1. **(10/100) At which frequency were the recordings sampled? Explain which frequencies you can expect to estimate from this recording.**

As seen in the field sMat.Time, there are 150 000 samples over 250 seconds. The sampling rate is 150 000/250s = 600Hz.

Since the Nyquist frequency is half the sampling rate, we can estimate the frequencies in the MEG signal up to 300Hz. The lowest frequency would theoretically be 1/250Hz (with one cycle fitting the whole dataset), but the signal is low-cut filtered under 1Hz.

The frequencies available to us are therefore 1 to 300Hz.

2. **(10/100) Compute the power spectrum of the continuous signals using different window lengths for the PSD (500ms, 1s, 2s, 4s).**

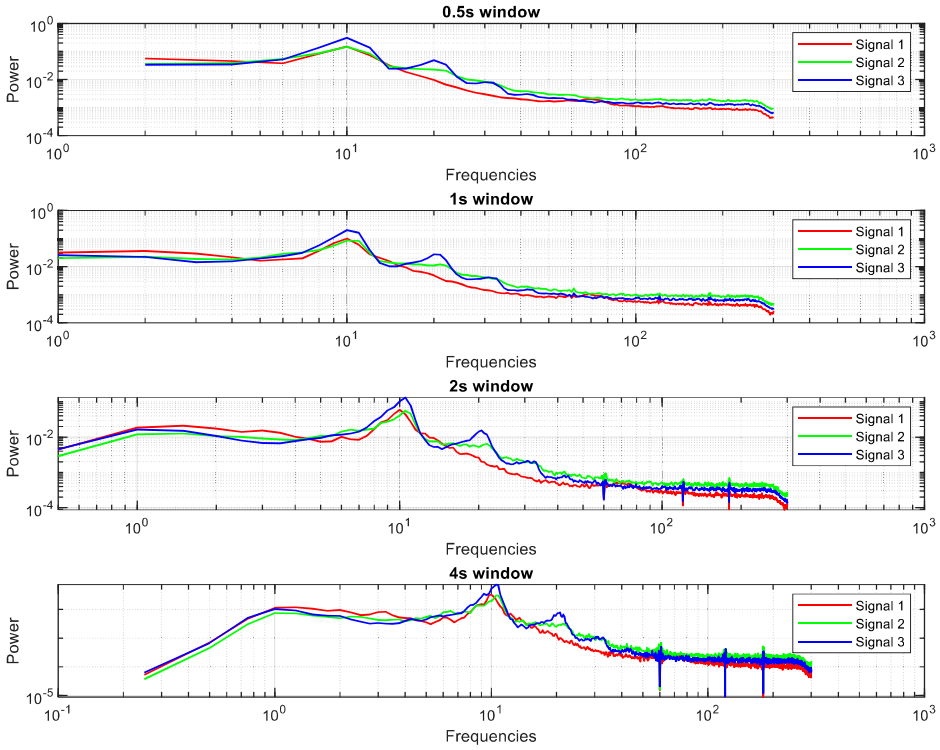

Figure 1. Power spectral density of the three signals computed using windows of varying widths.

The power spectral densities (PSD) of the three signals are shown in figure 1. The PSDs were computed using windows between 0.5 and 4s. These windows highlight different aspects of the spectra. The shorter windows flatten the curves more and obscure blips

that are present in the longer windows at 60Hz (which is probably due to the notch-filtering of this frequency) and above 100Hz. The 1Hz low-cut filter that has been applied to the data is reflected by a sharp drop in power in frequencies under 1Hz in the bottom two plots. In general, the over-all shape of the curves is similar across window lengths. The three signals also have largely similar power spectra with only small, albeit significant, differences. This is to be expected, since they are the same type of signal recorded in different brain areas.

All three signals have a peak around 10Hz. Signal 1 has few other defining characteristics, except for a small peak at 6Hz. Signal 3 shows other peaks around 20 and 30Hz, as does, to a lesser extent, signal 2.

