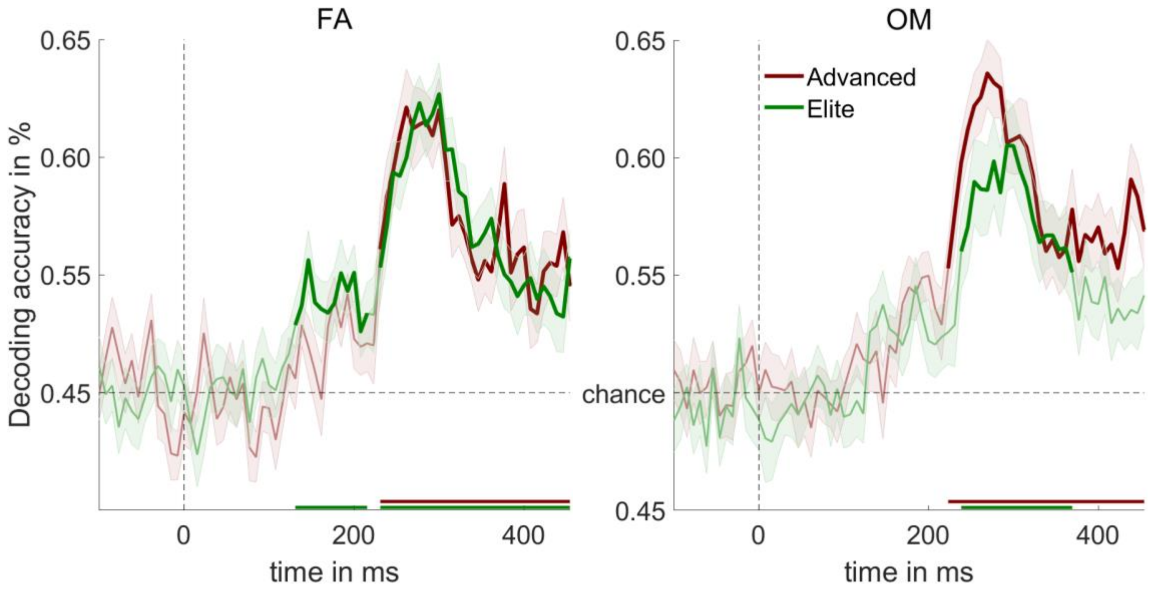


Note. Words and tones were distinguishable with decoding, in the pattern of brain activity, at approximately 300 msec after stimulus onset. Control (red line), FA (green line), and OM (blue line) condition. Differences between conditions were not significant when all conditions were merged together and for each condition.

Figure 2.

Multivariate pattern analysis "decoding" words from pure sounds separately for intermediate meditators and expert meditators.





Note. Words and tones were distinguishable with decoding at around 300 msec for both the advanced (red line) and elite (green line) practitioners for all analyses. On the concept level, decoding accuracy peaked at around 300 msec after stimulus onset.

PRELIMINARY CONCLUSION The above figures show evidence of successful decoding of linguistic concepts using EEG. We also see that there may be differences between experienced meditators and highly advanced practitioners in reducing conceptual processing, as we predicted, however, this is yet to be confirmed. We will finalize the analyses and plan to write our findings up in a publication to be submitted to a well-regarded scientific journal and will acknowledge BIAL funding in the publication.

OVERVIEW OF EXPERIMENT 2

AIMS and METHODS In Experiment 2, which was an extension to the studies proposed in our grant application but still addressed the same research question, we examined the neural responses of a highly advanced meditator (n=1) in a rare state known as "Nirodha-Samãpatti", or cessation. In this state, the practitioner goes "beyond" the state of pure consciousness into a state of suspended "hibernation" where there is no experience or awareness whatsoever. However, the state of pure consciousness is often an important intermediate step in the entrance and exit stages surrounding the state. We aimed to characterize this state at the neural level.

