



EEG Analysis on Brain.fm (Sleep)

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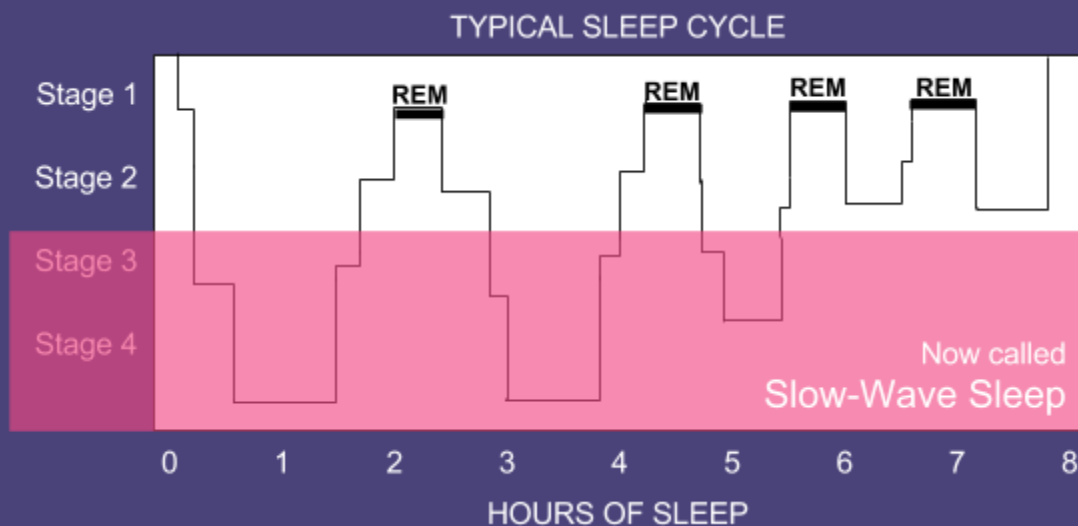
Dr. Giovanni Santostasi
Neuroscientist at Northwestern University,
Feinberg School of Medicine

Sleep Report Summary, by Adam Hewett

Slow-Wave Sleep: What Is it?

All of us can relate to feeling sleepy, foggy-headed and hungry after a night of poor sleep.

The answer to why we feel this way can be found in what is called Slow-Wave Sleep.



You might remember seeing something like the above figure in school. Since then, sleep stages 3 and 4 have been combined into a single third stage commonly called Slow-Wave Sleep (SWS).

SWS is arguably the most important stage of sleep, where your daily store of new memories are "encoded" into long term memory. A lot of people think memories are encoded in REM sleep and that's true, but only emotional memories. Declarative memories - facts, lists, dates, events - are almost exclusively encoded in the SWS stage¹. SWS is also where Alzheimer's-related peptides such as beta-amyloids², and drowsiness-inducing adenosine, are flushed from the brain, and that's very important because if adenosine isn't flushed from the system you'll wake up feeling groggy³. Finally, a deficit in SWS is linked to weight gain⁴.

¹ Walker, MP. "The Role of Slow Wave Sleep in Memory Processing." 2009. [NIH Link](#)

² Cedernaes, J. "Candidate mechanisms underlying the association between sleep ..." 2016. [NIH Link](#)

³ Bjorness, TE. "Adenosine and Sleep - NCBI - National Institutes of Health." 2009. [NIH Link](#)

⁴ Mokhlesi, B. "Predictors of slow-wave sleep in a clinic-based sample. - NCBI." 2012. [NIH Link](#)

Slow-wave sleep is the hardest stage to reach. Light naps won't take you there, and tossing and turning all night will put this stage at a minimum.

Sleep: The perfect time for acoustic intervention

While we sleep, the brain has one primary mechanism that it uses to determine if there is danger in the area: the ears.

The brain is constantly and intently listening to the sleeping environment, monitoring for the sounds of approaching predators even during the deepest stage of sleep. This makes audio a particularly powerful medium through which we can affect the sleeping brain.

Dr. Santostasi specializes in acoustic intervention during sleep, and the sleep lab in which he works at Northwestern spends considerable resources investigating it⁵.

How Does It Work?

- All sound is modulated at low frequencies to directly enhance SWS. For more information, see our white paper.
- "3D sound" is used to mimic the slow swinging of a hammock or rocking of a cradle. Using only regular headphones, sound appears to be moving gently around the head. We are able to position the perception of sound just far enough away that it will not awaken the user, but will also stimulate SWS activity.
- To aid in sleep-onset, the sounds used are gently engaging - unlike white noise. This assists in creating a dissociation from the worries of the day, and helps reduce mental chatter common to insomniacs.
- The sound is consistent and constant for the entire night. Consistency and repetitiveness enhances sleep-onset and also prevents startling, unwelcome sounds as in many nature recordings.

⁵ Ong, JL. "Effects of phase-locked acoustic stimulation during a nap on EEG ..." 2016. [NIH Link](#)

How To Interpret The Figures

SO - Slow Oscillations. Dr. Santostasi calls brainwave patterns within the very low frequency range of slow-wave sleep. In this context, an increase in SO is an increase in slow-wave sleep, and is the ultimate goal of the Brain.fm sleep sessions.

Delta - Delta is the name of a brainwave pattern that is faster than SO, but still very slow and associated with deep sleep.

Alpha and Theta - Alpha and Theta are faster brainwaves that you shouldn't see much of in a healthy sleep profile. We would want to see less of these two and more of SO and Delta.

Beta - Beta is the fastest brainwave pattern mentioned here, and is usually only associated with being awake. However, it is also associated with healthy REM sleep⁶. An increase in Beta is not something we specifically target, but as Dr. Santostasi points out, it is a sign that the Brain.fm sleep session is not only increasing SO but is also allowing for a healthier overall sleep pattern.

Spindles - Spindles are a feature of Slow-Wave Sleep associated with a new memory being "encoded" into long term memory⁷.

Summary Of The Findings

- 1) **24-29% increase in Slow-Wave Sleep activity.** To put this into context, Dr. Santostasi notes that if you were to pull an all-nighter tonight, the next night you would only experience a 10% increase in SWS to compensate. These numbers are so large that Dr. Santostasi was at first convinced that they must be a fluke. Further testing revealed that the increase is actually fairly consistent from person to person and even outside of a sleep lab in different sleeping situations (a mobile sleep monitor was used).
- 2) **Greater Spindle activity.** An increase in SWS is generally associated with improved memory. To test this hypothesis, Dr. Santostasi also analyzed what are called Spindles. Spindles usually occur when the brain is encoding new memories. And indeed these did go up as well and were highly correlated to the SWS activity being induced. This can be seen on the second to last page of this report.

⁶ Ferri, R. "Relationship between Delta, Sigma, Beta, and Gamma EEG bands at ..." 2001. [NIH Link](#)

⁷ Mölle, M. "Slow oscillations orchestrating fast oscillations and memory ... - NCBI." 2011. [NIH Link](#)

What's Next?

