Mindfulness Meditation vs Meditative Sound Stimuli

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1. ABSTRACT

Mindfulness meditation is a technique commonly studied with EEG. In this work, we aim to compare the effects of mindfulness meditation with meditative sound stimuli and evaluate whether using sounds can induce meditative states. Pre-existing EEG recordings were used to make the comparison. The datasets were analyzed in the time-frequency domain, specifically in the alpha frequency bands, commonly increased during meditation. Meditative sound stimuli did not prove more effective than mindfulness meditation, and its success heavily depended on the type of sound stimuli used and the subject performing the test. However, performing a correlation between datasets showed that certain sound stimuli have effects close to those of meditative states induced by mindfulness meditation and can induce a relaxed state.

2. PROBLEM AND MOTIVATION

There has been evidence that mindfulness meditation can have a positive impact in a person's well-being and even in different psychological and physical conditions, such as depression, anxiety, cancer, and hypertension [1] [2].

Meditative Sound Stimuli, on the other hand, is a more recent technique with no definitive proof of positive results. As such, this work has the goal of analyzing both mindfulness meditation and meditative sound stimuli and verify if the latter could also offer such a positive effect on well-being.

The biggest focus of this work will be the alpha waves of the EEG recordings, which are a good indicator of a relaxation state [3]. The objective is to explore the variations of alpha power between three states: a baseline with closed eyes, a meditative state and during a sound stimulus. The correlation between the alpha band in each of these states will also be computed to try and understand if the sound stimulus does have a similar effect to mindful meditation.

3. BACKGROUND AND RELATED WORK

There has been extensive research on sound stimuli and stress/relaxation response.

Studies have shown sound stimuli can reduce the perception of pain [4] [5]. This evidence is consistent with the idea discussed in this work that sound could potentially be used as a relaxation mechanism, similar to meditation, as that would probably also ease the pain.

The biological pathways responsible for sound therapy relaxation have also been studied [6]. With some of the biological pathways identified, there are however still doubts about how exactly the sound affects the brain waves. With this in mind, this work proposes to study the relation between alpha waves and sound and how well sound can emulate the relaxation resulting from mindful meditation.

4. APPROACH AND UNIQUENESS

4.1 Material

This work was performed on two pre-existing datasets, the 'Mind' dataset referring to mindfulness meditation, and the 'Sound' dataset, referring to meditative sound stimuli. Both datasets measured the EEG in 19 channels as per international 10-20 system of electrode placement, in different conditions.

The Mind dataset contained two baseline periods recorded with eyes open (EO1 and EO2) and two baseline periods recorded with eyes closed (EC1 and EC2), each with 120 seconds, a mindfulness meditation period of focused attention with 35 minutes (AF) and a mindfulness meditation period of open monitoring with 10 minutes (MA).

The Sound dataset was obtained for six aural stimuli trials («Shaman dream», «Mind awake & body asleep», «Calm», «Deep chillout», «Mantra» and «Relaxation»), and five different subjects (QSAL_6152, MCCN_1778, SIUY_9971, FDWF_6874 and WSAD_3215). The baseline data, 'bsdata', was obtained while the subjects had their eyes closed, before the application of the stimuli, while the stimuli data, 'sdata', was obtained while the subjects listened to the meditative stimuli, for 10 seconds.

4.2 Methods

For the Mind dataset, the baseline, AF and MA signals were fully plotted. Ten-second epochs with no visible artifacts were selected for the study: one epoch was chosen from each baseline signal, and three epochs were chosen for the AF and MA signals, corresponding to the beginning, middle, and end of the signal. The fast Fourier Transform (FFT) of all the selected epochs was plotted to verify the presence of noise or artifacts. A high-pass filter with cut-off frequency 0.5 Hz was applied to each signal to eliminate possible low frequency interferences caused by sweat, breathing or eye blinks.

Each signal from the Sound dataset was filtered with a bandpass filter with cut-off frequencies of 0.5 Hz and 40 Hz, to remove the baseline and respiratory artifacts, and the powerline interference. Moreover, some channels were also decomposed with Empirical Mode Decomposition (EMD) and reconstructed by omitting some of the lower-frequency intrinsic mode functions (IMFs), in order to eliminate trendlines and electrooculogram (EOG) artifacts. Independent Component Analysis (ICA) was also performed in an attempt to remove artifacts, but it was not used in the final datasets due to the poor quality of the reconstructions.