On Day 1 of testing, we compared neural (EEG) and physiological responses (including EOG, EMG, ECG, HRV, blood oxygen saturation, movement, respiration, respiratory sinus arrhythmia, and other measures of nervous system activity) during three states: focused attention meditation (FA), cessation meditation (CS), and resting state (RS). Each session consisted of 5 minutes without any task, an auditory oddball task, and a linguistic task (as in Experiment 1). We present an example of the auditory oddball results in Figure 3.
On Day 2 of testing, we took the same measures in three states with no task: Sleep (120 minutes), Cessation (90 minutes), and Rest (10 minutes). The intention of day 2 was to test whether there are spectral differences between the state of cessation and the sleep state. We present an example of the results of the spectral analysis comparing the nap and the cessation condition in Figure 4 (pg. 5). Data analysis is advancing, and we expect this to also result in a publication in a well-regarded scientific journal (with acknowledgement of BIAL funding).

PRELIMINARY RESULTS

Figure 3

ERP results for three states of meditation for deviant stimuli, standard stimuli, and difference (oddball) over midline frontal (top row) and parietal (bottom row) brain regions.

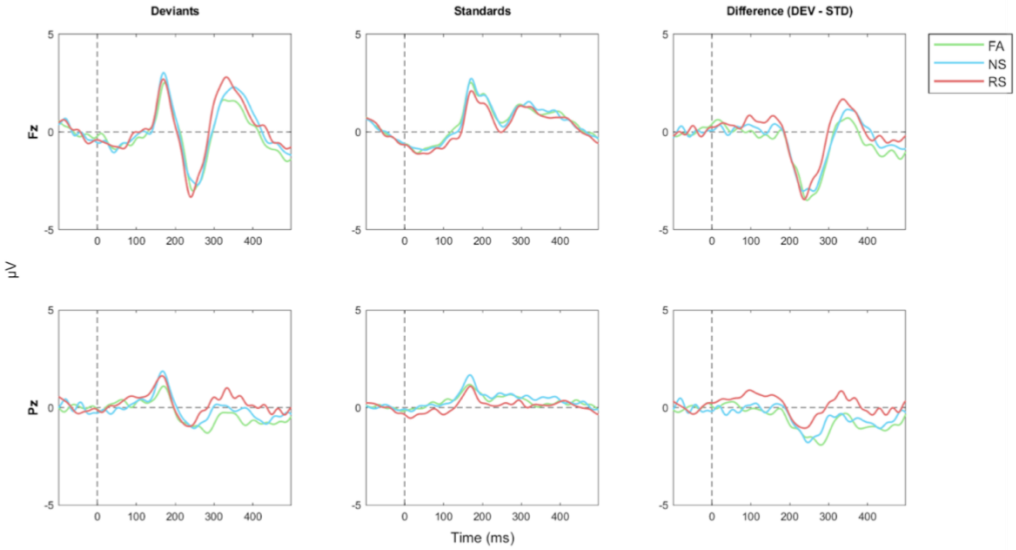
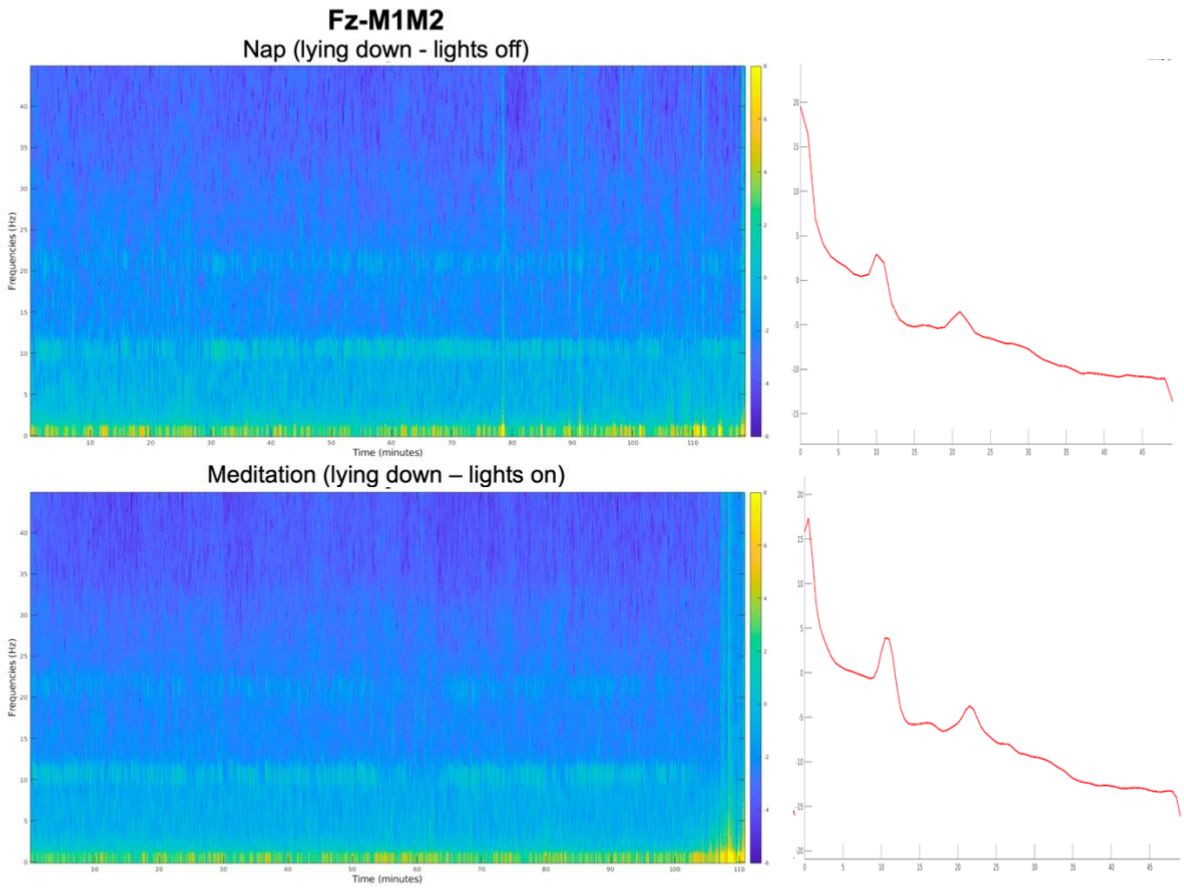