This report is part of a greater body of work pending publication for peer review. We are working hard on publishing and expanding on these exciting findings.

EEG Analysis On Brain.fm Sleep, by Dr. Giovanni Santostasi

Introduction

Brain.fm developed a sleep session to induce sleep and keep users in deep slow wave sleep (Sleep Session).

The main component of the sleep session is to modulate lower frequencies of a soothing musical piece.

The modulation starts at very low frequencies and ramps up to 0.5 Hz in 1 hour.

Also the sound is manipulated in such a way to appear to arrive from different directions.

The trace of the first few seconds of music is shown in Figure 1:

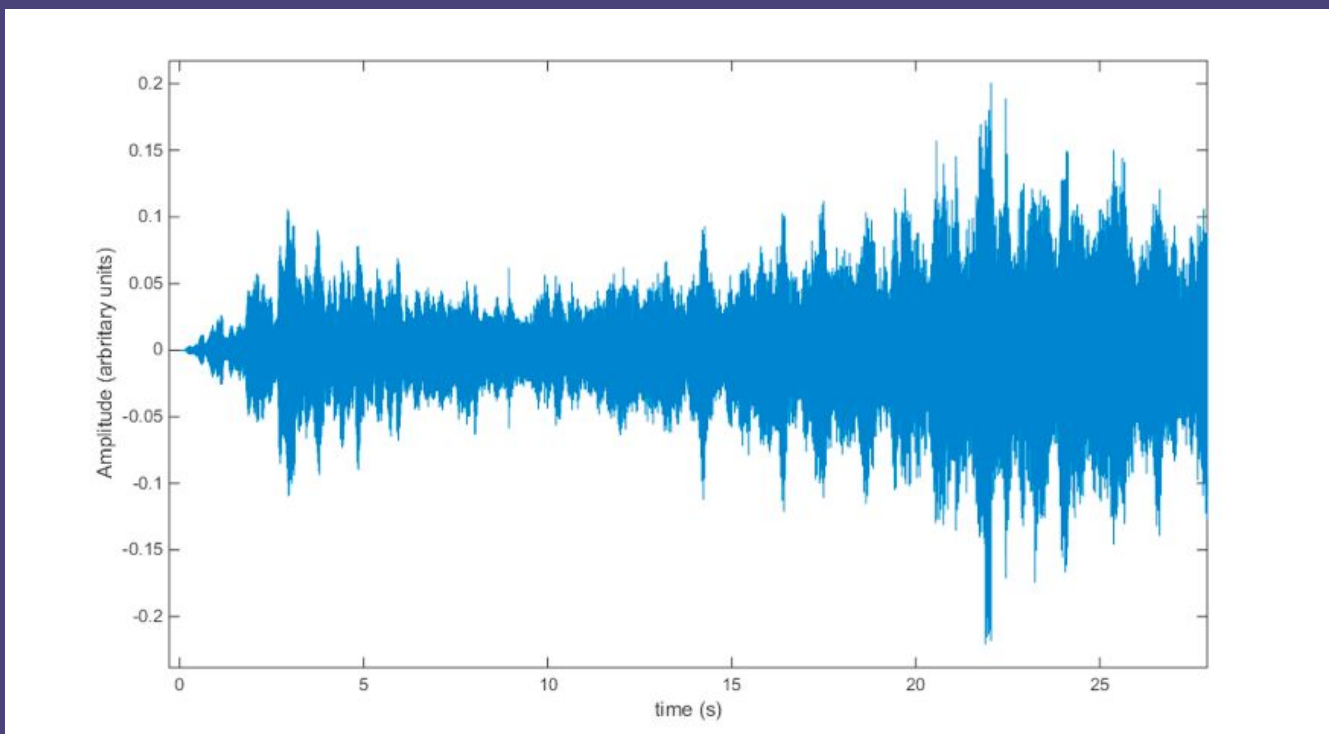


Figure 1: The amplitude trace of the sleep sound session

A power spectrum of the sound is shown in Figure 2:

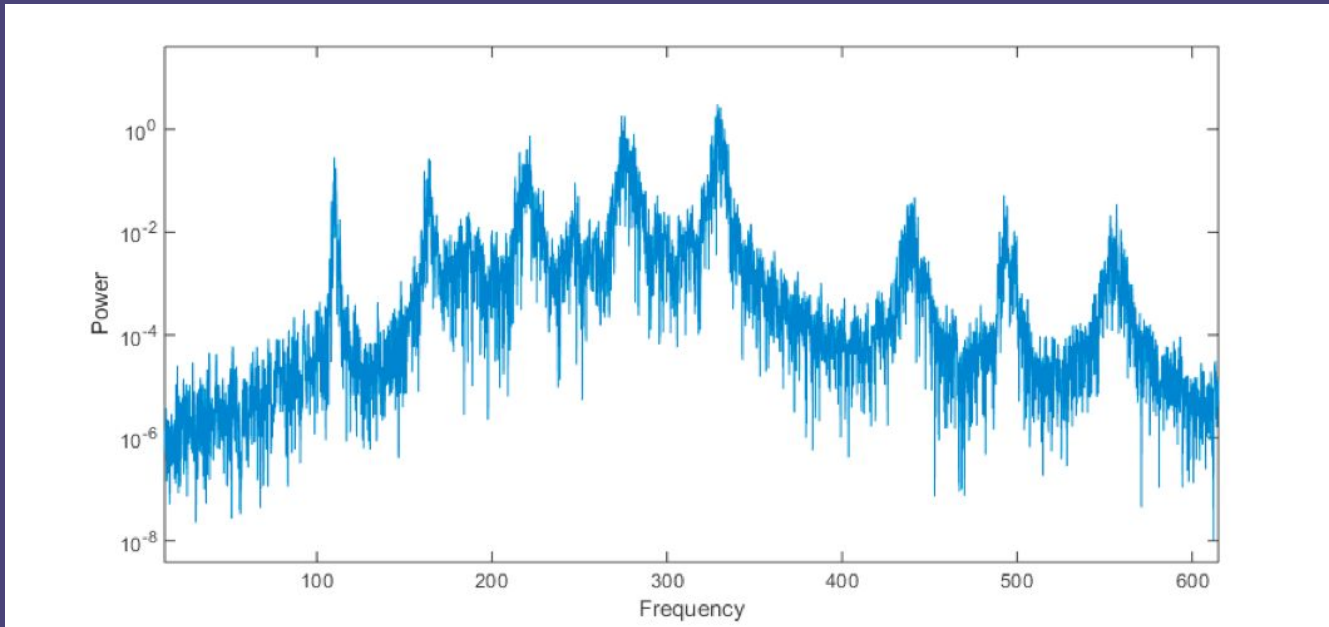


Figure 2: Spectrum of the sleep session music showing the main dominant peaks.

The music presents complex spectrum with dominant peaks that are separated by 54 Hz indicating a series of resonant modes of a main basis frequency of 110 Hz.

What seems to stimulate the slow oscillations of sleep are the complex modulation due to the modulation ramping and the simulation of the rotation of the source around the listener.