After preprocessing both datasets, each meditation signal and their FFT was plotted and compared with its baseline. All channels were separated into their EEG bands by application of bandpass filters (delta: < 3Hz, theta: 3-7.5 Hz; lower alpha: 7.5-9.5 Hz; upper alpha: 9.5-12.5 Hz; beta: 12.5-30 Hz; gamma plus noise: > 30 Hz), which were plotted separately. The time-frequency plots of all channels were built with Matlab's default windowing function, with length equal to 256 and 0% overlap. Furthermore, EEG topographic maps were constructed for both datasets to evaluate brain activity before and during meditation. Finally, the alpha power of each signal was calculated to identify successful meditative states.

The correlation between the alpha waves of the meditation and sound datasets was calculated to assess whether meditative states induced by sound were more similar to the baseline or to mindful meditation.

4.3 Proposed solution

Mind and Sound datasets were used to study a possible correlation between these two types of relaxation techniques. Both datasets had to be processed before analysis. Then, each set was analysed independently using FFT and plot comparisons between different signals. All channels were separated into EEG bands and plotted as well. Time-frequency and topographic plots were also performed.

The main point of analysis was the alpha power of each signal. This measurement allowed for comparison of different signals within the same data base and between signals from the two databases, allowing us to identify successful meditative states.

The correlation between the meditation and sound datasets was also calculated. It served as a confirmation of the success/unsuccess of each sound in the relaxation of each person.

With this, it seems alpha power is an effective way of studying sound stimuli effect on relaxation.

5. RESULTS AND CONTRIBUTIONS

Ten-second epochs were chosen manually for each signal in the Mind dataset (Figure 1).

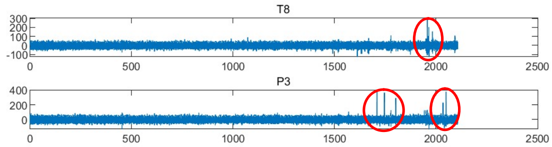

Figure 1. Plot of the full AF signal for the T8 and P3 bands and areas which were avoided when selecting the epochs to sample (marked by the red circles).

When comparing the closed eyes baseline with the open eyes baseline, the alpha signals were quite easily distinguishable, both in the time plot and in the spectrum (Figure 2). In the time plot, there are very clear higher amplitude and lower frequency oscillations which correspond to the alpha waves. In the spectrum, these are reflected as a large peak around 10 Hz, in accordance with the usual frequency band for alpha waves of 7.5 to 12.5 Hz. The same type of behavior was observed on all channels, with varying intensities of the alpha contributions.

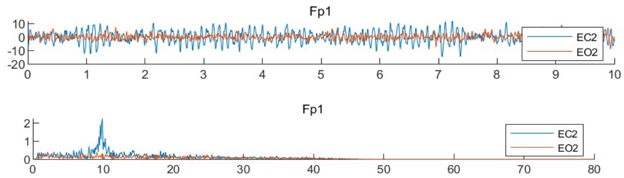

Figure 2. Plot of 10 seconds of channel Fp1 from the EC2 and EO2 signals (top) and the corresponding spectrum (bottom).

To assess the effect of meditation on the alpha waves, the meditative state was also compared with the closed eyes baseline. This baseline was chosen instead of the open eyes one since the meditation study was also performed with closed eyes. Alpha waves can now be seen on both signals (Figure 3). The intensity in the spectrum seems similar between the meditative state and the baseline, which goes against the expected alpha wave increase in meditation [7].

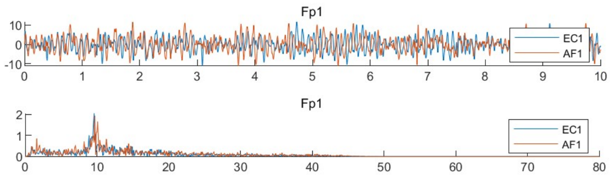

Figure 3. Plot of 10 seconds of channel Fp1 from the EC1 and AF1 signals (top) and the corresponding spectrum (bottom).

Table 1. Relative Alpha Power for each EEG channel of each Mind signal.