Figure 4

EEG spectral analyses for two states, meditation (i.e., cessation), and sleep (i.e., nap).

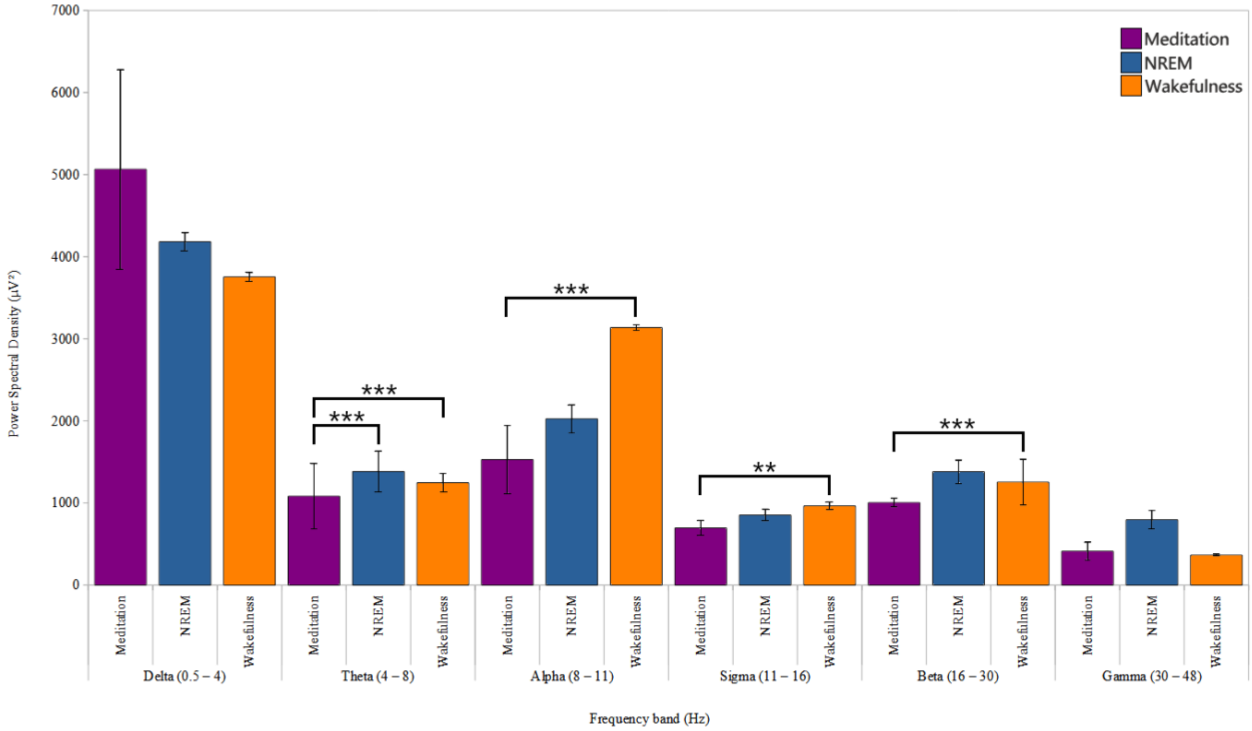


Although progress has been slower than we had hoped due to the new position of the lead postdoc on the project, several notable new findings have emerged in recent months. For example, we analysed data from Day 2 of testing using Phase Lag Index, a measure of neural synchronization over time. Previous work has shown that 'breakdowns' in neural synchronization occur during drug-induced states of non-consciousness (e.g., Ketamine, Blain-Moraes et al., 2014, and propofol, Kalionpää et al., 2020; Lee et al., 2013). We found that our subject also experienced a breakdown in neural synchronization, which was highest during the cessation state, followed by the nap, and then the control condition.

In addition to this, we conducted broad-band and narrow-band spectral analyses to investigate the power of all EEG frequency bands under the three conditions on Day 2. We found that across most frequency bands, the cessation condition showed a decrease in power compared to both the control and nap conditions, or a trend towards a decrease (see Figure 5 and 6).