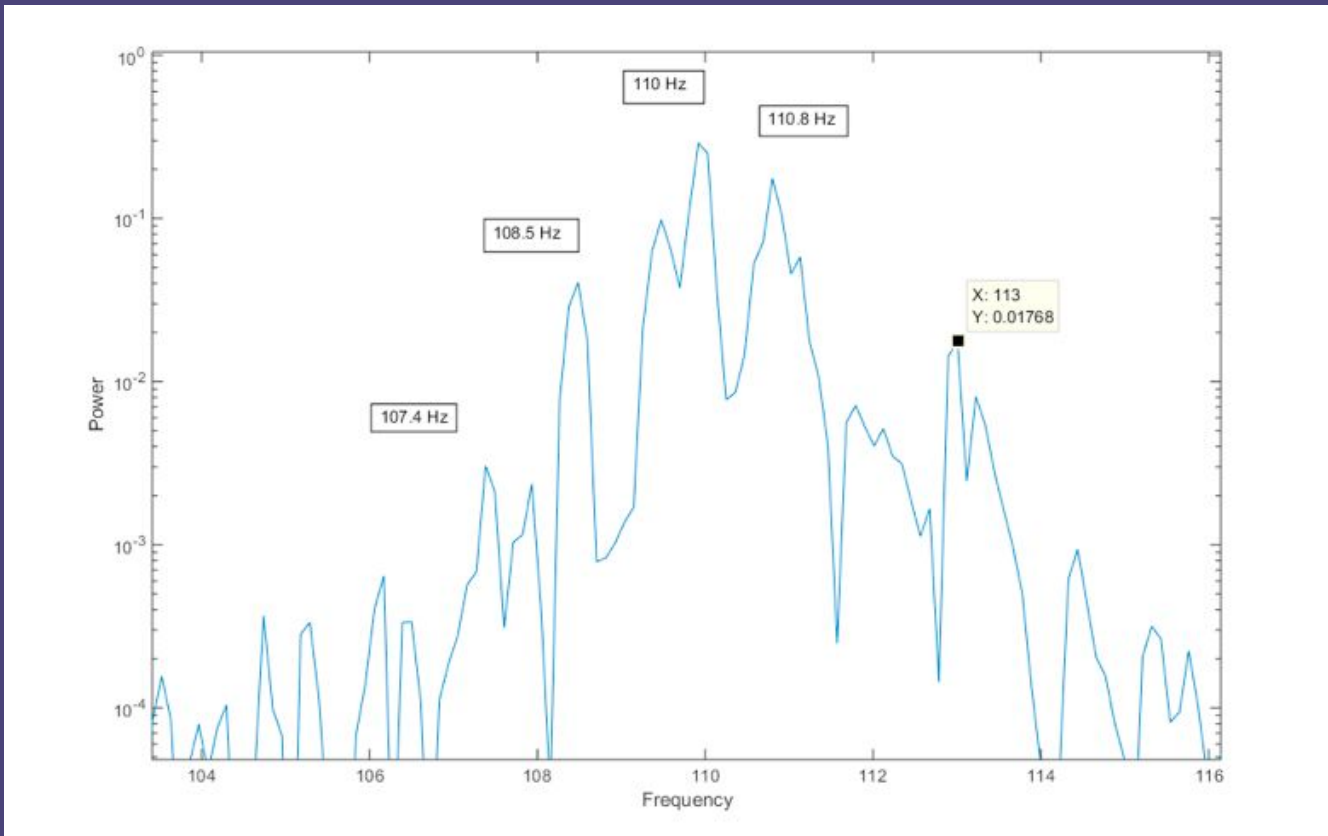


Figure 3: Zoom in of channel 1 for the music of the Sleep session.

Around the main peaks it is possible to observe many sidebands that indicate modulation at 0.5, 0.8 and 1.1 Hz all in the range of slow wave sleep dominant frequencies.

Data Analysis

We recorded several nights of sleep EEG using Advanced Brain Monitoring SleepProfiler and Brain Products V-Amp on 3 subjects, varying in age from 30 to 48 years old (2 male, 1female). We recorded 3 nights of stimulation and 3 nights of baseline. The recording are from the frontal area channel Fpz. All the 3 subjects showed an increase in delta power during the stimulation nights relative to baseline.

Subject 1

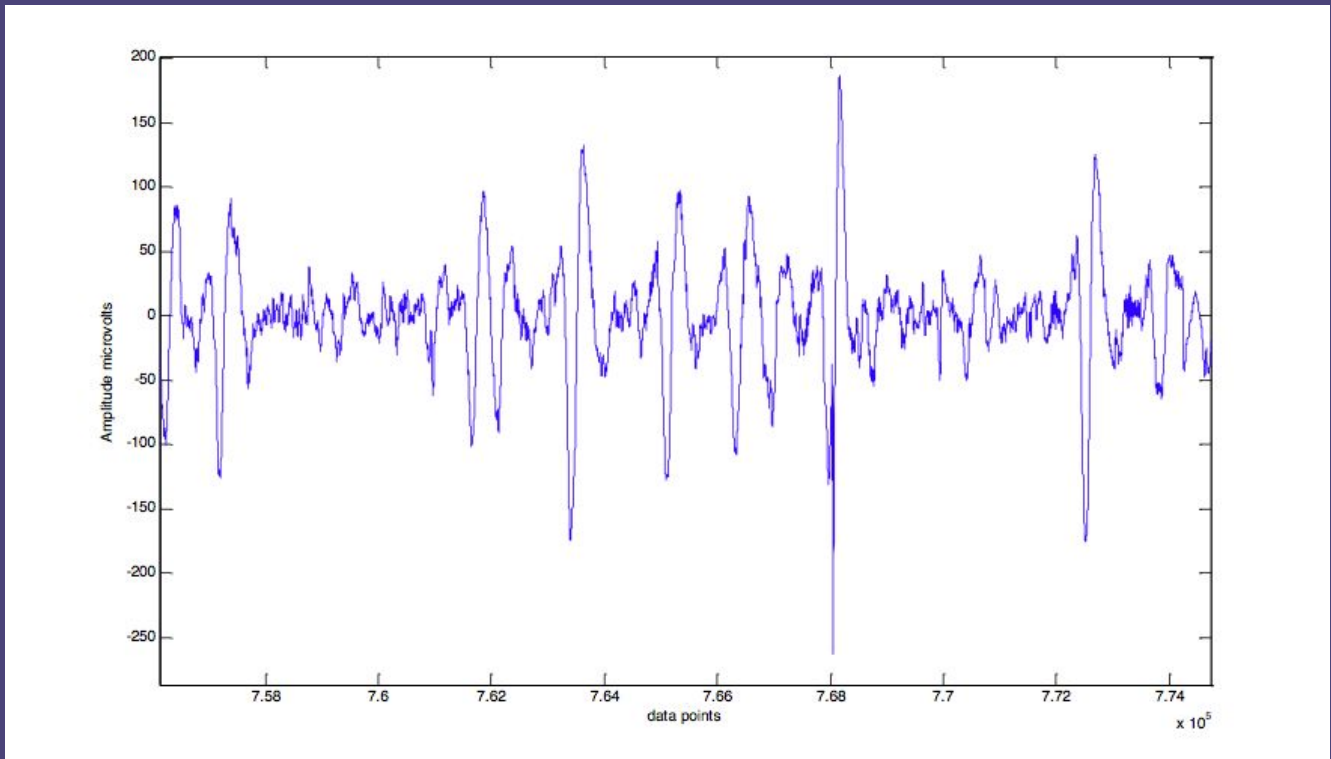


Figure 4: Slow wave bursts for subject 1 during night 06 (stimulation night).