	Fp1	Fp2	F7	F3	Fz	F4	F8	T7	Cz	T8	P7	P3	Pz	P4	P8	O1	O2
EC1	0,69	0,30	0,31	0,44	0,46	0,37	0,57	0,61	0,56	0,60	0,60	0,61	0,58	0,59	0,55	0,63	0,60
EC2	0,73	0,35	0,35	0,53	0,54	0,51	0,62	0,71	0,58	0,70	0,70	0,71	0,68	0,68	0,63	0,54	0,65
EO1	0,26	0,15	0,11	0,28	0,31	0,29	0,40	0,27	0,29	0,17	0,22	0,24	0,25	0,33	0,34	0,29	0,26
EO2	0,26	0,16	0,16	0,33	0,42	0,30	0,38	0,34	0,30	0,23	0,26	0,31	0,25	0,25	0,32	0,19	0,23
MA1	0,64	0,34	0,24	0,53	0,43	0,53	0,55	0,70	0,48	0,61	0,62	0,55	0,63	0,50	0,67	0,50	0,56
MA2	0,70	0,31	0,25	0,57	0,44	0,44	0,51	0,68	0,52	0,59	0,62	0,62	0,60	0,53	0,59	0,60	0,59
MA3	0,68	0,32	0,25	0,49	0,42	0,44	0,48	0,63	0,60	0,58	0,62	0,58	0,57	0,55	0,49	0,50	0,62
AF1	0,64	0,28	0,27	0,43	0,42	0,36	0,48	0,65	0,54	0,58	0,60	0,61	0,61	0,59	0,60	0,58	0,58
AF2	0,54	0,31	0,35	0,53	0,45	0,51	0,46	0,64	0,57	0,50	0,50	0,49	0,49	0,50	0,57	0,47	0,48
AF3	0,66	0,34	0,39	0,55	0,51	0,59	0,55	0,72	0,63	0,61	0,60	0,58	0,56	0,58	0,59	0,56	0,58

Table 2. Relative Alpha Power for each EEG channel of each Mind signal, setting the alpha band limits to 8.6-11.9 Hz.

	Fp1	Fp2	F7	F3	Fz	F4	F8	T7	Cz	T8	P7	P3	Pz	P4	P8	O1	O2
EC1	0,60	0,25	0,25	0,36	0,32	0,27	0,40	0,50	0,45	0,53	0,52	0,47	0,53	0,53	0,46	0,42	0,46
EC2	0,52	0,28	0,32	0,43	0,35	0,41	0,34	0,55	0,39	0,51	0,46	0,50	0,64	0,61	0,56	0,46	0,51
EO1	0,19	0,11	0,07	0,23	0,26	0,23	0,33	0,20	0,20	0,13	0,16	0,18	0,18	0,25	0,26	0,21	0,19
EO2	0,20	0,13	0,10	0,29	0,38	0,25	0,34	0,27	0,25	0,18	0,21	0,24	0,21	0,21	0,27	0,15	0,18
MA1	0,61	0,31	0,21	0,50	0,39	0,50	0,51	0,67	0,42	0,57	0,59	0,52	0,59	0,44	0,63	0,46	0,52
MA2	0,65	0,27	0,21	0,53	0,35	0,40	0,47	0,63	0,43	0,56	0,59	0,57	0,57	0,46	0,55	0,55	0,52
MA3	0,64	0,27	0,21	0,43	0,33	0,39	0,41	0,59	0,50	0,53	0,58	0,53	0,53	0,45	0,44	0,45	0,55
AF1	0,61	0,24	0,23	0,37	0,36	0,27	0,39	0,58	0,50	0,55	0,57	0,57	0,58	0,55	0,54	0,52	0,55
AF2	0,50	0,27	0,29	0,48	0,37	0,44	0,38	0,59	0,47	0,46	0,46	0,45	0,45	0,43	0,52	0,43	0,42
AF3	0,61	0,29	0,33	0,49	0,38	0,53	0,45	0,67	0,53	0,55	0,55	0,52	0,52	0,50	0,53	0,50	0,51

To verify whether there was an increase which might not be visible through the plots, the alpha power of the signals was calculated (Table 1).

Measurements for the C3/C4 channels were not included in the table as they typically correspond to the Mu Rhythm, an Alpha-like rhythm that relates to motor system activation.

The open eyes baseline has a smaller alpha power than both the closed eyes baseline and the meditation. However, the meditation periods do not exhibit higher alpha power than the closed eyes baseline; in fact, the alpha power seems to be slightly smaller in the meditation data.

One of the possible reasons for this finding may be the error in the definition of the alpha band. The band limits were defined as 7.5 and 12.5 Hz, but these limits can be flexible. One alternative to find the alpha band limits is to calculate the interception of the spectrum of the open and closed eyes baselines for the Cz channel [8].