3. **(15/100) Plot the average over trials aligned to both events.**

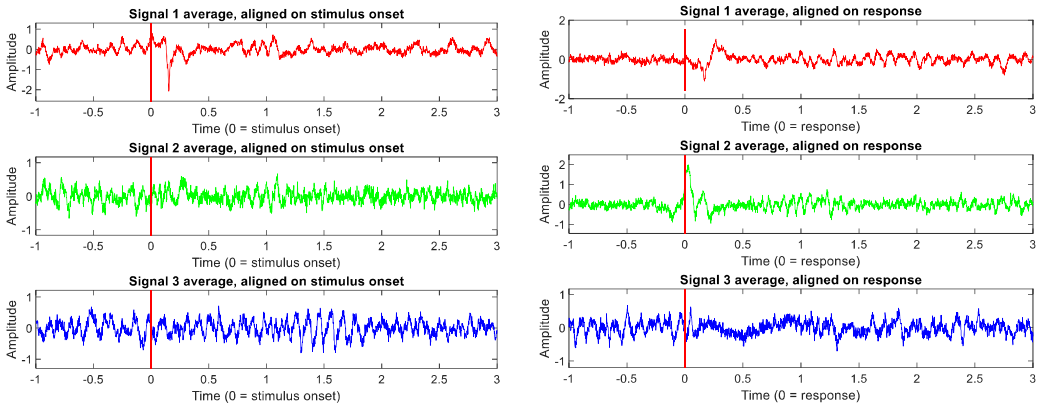

Figure 2. Average of three signals aligned on stimulus onset (left) and on response (right).

Signal 1 shows large, quick responses to both events: a dip after stimulus onset and a peak after response. It also switches from high-frequency to lower-frequency activity after the response. Signal 2 has a similar pattern around response, but has no large response after stimulus onset. Signal 3 shows the reverse pattern to the other two: its frequency content gets higher right after the response.

All three signals are hard to interpret around stimulus onset, which doesn't seem to have as much of an effect as the response. This makes sense as two of them are recorded from motor areas.

4. **(20/100) Compute time-frequency decompositions for each trial and both events**

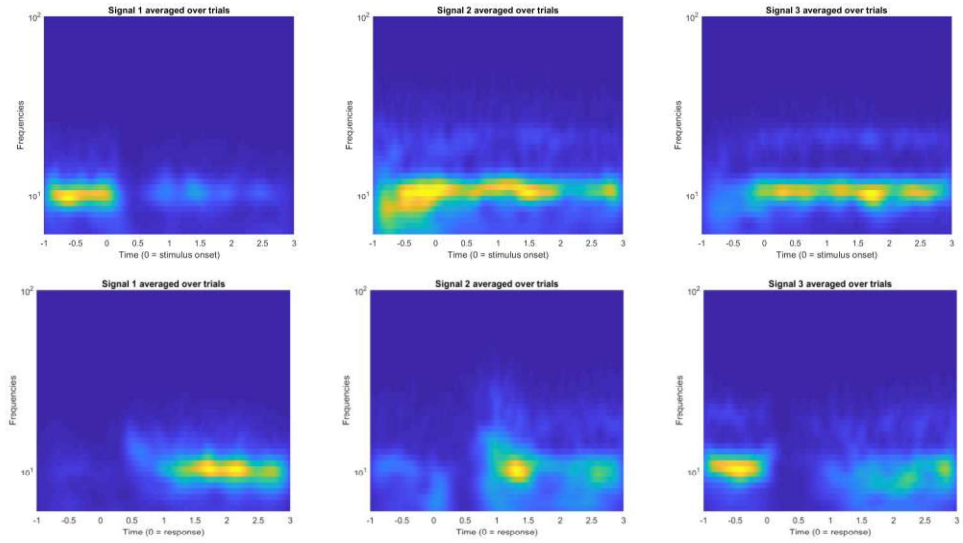

Figure 3. Time-frequency representations averaged over trials. Left: signal 1, middle: signal 2, right: signal 3; top: average centered around stimulus onset, bottom: average centered around response.

