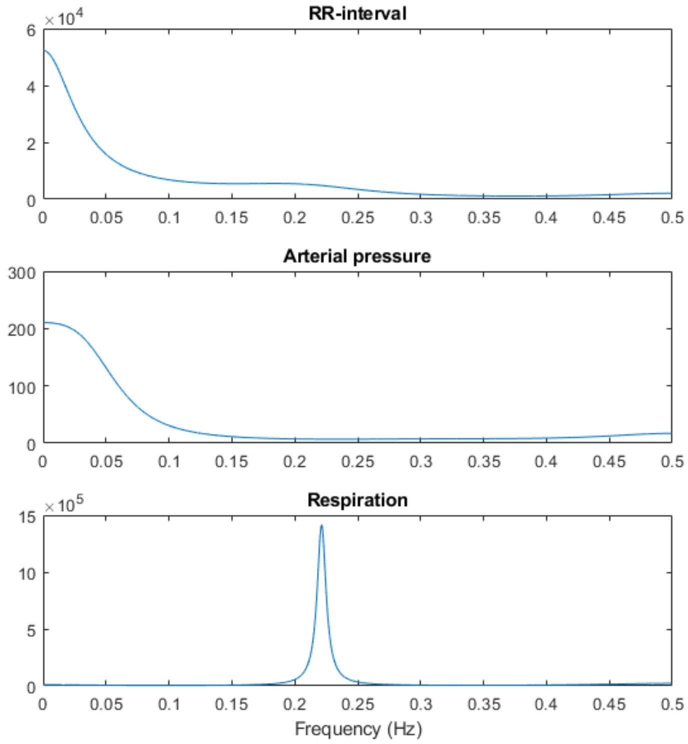
EE512 – Applied Biomedical Signal Processing

Practical session – Linear Models II

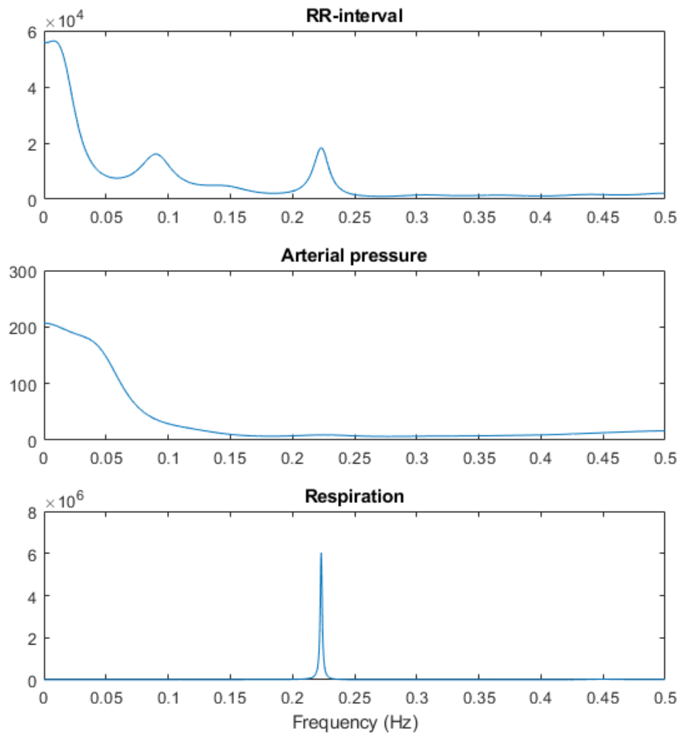
Experiment 1: Parametric spectral estimation of physiological signals

a) The answer should include three plots similar to the following:

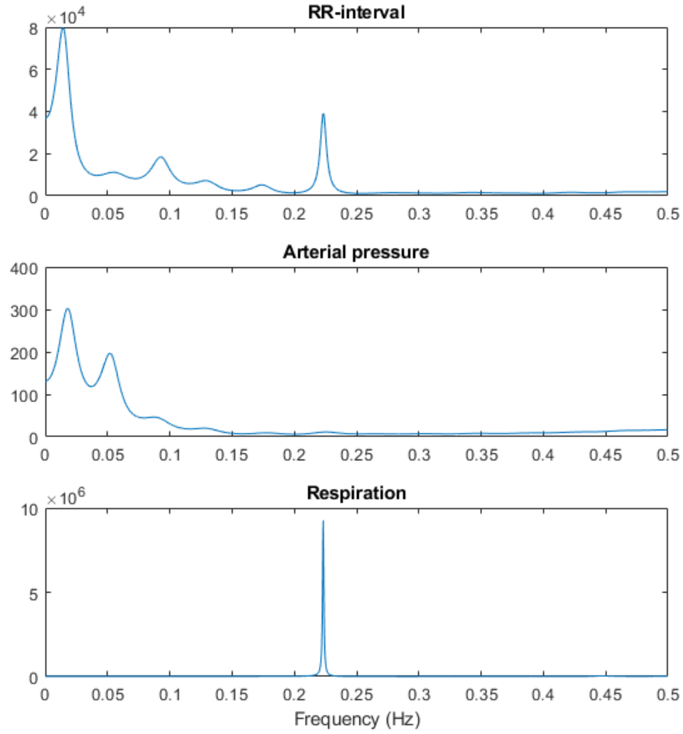
Order 5:



Order 15:

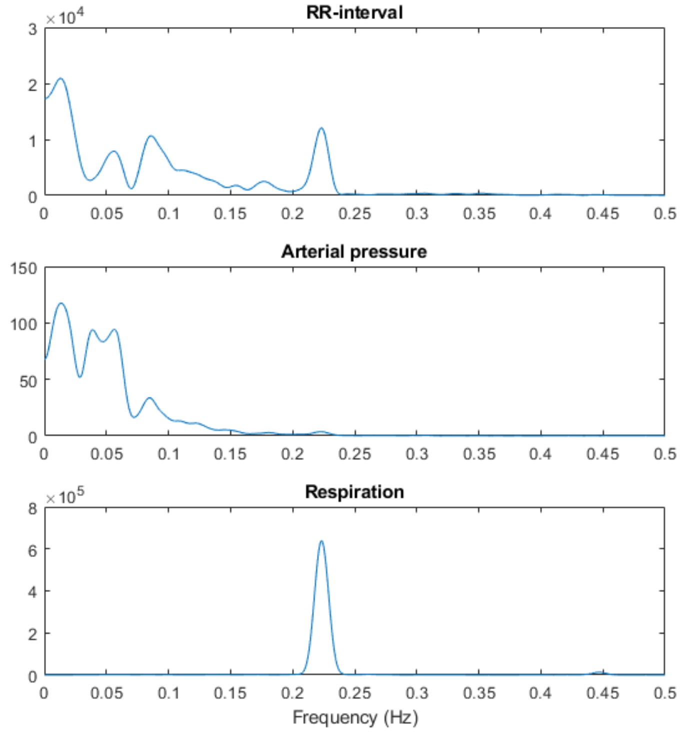


Order 25:



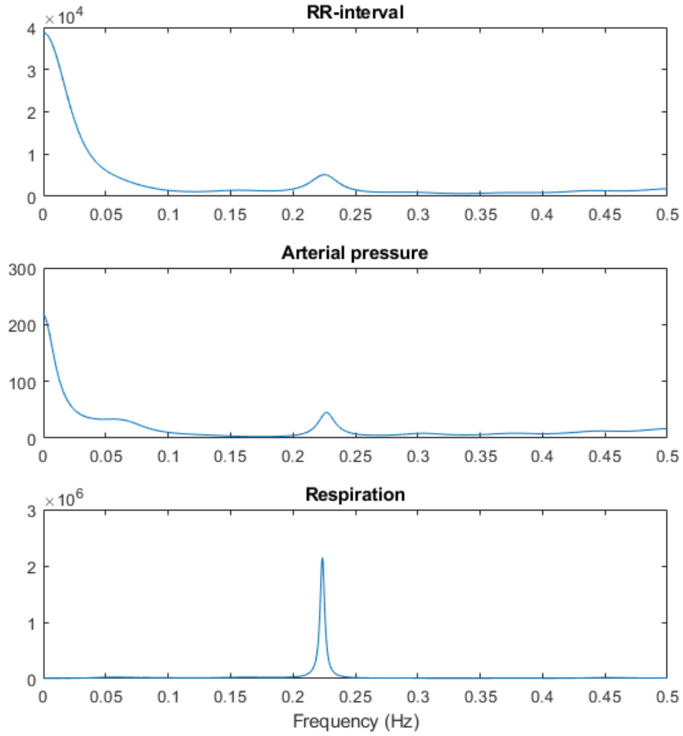
It should be observed that increasing the order generally leads to more flexible but complex spectra, with increasing presence of oscillations/"peaks". Based on the description of the expected peaks in the RR-interval spectrum, the intermediate order of 15 appears to be the most reliable; at order 5 none of the two peaks are visible; at order 25 several others appear, hindering the interpretation.