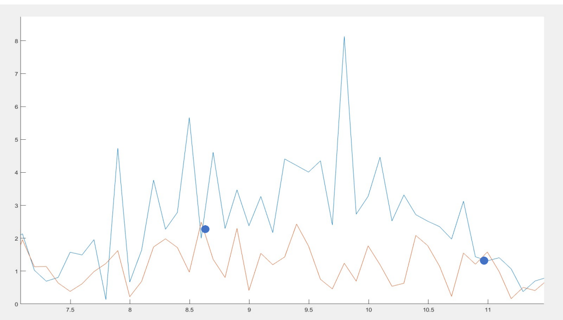

Figure 4. Spectrum of the EO2 (orange) and EC2 (blue) baseline signals. The blue dots correspond to the limits of the alpha band.

The lower limit for the alpha band should then be 8.6 Hz and the upper limit 11.9 Hz. The alpha power was recalculated with these limits (Table 2). The meditation alpha power values became slightly larger than the closed eyes meditation when using these new band limits. However, the difference is not as accentuated as expected. One can hypothesize that this could be caused by the volunteer's experience with meditation. If this person is used to meditating, it could be possible their alpha power is higher even when not meditating as they are naturally more relaxed.

For the Sound dataset, each signal and corresponding FFT was plotted to evaluate their quality. Most FFTs contained a peak at 50 Hz corresponding to the power line, which was filtered with a bandpass filter (Figure 5). The quality of the signals for the subject MCCN_1778 was significantly worse than the others, possibly due to ocular movements.

The topographic maps showed a slight decrease in brain activation for most subjects during the application of the stimuli (Figure 6).

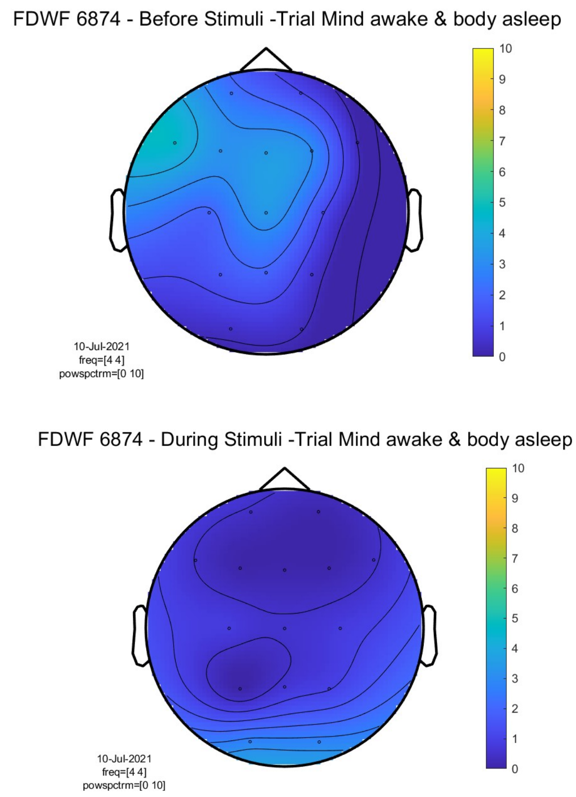

Figure 6. Topographic map for one of the signals of the Sound Dataset before application of the stimuli (top) and during the stimuli (bottom).

Figure 5. FFT of one of the signals from the Sound dataset (top) and FFT of the filtered corresponding signal (bottom).

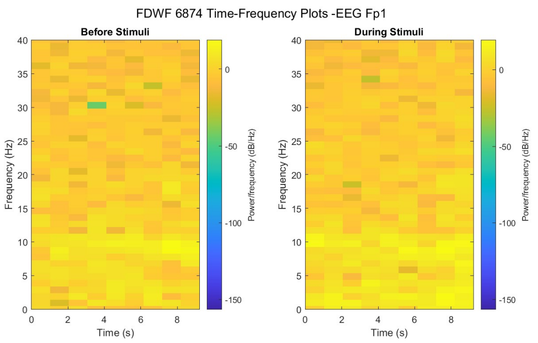

Figure 7. Time-frequency plot for Channel Fp1 of one of the Sound signals before and during sound stimuli.

The time-frequency plots for each subject and each trial did not differ significantly with time and between the periods 'before stimuli' and 'stimuli' (Figure 7). Thus, the state of the subjects was consistent across the 10-second samples studied.

Table 3. Qualitative analysis of the alpha power of each EEG channel for the Sound dataset.