Figure 5

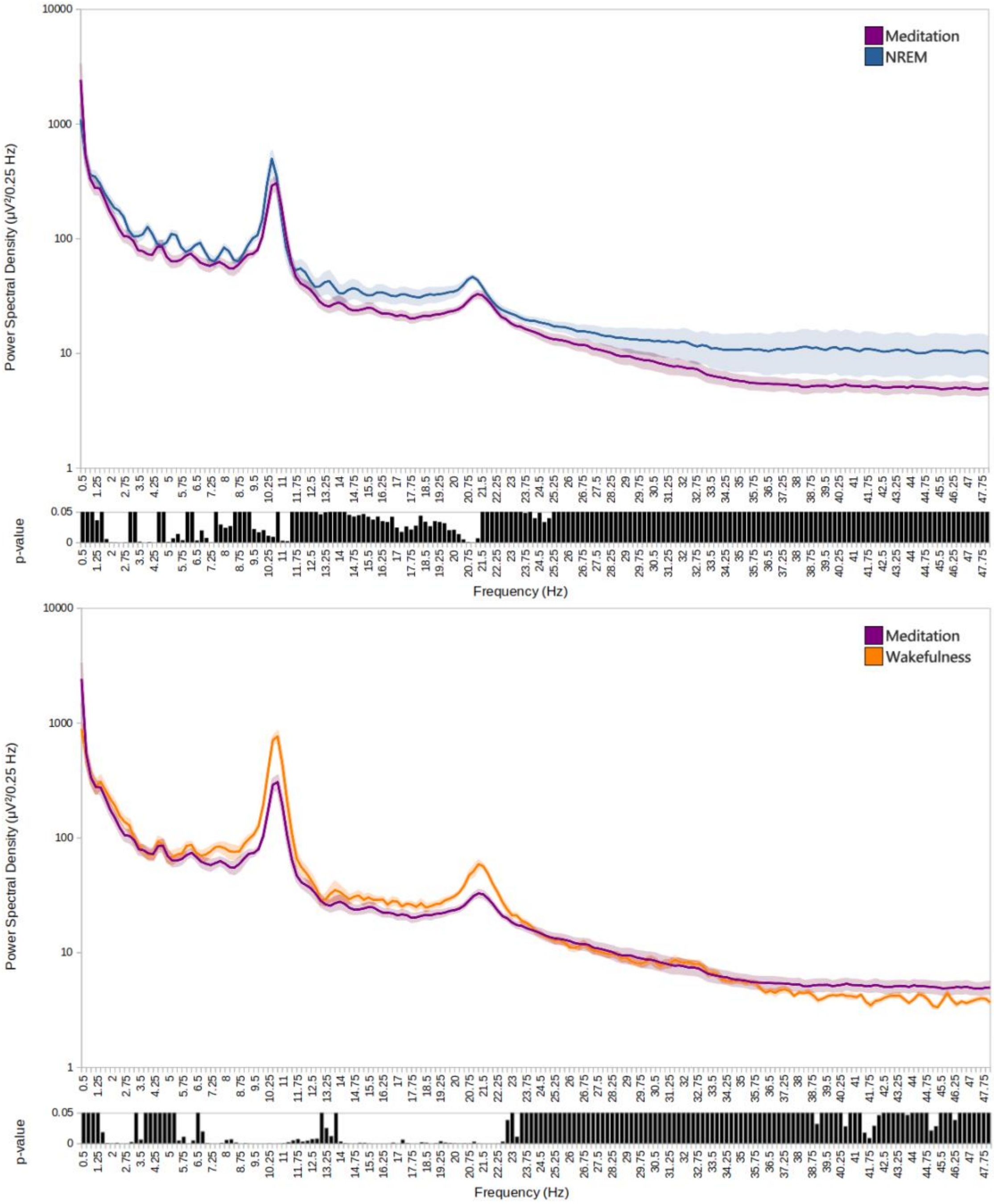
Absolute Band Power for Meditation, NREM and Wakefulness



Note. Absolute power spectral density (μV^2) is presented per frequency band for the meditation, NREM and wakefulness condition. The frequency bands used are Delta (0.5-4 Hz), Theta (4-8 Hz), Alpha (8-11 Hz), Sigma (11-16 Hz), Beta (16-30 Hz), and Gamma (30-48 Hz).

Figure 6

Absolute Bin Power and p-values for Meditation, NREM and Wakefulness



Note. Absolute power spectral density (µV[2]/0.25 Hz) is presented per 0.25 Hz frequency bin for the meditation, NREM and wakefulness condition. Paired-samples t-test p-values are shown comparing meditation to NREM, and meditation to wakefulness. No multiple comparison correction was applied to these p-values and they should therefore be considered with caution.

We also used a machine learning approach to classify the different states using an EEG-based Neural Network (known as *EEGNET*). The preliminary results using this approach are promising: The algorithm is capable of accurately classifying the three different states. These findings suggest that each state has a unique neural signal, or pattern of signals, which allows the algorithm to consistently predict what state the participant is in based on the EEG activity alone. Some of these results are presented in Figure 7 and 8. As can be seen, classification accuracy reaches well over 90% using 20 epochs of training data. From the loss and accuracy curves we can observe that beyond 50 epochs, the model starts to “unlearn” which is indicated by the increasing loss and decreasing accuracy trends. Thus, Epoch 50 is observed to be the ideal number of training iterations, and provides good evidence that the cessation state has a qualitatively different neural signature compared to the awake and nap condition.