b) The answer should include a plot such as:



It should be observed that the non-parametric approach generates more complex plots, with more peaks in the spectral profile, similar to the case of the parametric approach when the AR order is set too high. While it is not possible to say without doubt which approach is more accurate, the parametric approach at order 15 clearly appears to be more consistent with the expectations described in the question for the RR-interval signal. This also supports the idea that parametric approaches can be more robust and accurate than non-parametric methods by conditioning their estimates with prior assumptions about the signal – as long as the model is adequate to the problem.

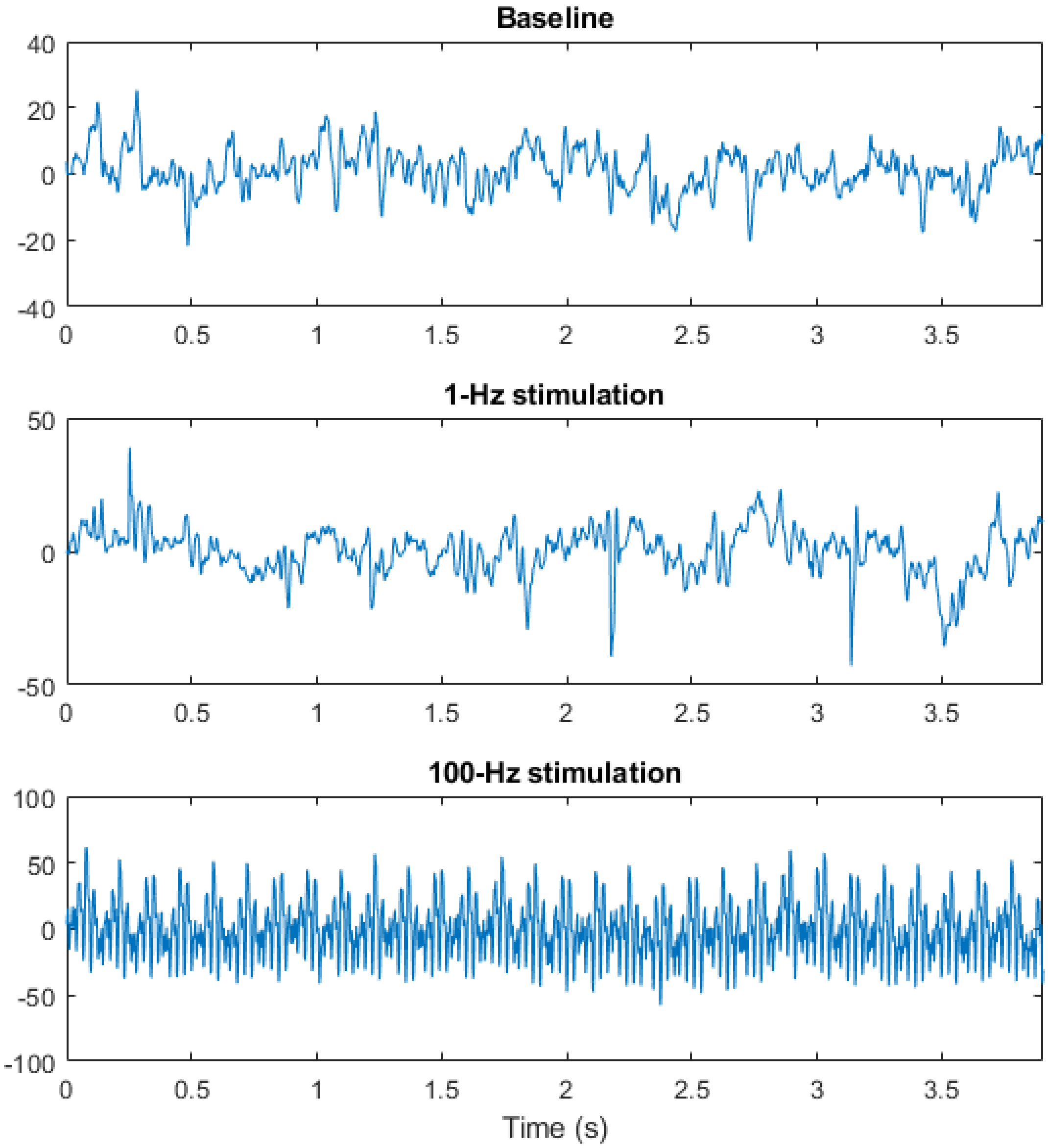
c) The answer should include a plot such as:



It should be noted that there are several clear differences between the pre- and post-alcohol states. For the RR-interval, the peak at 0.08 Hz has mostly disappeared, suggesting an important disruption of the baroreflex mechanism; the peak at 0.225 Hz is partially reduced, suggesting that sinus arrhythmia is affected as well. The arterial pressure becomes more dependent on the respiration (peak appearing at 0.225 Hz). The respiration becomes partially less regular, as can be seen from the widening of the peak.

Experiment 2: Pisarenko harmonic estimation of brain signals

a) The answer should provide a plot such as:



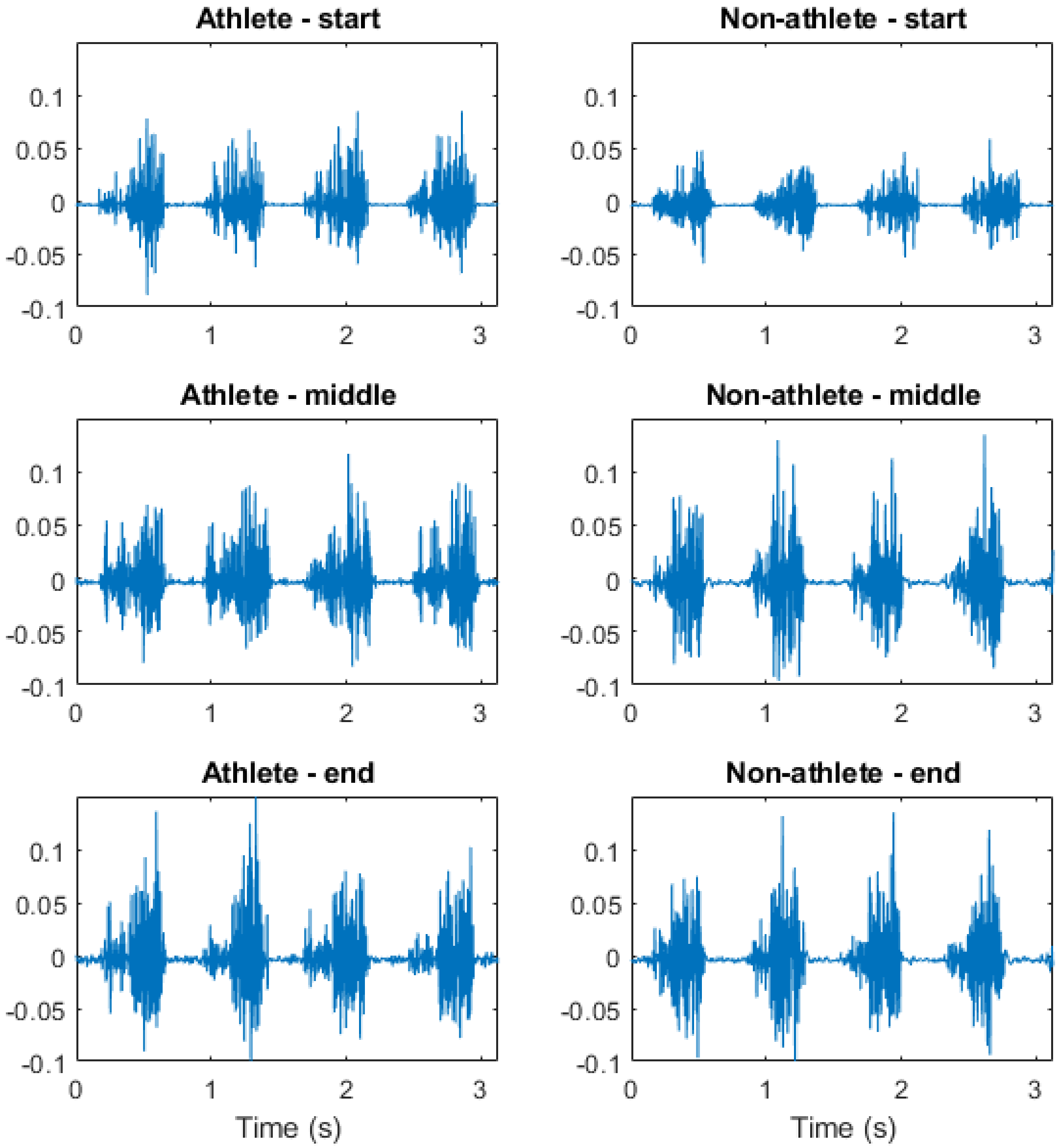
b) The answer should report the Pisarenko estimation results, including the frequency and amplitude of the 5 sinusoids plus excitation variance, for each of the three conditions. For example, reported as:

Condition	**Property**	**Sinusoid**				
		1	**2**	**3**	**4**	**5**
Baseline	Frequency (Hz)	178.0	130.1	84.4	38.9	9.0
	Amplitude	0.008	0.058	0.39	4.3	39.6
	Variance	0.033				
1-Hz stimulation	Frequency (Hz)	181.1	132.8	85.0	39.6	8.7
	Amplitude	0.027	0.16	1.1	9.0	71.0
	Variance	0.061				
100-Hz stimulation	Frequency (Hz)	185.9	136.1	93.6	50.8	23.5
	Amplitude	1.3	7.7	39.3	155.0	265.7
	Variance	3.76				

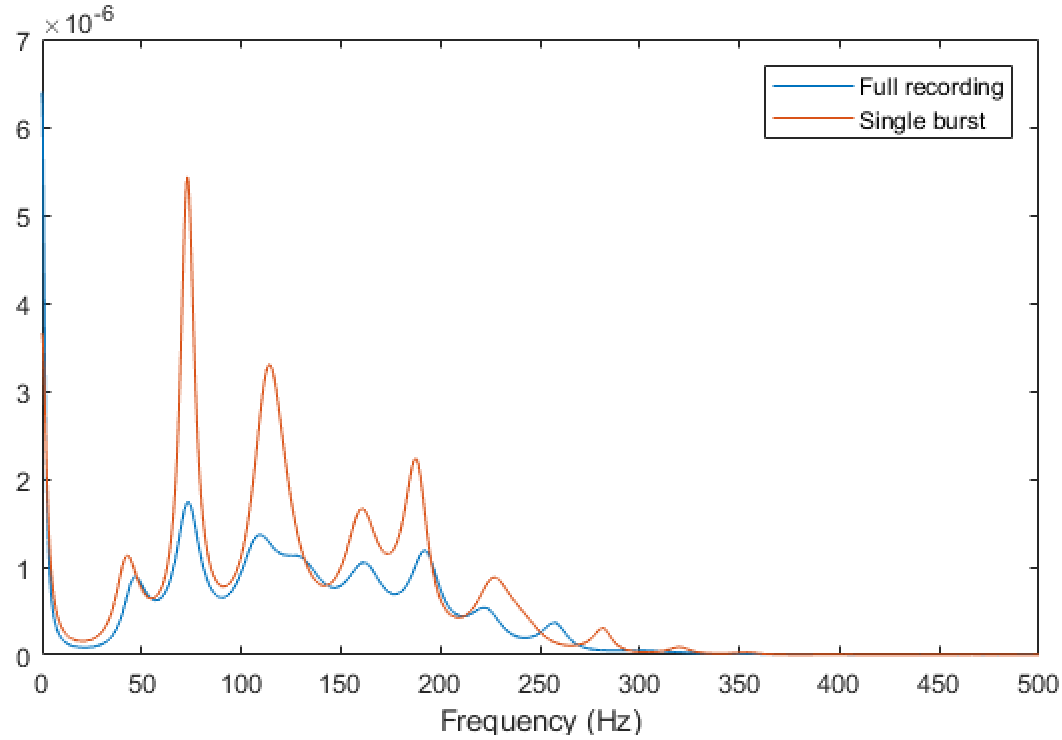
It should be observed that at baseline, the EEG is dominated by an oscillation near 9 Hz (probably the so-called alpha rhythm) – the amplitude of this sinusoid is considerably stronger than the others. With 1-Hz stimulation the situation is relatively similar, with a dominant frequency at 8.7 Hz, and the four other sinusoids at frequencies quite close to those of the baseline period. In contrast, at 100-Hz stimulation, the signal becomes less dominated by a single frequency, and instead shows three strong oscillations at 23.5, 50.8 and 93.6 Hz (and none at all around 9 Hz). Thus, it appears that it is the 100-Hz stimulation that has a measurable impact on brain activity.