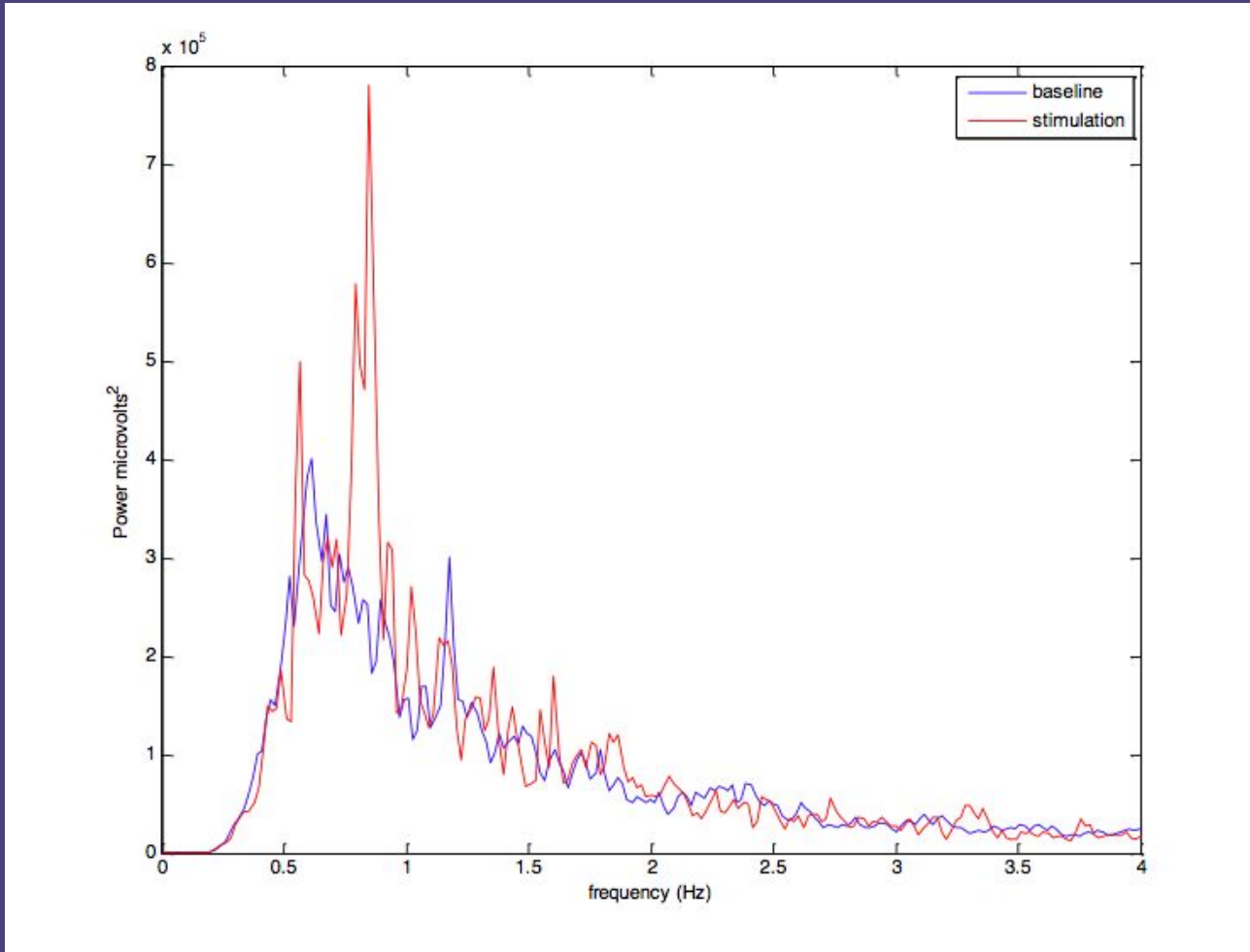


Figure 5: Spectrum comparing averaged stimulation nights for subject 1 (in red) versus baseline nights (in blue).

In Figure 5 we can observe a comparison of the average EEG spectrum during stimulation nights in red and the spectrum during baseline nights. A clear difference in power is observable in the delta range. The statistics are that the increase in power for the Slow Oscillation range (below 1 Hz) is 24 %, the increase in the delta range (0.5-4 Hz) is 11.8 %. There was a decrease in Theta (4-8 Hz) of about 14.7 % and a decrease in alpha (8-15 Hz) of 17 percent a slight increase of beta (16-30 Hz) of 8 % but non significant statistically. The large increase in delta and the small change in beta and the decrease in alpha is encouraging because it may indicate a more stable and deep sleep.

SO (< 1 Hz)	Delta	Alpha	Theta	Beta
24%	11.8 %	-17 %	-14.7 %	8 %

Table 1: statistics for stimulation/baseline for subject 1.