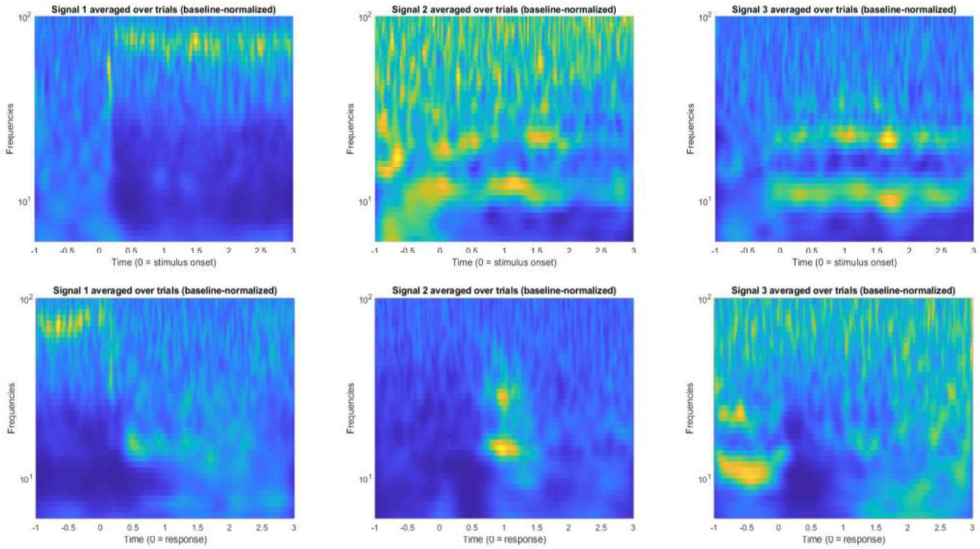

Figure 4. Baseline-normalized time-frequency representations averaged over trials. The baseline has been computed as the mean response during the second prior to each event, in the averaged signal. Left: signal 1, middle: signal 2, right: signal 3; top: average centered around stimulus onset, bottom: average centered around response.

This section will not discuss figure 3, as figure 4 contains the same dx/ata but normalized by its baseline, which makes high-frequency effects much easier to see.

Signal 1 presents a wide-band suppression between ~5-25Hz after stimulus onset, as well as a surge in high gamma at the same time. This seems to continue until the response, after which activity switches back to approximately what it was during baseline.

After stimulus onset, signal 2 presents suppression under 10Hz and in low beta (~13-20Hz), as well as activity in the alpha and high beta and gamma bands. There is a lot less activity around the response: some suppression under 15Hz followed by a short surge in beta about 1s after response.

As for signal 3, it also seems to keep the same post-stimulus pattern until response: activity in the alpha and high beta (~20-25Hz) bands with suppression between and below these frequencies. However, after response, there is wide-band suppression up to around 30Hz, with activity in gamma, followed by activity in all recorded bands.

5. **(15/100) Based on the event-related averages and time-frequency maps that you plotted in the last two questions, make a guess which anatomical regions those 3 signals are coming from, and explain how the results fit with that guess.**

   We know that two of the signals come from left and right motor cortex, and the other is from visual cortex. The signals from motor cortices should therefore be similar until response, and both should be different from the visual cortex signal. In this regard, signals 2 and 3 seem the most similar, as both show similar activations and suppressions after stimulus onset, especially under 50Hz. The pattern of signal 1 also matches that of an activation (i.e.: gamma activity and suppression in lower frequencies) in the visual cortex, which is activated in this case since the stimulus is present until the button press.

   As for which, between signals 2 and 3, is the left motor cortex that controls the responding hand, we can look to Donner *et al.,* (2009) (figure 5). They show that in the contralateral motor cortex, there is a surge in high-frequency activity coupled with low-frequency suppression after button press in a very similar task. This makes signal 3 the best candidate for left motor cortex, as it has a very similar pattern to this (figure 4).

In short, here's my guess for which signal is recorded where:

- Signal 1: Primary visual cortex;
- Signal 2: Right motor cortex;
- Signal 3: Left motor cortex.

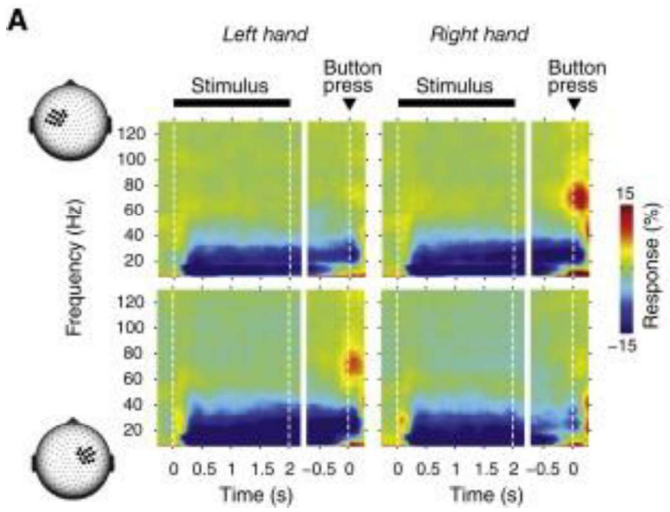

Figure 5. Figure 2A from *Donner et. Al (2009)*. MEG recordings from left and right precentral gyrus during a signal detection task. There is bilateral suppression under 40Hz (except for a slim band in the middle) until button press, at which point there is a burst of activity in gamma contralatarally from the used hand and a return of low-frequency activity in the ipsilateral motor cortex. This should be similar to the signal from left and right motor cortex in figure 4.

6. (30/100) Phase-Locking Value

A) Filter the continuous signals between 8-13 Hz. Estimate the instantaneous phase/angle of the filtered signals using the Hilbert transform. Compute and plot histograms of the phase differences.

