Does sleep play a role in the consolidation of motor skills? A Brainwave Analysis

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Introduction

Very little is known about what the brain does during sleep. It is thought that sleep allows us to replay and learn memories and skills acquired throughout the day; there are numerous theories as to how this happens[1]. We can look at two electrophysiological signals to help us determine brain activity.

The first is the summed signals generated by a group of brain cells (neurons) in a certain area of the brain. These signals are called local field potentials (LFPs). The second is the signal generated by an individual neuron, this is called a spike.

During sleep, the brain progresses through a number of different sleep stages that are characterised by the relative power of different brain wave frequencies. By using different mathematical analysis and MATLAB we looked at the different brain wave frequencies contained in the LFP and how this related to spikes in the motor cortex, an area of the brain responsible for movement.

Aims :

1. Analyse local field potentials (LFPs) during different sleep phases.
2. Characterise the activity patterns of individual brain cells during different sleep phases.

Method:

24 hour data recordings had previously been collected from an electrode implanted into the brain of a female Macaque monkey. This electrode had been implanted into the part of the brain responsible for movement.

This data in total represented sixty three days worth of recordings. I was able to analyse these recordings using custom MATLAB scripts.

Calculating sleep start and end:

Overnight video recordings of the monkey were taken, allowing us to visually determine the start and end of sleep.

Sleep start and end time was also determined by looking at the increase in amplitude of low frequencies during sleep in the LFPs. This was not statistically different to the start (p – value of 0.4228) and end time (p – value of 0.8508) determined by video recording.

References

1. Rasch B, Born J. About Sleep's Role in Memory. *Physiological Reviews*. 2013;93(2):681-766. doi:10.1152/physrev.00032.2012.
2. Scullin MK. Sleep, Memory, and Aging: The Link Between Slow-Wave Sleep and Episodic Memory Changes from Younger to Older Adults. *Psychology and aging*. 2013;28(1):105-114. doi:10.1037/a0028830.

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Analysis of sleep LFPs:

A Fourier transform, a mathematical technique used in signal processing, was applied to the overall signal detected in the electrode. This allowed us to extract five distinct brainwaves from the overall signal. Each brainwave represented a different frequency band from the overall signal. These are shown below:

- Delta - <4 Hertz
- Theta – 4 ≤ to < 7 Hertz
- Alpha – 7 ≤ to 15 < Hertz
- Beta -15 ≤ to 31 < Hertz
- Gamma – 31 ≤ Hertz

These different brainwaves for one nights sleep are shown in figure 1.