Experiment 3:

a) The answer should include six plots similar to the following:

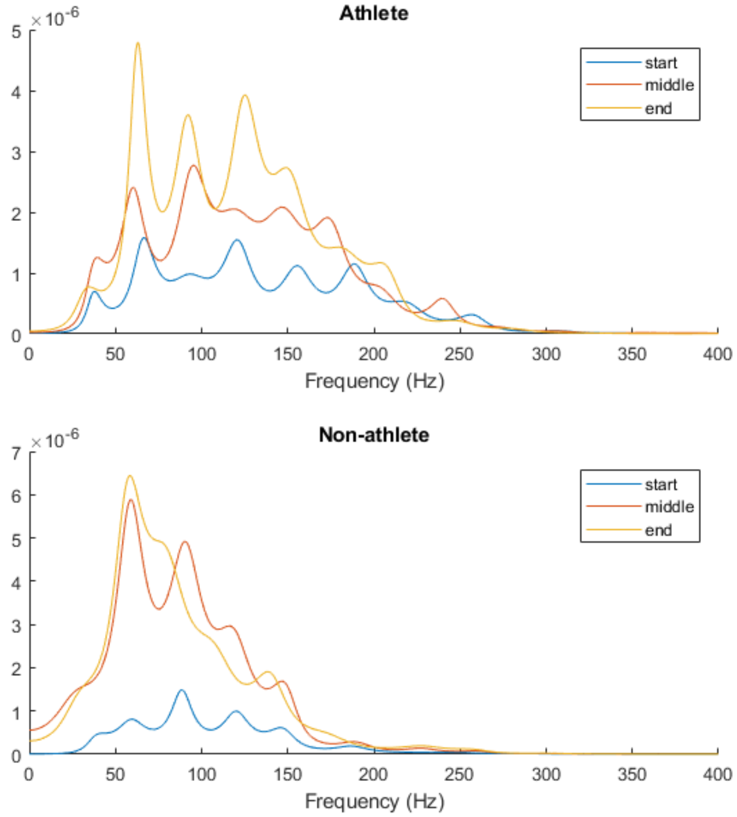


b) The answer should show a plot of the two overlapped spectra, as follows:



It should be observed that the two spectra have a relatively similar profile, in terms of the most prominent peaks, their location and width. In the full recording, however, the peaks have considerably smaller amplitude. The reason for this outcome is that the full recording contains both the bursts (which contribute to the peaks) and "silent" periods in between; because the spectral power is taken as an average over the provided time window, the estimated power for the peaks is therefore lower when the signal does not contain only the bursts but also silent periods, compared to a window that contains only the burst.

c) The answer should show a plot of all PSDs such as:



The mean frequencies should be reported as well:

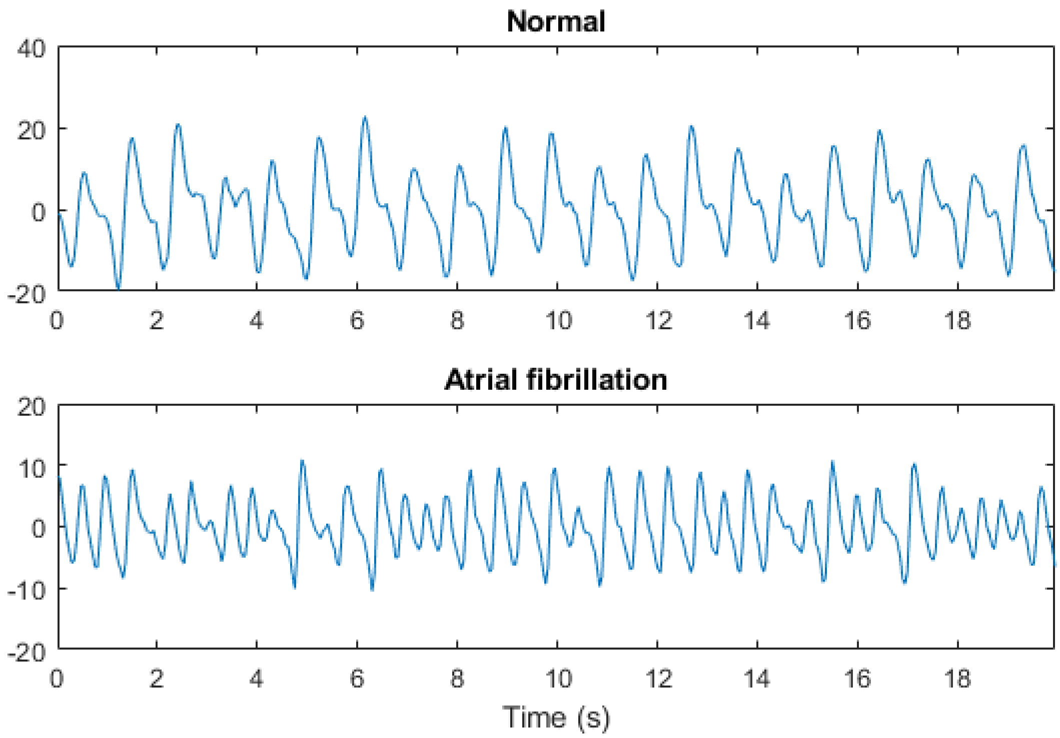
Subject	Mean frequency		
	Start	Middle	End
Athlete	136.0	126.5	120.9
Non-athlete	105.9	87.7	87.4