	Calm	Deep Chillout	Mantra	Mind awake & Body Asleep	Relaxation	Shaman Dream
FDWF 6874	Increase In occipital and parietal areas; Decrease elsewhere	Increase fp1 fp2	Increase in frontal and central areas	No change	Overall increase in frontal area	Decrease
MCCN 1778	No change	Increase in frontal areas	No change	No change	Decrease in frontal; increase elsewhere	Increase
QSAL 6152	Decrease	No change	No change	Decrease in temporal and occipital areas	Decrease	Increase in frontal and central areas
SIUY 9971	Decrease in frontal area	Decrease	No change	No change	No change	Increase
WSAD 3215	Decrease	Increase in parietal and occipital areas; decrease elsewhere	Increase in parietal and occipital areas;	No change	No change	Decrease in parietal area

The relative alpha power was calculated for all subjects and all Sound trials. The analysis of the results led to construction of Table 3. During meditation, a shift to the higher power in alpha frequencies is expected to happen, particularly in the frontal area. Thus, the success of meditation across subjects differed greatly depending on the sound stimulus played. Subject FDWF_6874 entered a successful meditative state with «Deep Chillout», «Mantra» and «Relaxation»; subject MCCN_1778 had successful meditation with «Deep Chillout» and «Shaman Dream»; subject QSAL_6152, with only «Shaman Dream»; the only musician in the group, SIUY_9971, entered a meditative state solely with «Shaman Dream»; and subject WSAD_3215 was not successful with any of the stimuli.

Different people had different reactions in terms of alpha power to different sounds. To further understand these reactions, the correlation between the alpha waves of meditation and sound signals was calculated. In Table 4, some examples are shown.

The correlation findings along with the alpha powers calculated seem to indicate that sound can contribute to a more relaxed state, similar to that of relaxation, causing the increase of alpha waves, which explains why the correlation with the meditation periods increases as well, since meditation periods have a very significant contribution from alpha waves. However, sounds can also affect relaxation in a negative way, case in which both the alpha power and the correlation with the meditation signals both decrease.

Table 4. Correlation between datasets.

	Alpha power	Correlations before stimulus	Correlations after stimulus	Effect seen during the stimulus
FDWF Calm sound	Increase in Occipital areas.	Calculated for O1: BS_EC1=0.2041 BS_AF1=0.0610 BS_MA1=0.0749	Calculated for O1: S_EC1= 0.0284 S_AF1= 0.1663 S_MA1= 0.1114	The correlation with the baseline decreased and the correlation with the meditation periods increased
MCCN Chillout sound	Increase in frontal areas.	Calculated for fp2: BS_EC1= 0.0525 BS_AF1=0.0053 BS_MA1=0.0076	Calculated for fp2: S_EC1= 0.0253 S_AF1= 0.0407 S_MA1= 0.0363	The correlation with the baseline decreased and the correlation with the meditation periods increased
QSAL Mantra sound	No change	Calculated for P3: BS_EC1= 0.0674 BS_AF1=0.1285 BS_MA1=0.1167	Calculated for P3: S_EC1= 0.1380 S_AF1= 0.0829 S_MA1= 0.1122	The correlation with the baseline increased, whilst the correlations with the meditation periods both decreased.

6. DISCUSSIONS AND CONCLUSIONS

The first interesting observation was how easily the difference in alpha waves was observed in the signal and its spectrum between the open eyes and closed eyes baselines, but not between the closed eyes and the meditation. One can speculate that this difficulty in visualizing the difference between closed eyes and meditation could be related with the experience of the person meditating as a person with a lot of experience and who has meditated recently might naturally be in a very relaxed state with a high alpha component, even when not meditating.

It was also possible to observe the difference in the alpha power values obtained when using the theoretical alpha band limits and when calculating the specific limits for the subject. With this conclusion, it would be recommended that in future studies, the limits are always calculated adjusted to the specific individual as to avoid possible errors.

In the sound data, it was discovered that different people had clearly different reactions to the same stimuli. This was seen through the alpha power corresponding to each stimulus. If the state of relaxation is indeed related with the alpha power, one could possibly modulate the state of relaxation of individuals through the use of different sounds. Overall, results are inconclusive when it comes to evaluate which sound stimuli works better for meditation. The success of each trial varied greatly between each subject when analyzing the alpha power of each EEG channel. The sound stimuli «Shaman Dream» was the most successful trial – it stimulated three out of five participants in maintaining a meditative state. Further conclusions about stimuli can only be made with a larger number of participants in the study.

Overall, it appears that sound may have a similar effect to mindfulness meditation on individuals, however it does not seem possible to predict what the relation between each sound and the individual response will be without measuring it, as each individual had very different responses.

7. REFERENCES

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