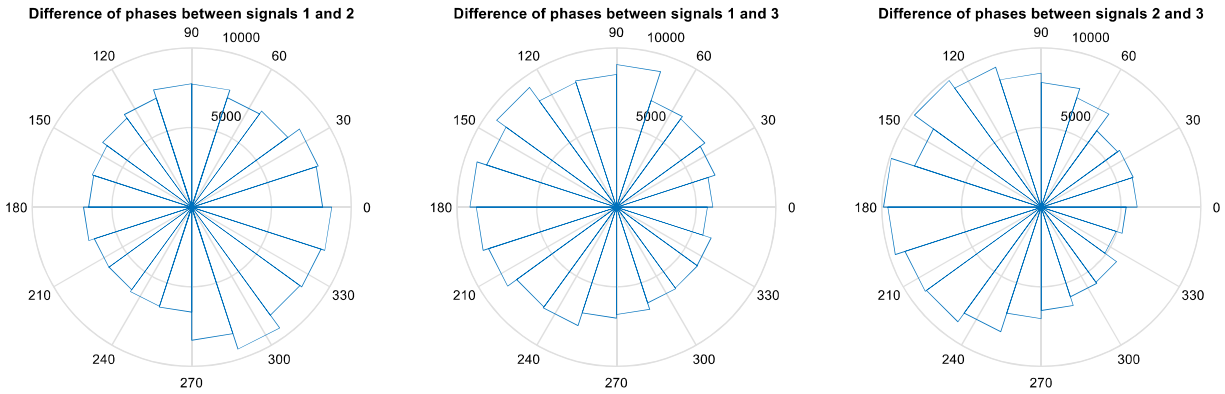

Figure 7. Differences between alpha-band (8-13Hz) phases for signal pairs.

B) Plot histograms of the phase differences only for the time samples during visual stimulation.

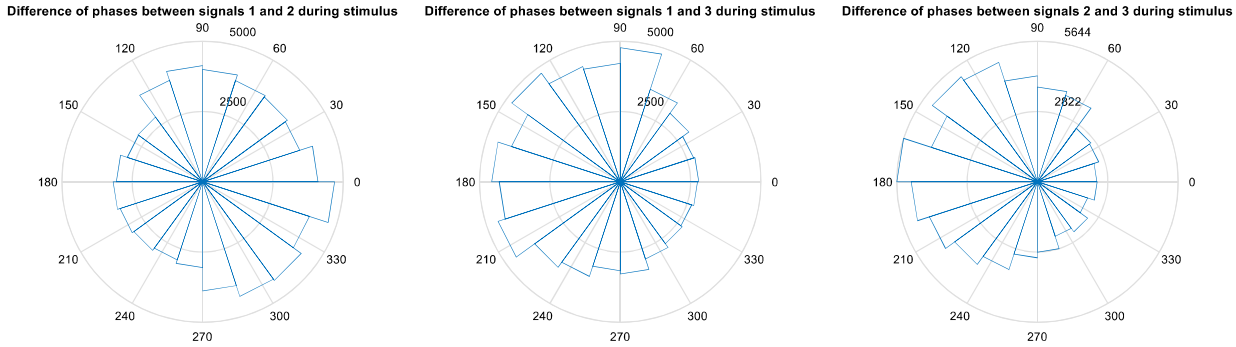

Figure 7. Differences between alpha-band (8-13Hz) phases for signal pairs during signal presentation.

C) Compute the phase-locking-value between signal pairs during visual stimulation, using the phase differences computed before. Describe which signal pairs show the most synchronization and how this can be seen in the histograms plotted in b)

The phase-locking values are as follows:

Table I. Phase-locking values.

Signal pair	*1 & 2*	*1 & 3*	*2 & 3*
PLV	0.088	0.135	0.212

Signals 2 & 3 show the most synchronization, followed by signals 1 & 3, then signals 1 & 2. This can be seen in figure 3 as the third histogram (for signals 2 & 3) is the most 'lateralized': it has much greater bars in the 60-240-degree range than in the other half of the phases. This is also true, to a lesser extent, in the second histogram (for signals 1 & 3) and even less in the first (for signals 1 & 2).

This also fits with the hypothesis that signals 2 and 3 are the motor cortices: they should be more synchronized together than with the visual cortex.

Bibliography

Donner TH, Siegel M, Fries P, Engel AK (2009) Buildup of Choice-Predictive Activity in Human Motor Cortex during Perceptual Decision Making. Current Biology 19:1581-1585.