The provided expression to derive the mean frequency is simply a weighted average of all possible frequencies, where the weighting is provided by the respective power; the sum of all powers is used to normalize the weights to a total sum of 1.

As seen in the plots and in the mean frequency, the athlete has lower sEMG power overall, but a higher mean frequency. The mean frequency is also decreasing less abruptly from the start to the middle than in the moderately trained subject, indicating less fatigue.

Experiment 4:

a) The answer should include two plots similar to the following:

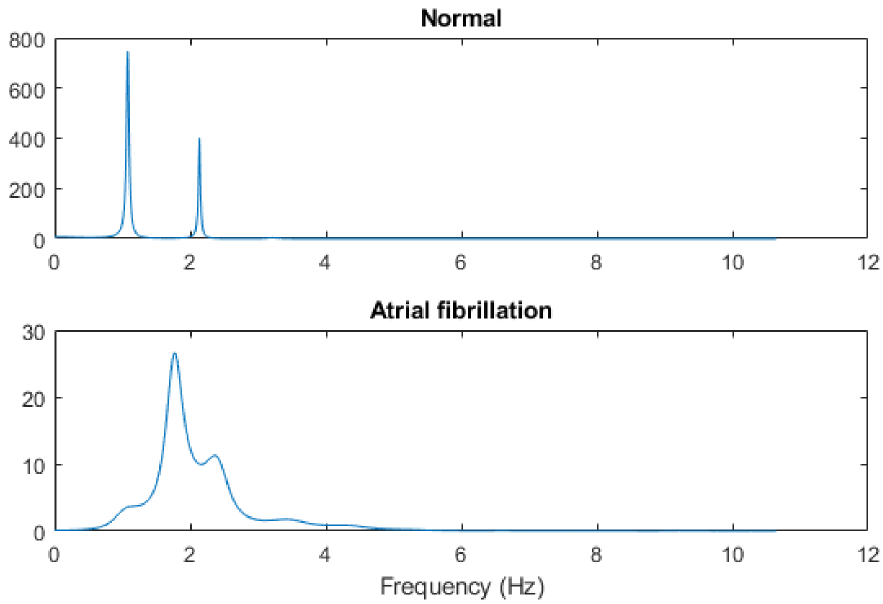


The normal signal looks clearly more regular than the atrial fibrillation (AF) case.

b) The answer should report the order estimates: 20 for the normal case, 5 for AF.

c) The answer should report the ratios: 0.028 for the normal case, 0.109 for AF.

d) The answer should provide two plots similar to the following:



e) The answer should report the entropy estimates: 4.7 for the normal case, 6.2 for AF.

f) It should be discussed that all measures essentially point to a considerably higher degree of structure/organization in the normal case, compared to the AF case. The normal PPG has a higher AR order and lower excitation-to-signal ratio, both showing that in this case there is more dependence on the preceding values of the signal, rather than on the random excitation input. Regarding the PSDs, the normal case has its power concentrated at a peak around 1 Hz (corresponding to the subject's heart rate) and its first harmonic, reflecting a very regular cardiac cycle; the AF case has a clearly more disperse profile, without well demarcated peaks – reflecting a much less regular cardiac cycle. The entropy provides a good summary measure of these differences in the PSD, with a lower value for the normal case where the profile is very sparse and organized, compared to a higher value for the AF case where the profile is much more disperse.