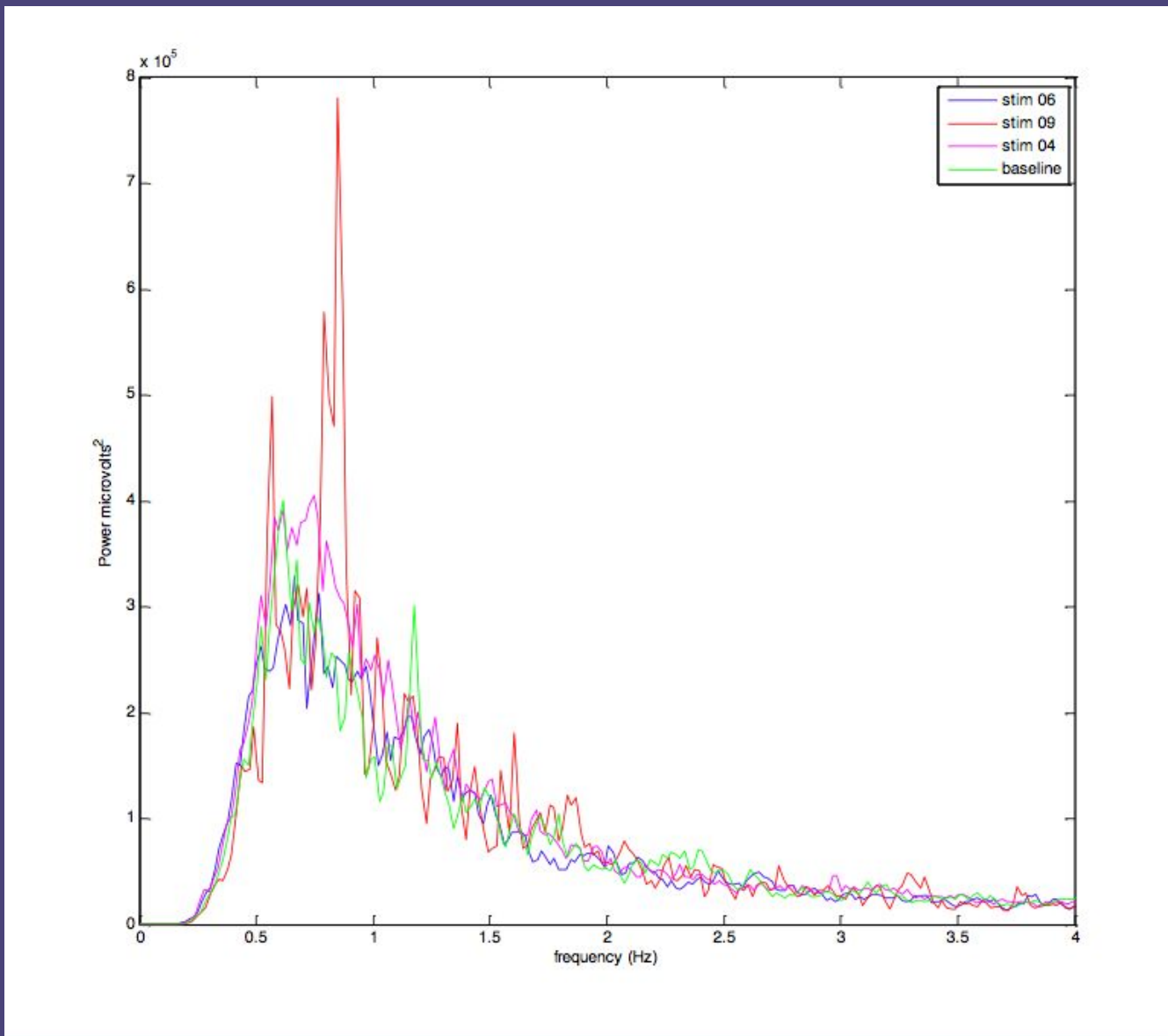


Figure 6: The 3 distinct stimulation nights versus an averaged baseline for subject 1. All 3 nights showed an increase in the delta region although stim 06 had a relatively small increase in delta relative to the other 2 nights.

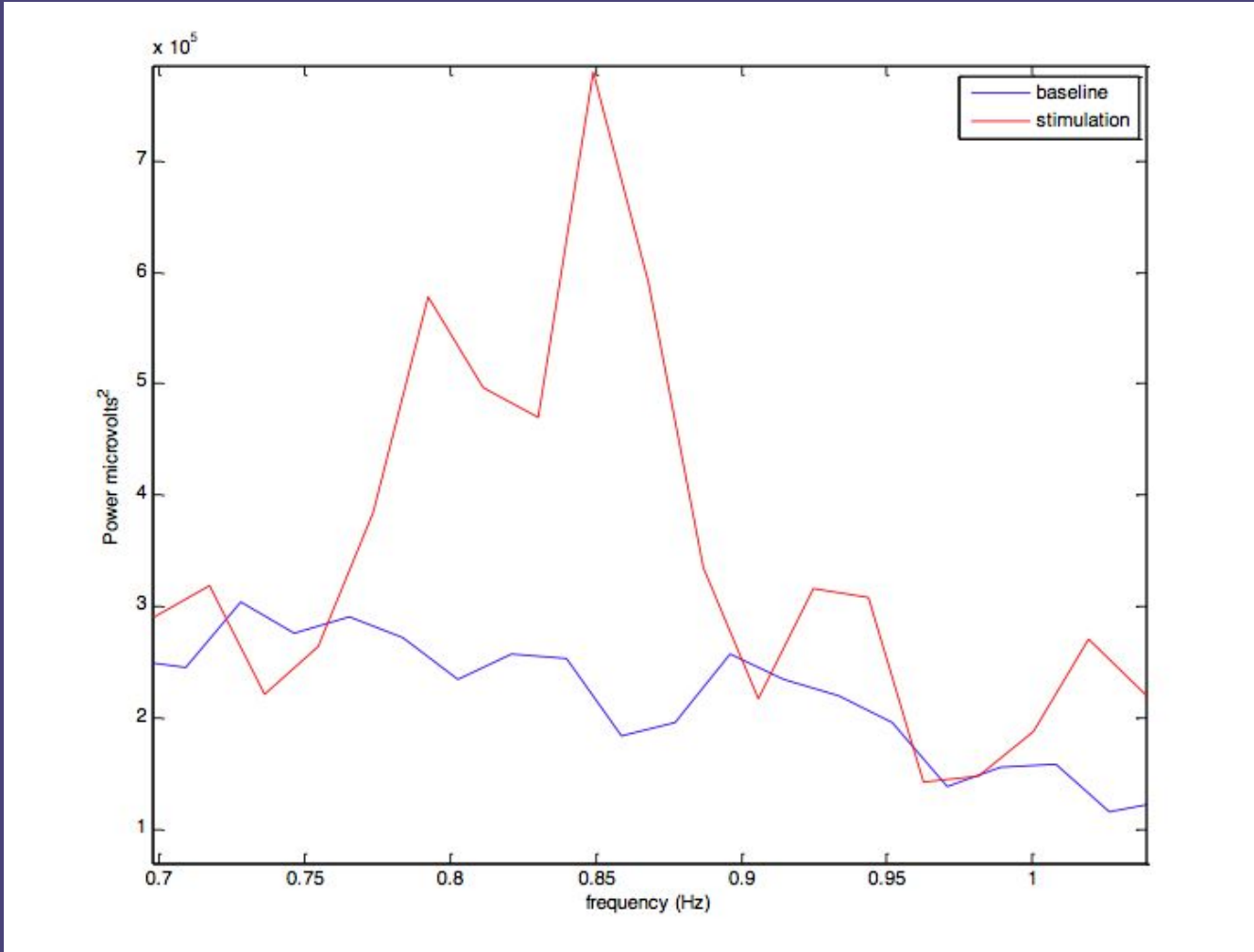


Figure 7: Zoom in for the EEG spectrum of stimulation and baseline for subject 1. A clear peak at the slow wave dominant frequency of 0.85 Hz is visible in the stimulation averaged nights.

Subject 1 showed a clear peak at the dominant slow wave frequency of 0.85 Hz.

Subject 2

Subject 2 showed a similar increase in the delta region as subject 1. The main dominant frequency was at about 0.6 Hz.