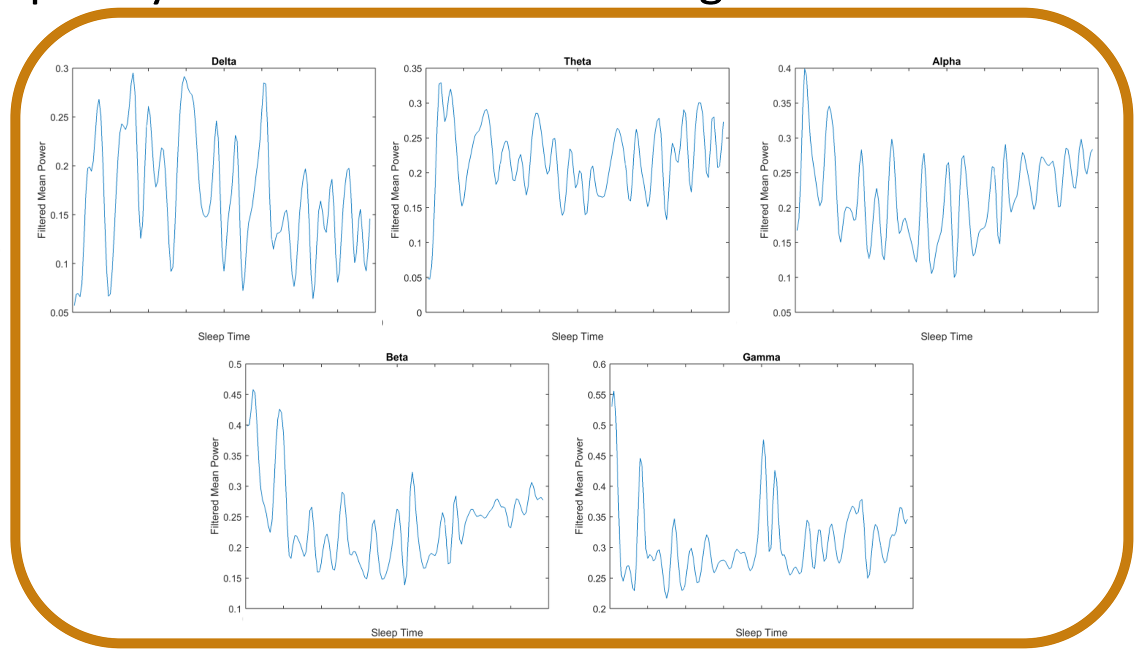

Figure 1: Filtered Mean Power Against Sleep for each Frequency

We looked at how different brain waves changed in the first and second half of sleep over sixty three nights.

	Mean Cycle Duration			Mean Power		
Frequency	First half	Second half	p - value	First half	Second half	p - value
Delta	81.75	72.75	0.041*	0.2072	0.2224	0.0001*
Theta	84.84	76.71	0.065	0.2266	0.2442	0.0006*
Alpha	73.14	70.77	0.321	0.2158	0.2376	0.0001*
Beta	86.45	76.1	0.044*	0.2403	0.2585	0.0001*
Gamma	88.22	83.53	0.301	0.3179	0.327	0.248

Table 1: How Mean Cycle Duration and Mean Power Vary in the First and Second Half of Sleep (* p - value < 0.05)

Table 1 shows delta, theta, alpha and beta all have a higher mean power during the second half of sleep. Power is derived from the voltage that the brain waves produce; it is a marker of how strong the signal is. Furthermore, the average cycle duration is shorter in the second half of sleep for both delta waves and beta waves, suggesting a greater number of cycles occur in the second half of sleep for these frequencies.

Delta waves are associated with deep slow wave sleep, which usually precedes rapid eye movement sleep. It has previously been shown that slow wave sleep is important for the consolidation of episodic memories (a memory of an autobiographical event)[2]. This could indicate episodic memories are consolidated early on in sleep.

Phase difference of sleep LFPs:

Phase difference to delta frequencies was put into 10 bins from minus π to π. For each brain wave frequency and bin number, the section of signal which had a corresponding phase difference to the delta frequency was isolated and the mean power was calculated. This was done for all sixty three nights and plotted as shown in figure 2.