Figure 7

Training loss and model accuracy of EEG for 50 epochs (left) and 100 epochs (right).

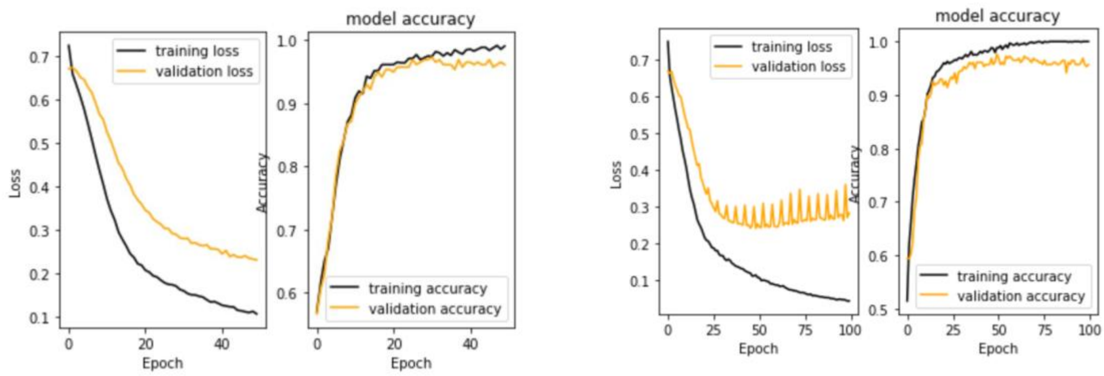
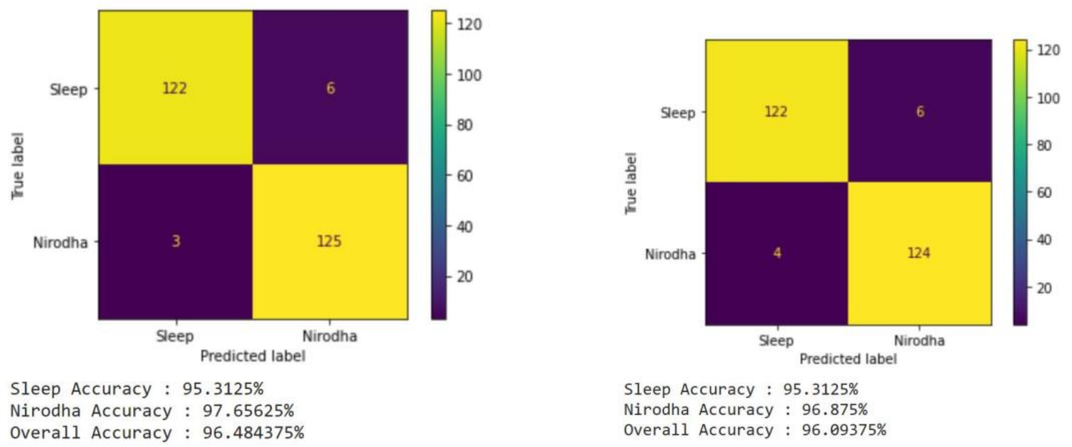


Figure 8



Confusing Matrixes for 50 epochs (left) and 100 epochs (right), showing the number correct and incorrect classifications.

PRELIMINARY CONCLUSIONS

These results shed first light on the neural correlates of one of the most advanced meditative states out there: 'cessation', which goes beyond even pure awareness. They suggest that while basic auditory processing is largely preserved during cessation (as in comatose patients), the state of cessation of consciousness can be neurally dissociated from other states of (altered) awareness, including focused attention meditation, normal rest, and the brain during a nap, and is associated with desynchronization of neural activity (in the alpha frequency range). We anticipate our study findings to have a large impact on the field, as they for the first time reveal what happens at the level of the brain during a *voluntarily* induced state of unconsciousness.