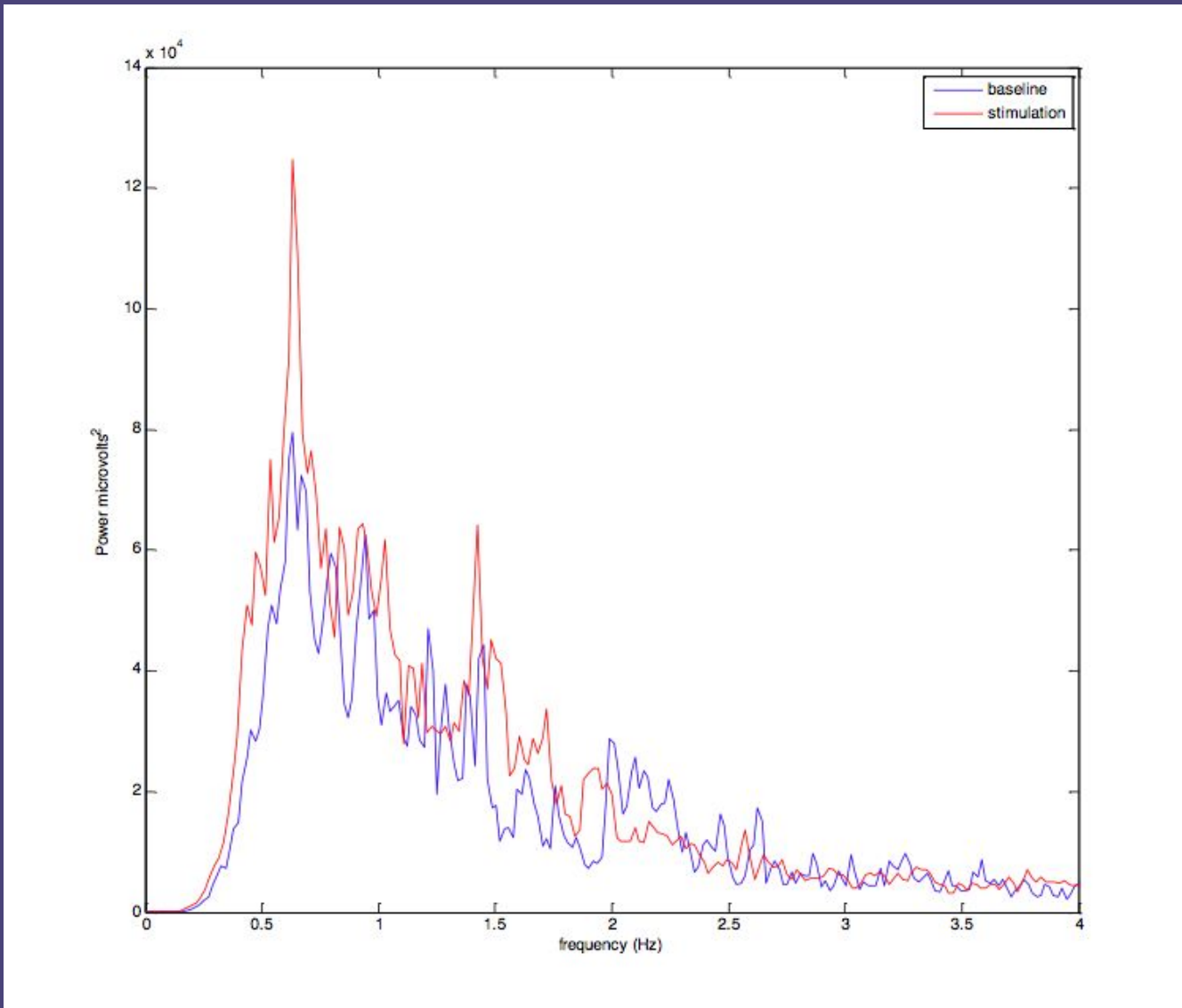


Figure 8: Spectrum comparing averaged stimulation nights for subject 2 (in red) versus baseline nights (in blue).

The statistics for subject 2 are that the increase in power for the Slow Oscillation range (below 1 Hz) is 27.2 %, the increase in the delta range (0.5-4 Hz) is 13.6 %. There was a decrease in Theta (4-8 Hz) of about 12.1 % and a decrease in alpha (8-15 Hz) of 13.2 percent a slight increase of beta (16-30 Hz) of 1 % but non significant statistically. The large increase in delta and the small change in beta and the decrease in alpha is encouraging because it may indicate a more stable and deep sleep.

SO (< 1 Hz)	Delta	Alpha	Theta	Beta
27.2 %	11.8 %	-13.2 %	-13.6 %	1 %

Table 2: statistics for stimulation/baseline for subject 2.

Subject 3

Subject 3 is an older male relative to the previous subjects with an expected decline in slow wave power. The stimulation protocol seemed to have worked too for this subject with a noticeable increase in spectral power in the delta region.