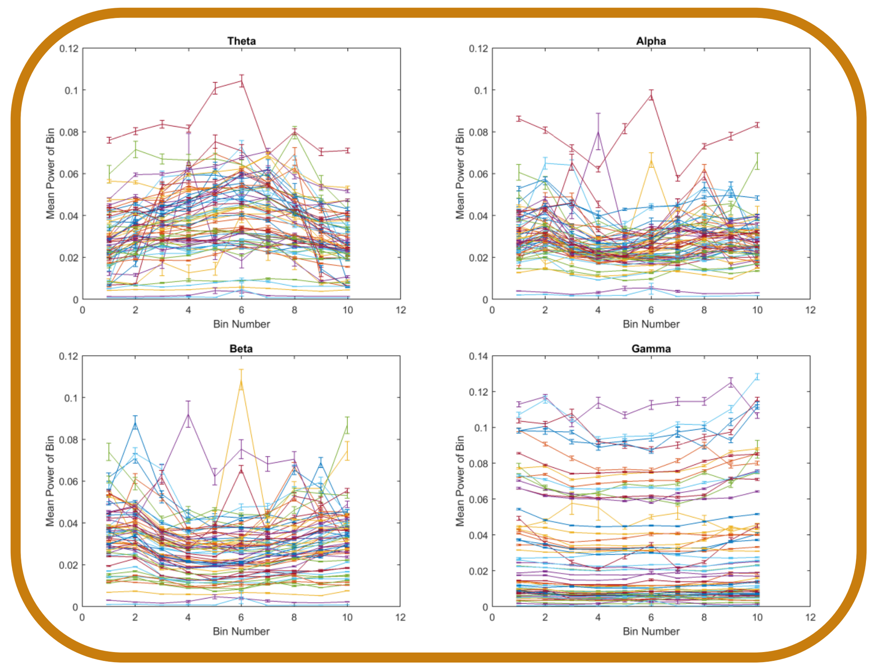

Figure 2: Mean power against phase difference

Figure 3 shows, for all brain wave frequencies, how many times the maximum power occurred in a given phase difference relative to the delta brain waves.

Theta frequencies in the hippocampus, an area of brain responsible for emotion and memory, are thought to be very important for memory consolidation [1].

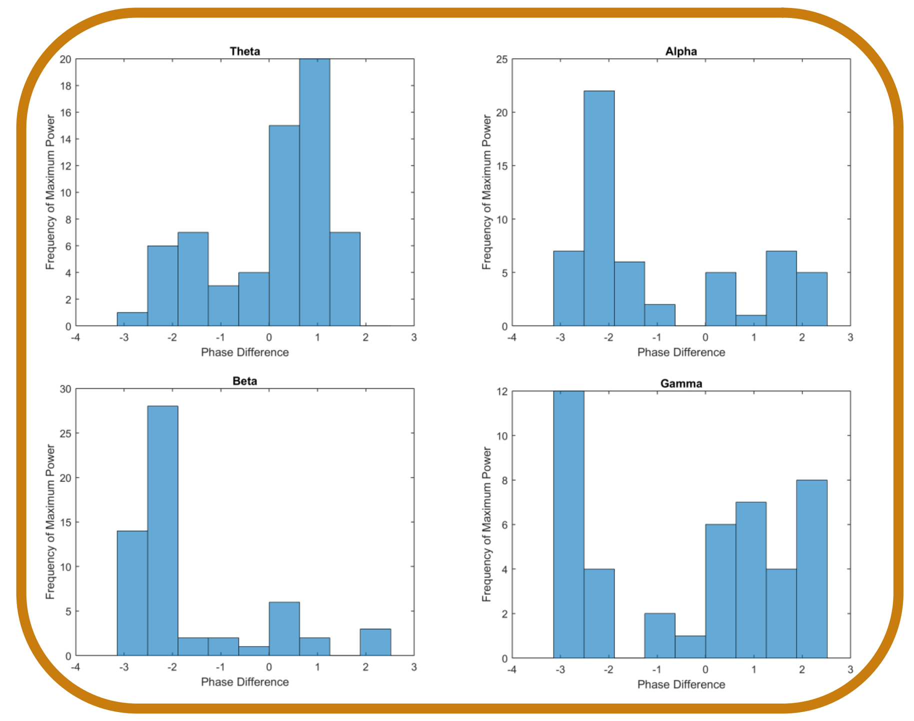

Figure 3: Histogram of maximum power against phase difference

This data would indicate that theta waves consistently have a maximum power at a recurring given time after the delta frequencies during the sleep cycles.

Analysis of spikes:

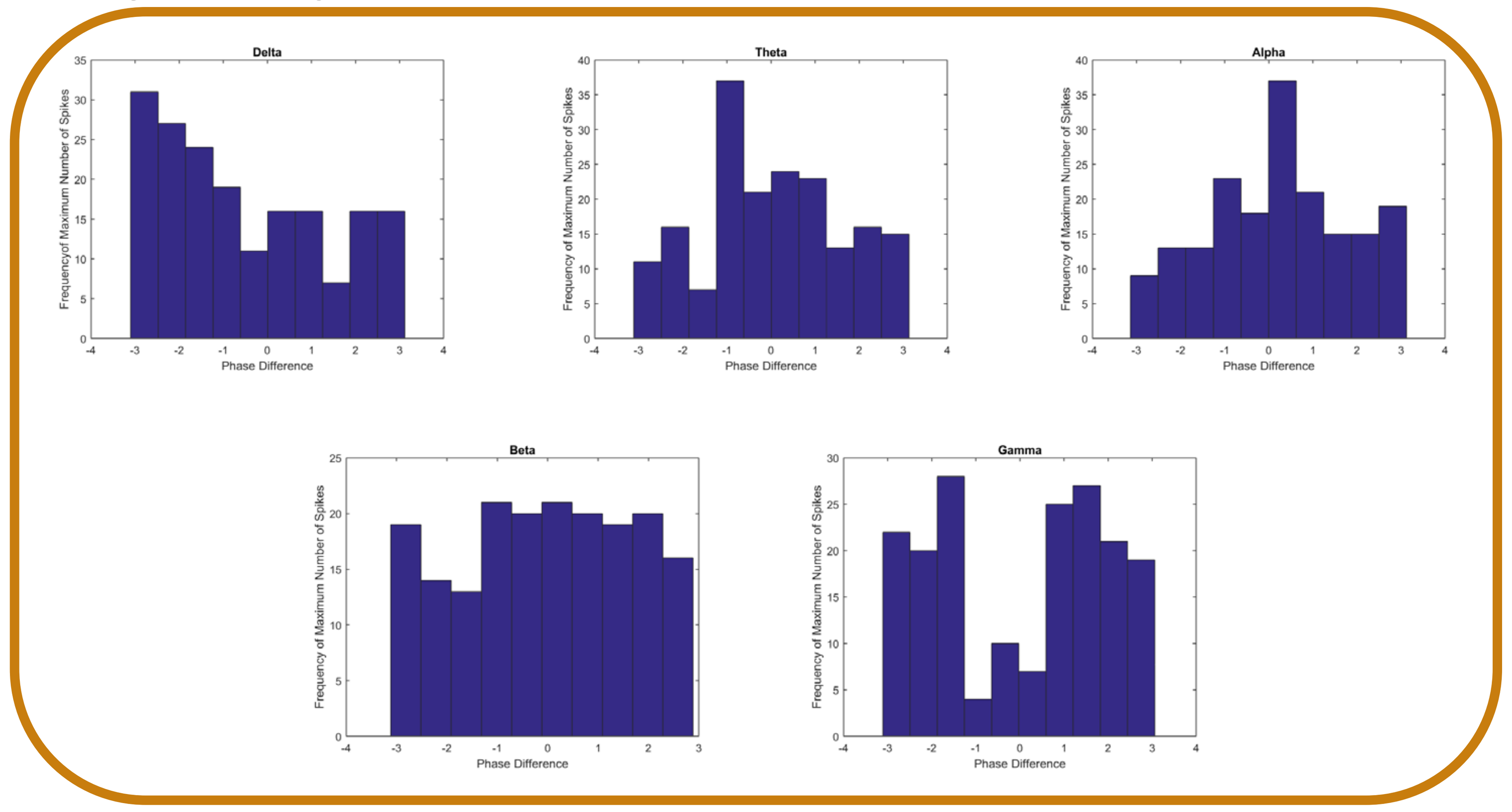

Figure 4: Histogram of the maximum number of spikes against phase difference

For a given sleep phase, the number of spikes in that window was calculated for each spike train present in the data. The sleep phase with the highest number of spikes was noted for each spike train and a histogram was plotted in Figure 4. This shows how often the maximum number of spikes occurred for a given phase difference for the different frequencies of brain waves.

Conclusions:

- During the second half of sleep all brain waves except gamma are more powerful, there are also more delta waves as the cycle duration is quicker.
- Theta waves occur after delta waves with a consistent phase difference. All other waves occur in anti-phase to delta waves, they are at their most powerful when delta is weakest.
- More spikes occur in anti-phase with delta. There are more spikes when delta is weakest.