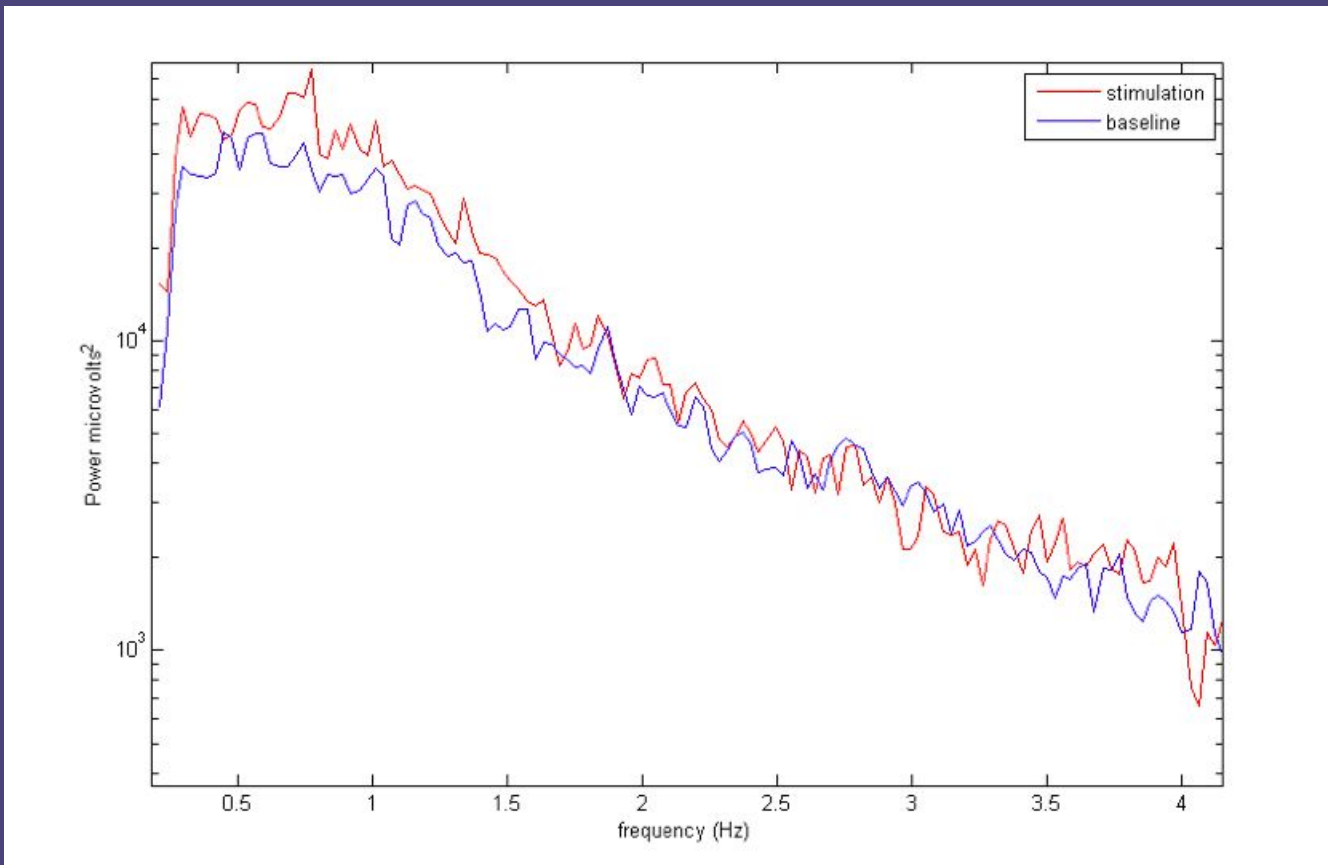


Figure 9: Spectrum comparing averaged stimulation nights for subject 3 (in red) versus baseline nights (in blue).

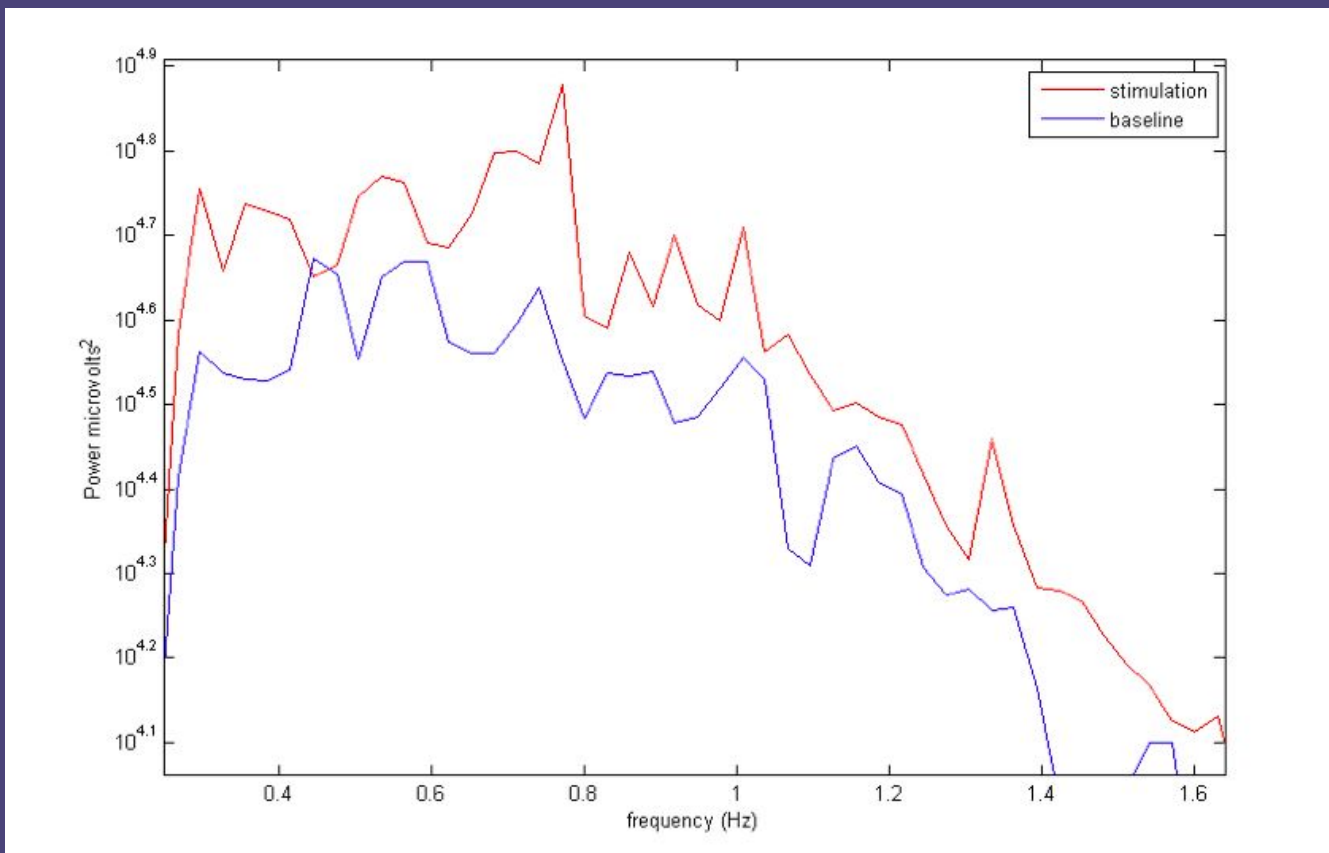


Figure 10: Zoom of the EEG spectrum showing the SO region. A peak at the dominant frequency of 0.79 Hz is clearly visible.

The statistics for subject 3 are that the increase in power for the Slow Oscillation range (below 1 Hz) is 29.1 %, the increase in the delta range (0.5-4 Hz) is 13.2 %. There was a decrease in Theta (4-8 Hz) of about 9.6 % and a decrease in alpha (8-15 Hz) of 12.2 percent a slight increase of beta (16-30 Hz) of 0.2 % but non significant statistically. The large increase in delta and the small change in beta and the decrease in alpha is encouraging because it may indicate a more stable and deep sleep.

SO (< 1 Hz)	Delta	Alpha	Theta	Beta
29.1 %	13.2 %	-12.2 %	-9.6 %	0.2 %

Table 3: statistics for stimulation/baseline for subject 3.

What is also interesting is to notice that following burst of slow waves there were more often bursts of spindles following the slow waves during the slow wave stimulation nights. The following graph is a ratio of averaged slow bursts for stimulation nights vs baseline nights. There is a noticeable enhancement in both slow wave power and subsequent spindle bursts locked to the slow waves for the stimulation nights. We will study this phenomenon further and present statistics in following reports.

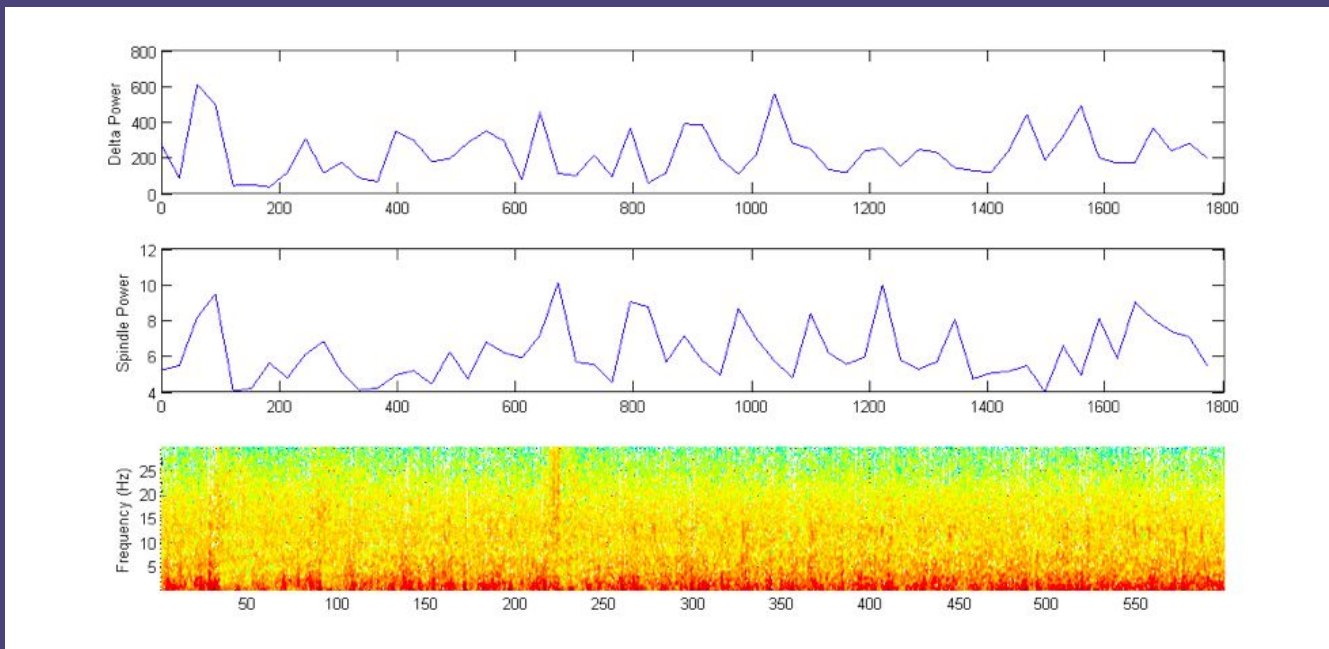


Figure 11: Averaged spectrogram ratio between stimulation nights and baseline nights. Low frequency burst associated with slow waves are followed more frequently by locked spindles during the stimulation nights.

Correlation of music spectral power and EEG power

We used a spliced 3.5 mm audio stereo jack and an audio splitter to send low voltage signal (millivolts) to channel 2 and 3 of the amplifier. The audio splitter sent the other voltage to a sleep headphone that allowed subject 3 to listen to the music and the music to be recorded simultaneously with the brain EEG while listening to the sleep music session.

The result is show in Figure 12:

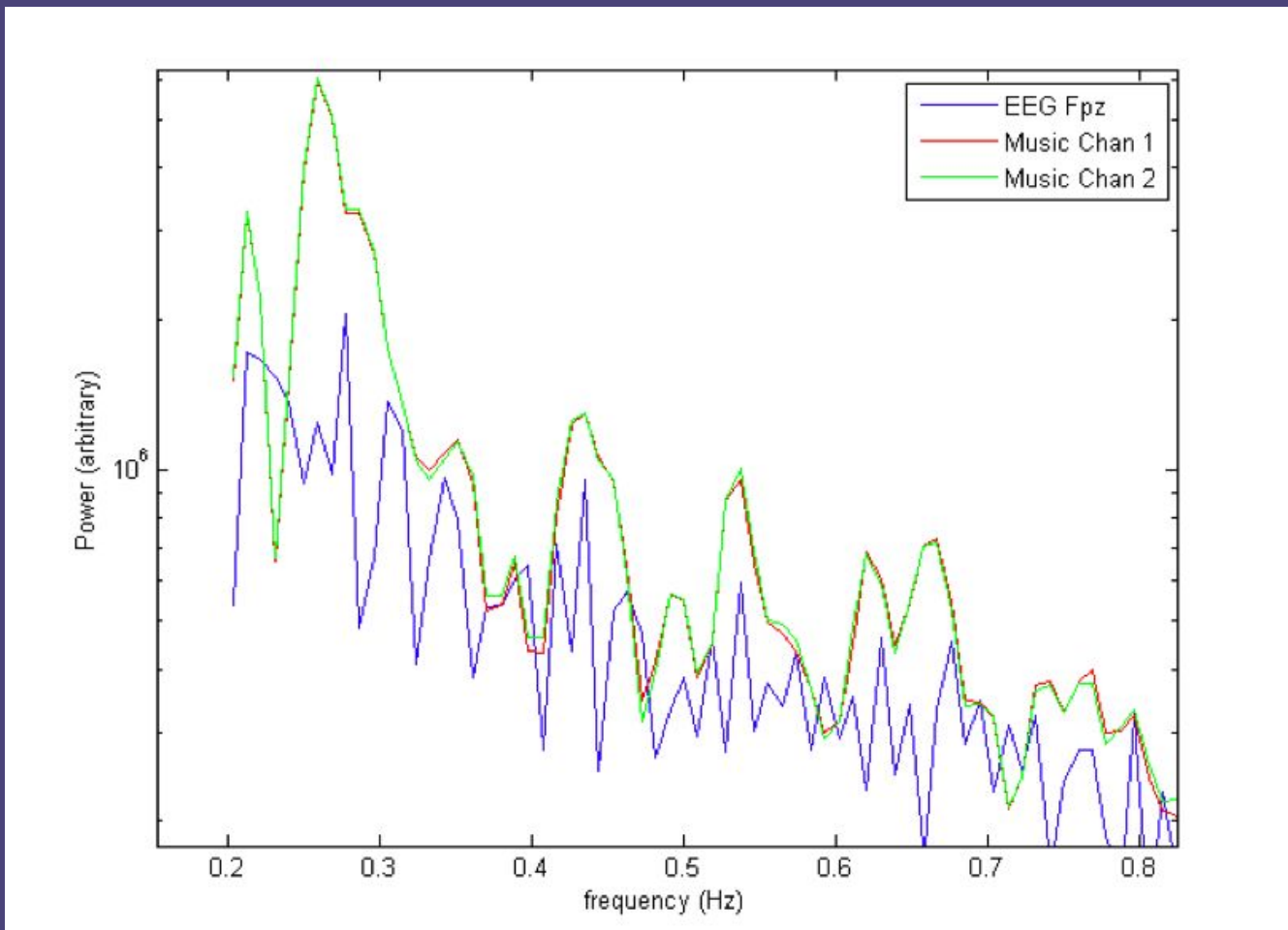


Figure 12: The voltage spectrum from channel 1 and 2 of the audio recording and the EEG from channel Fpz for subject 3 while listening to music. Strong correlations are seen at several peaks (0.25, 0.45, 0.55, 0.65 and 0.8 Hz).