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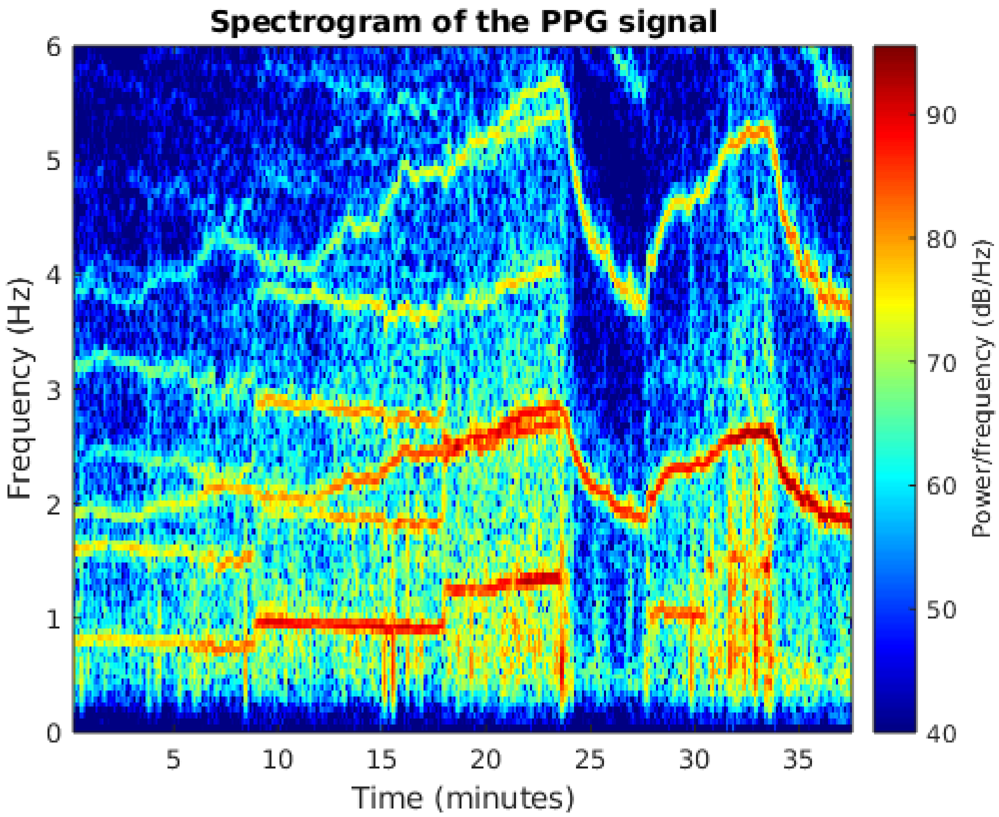
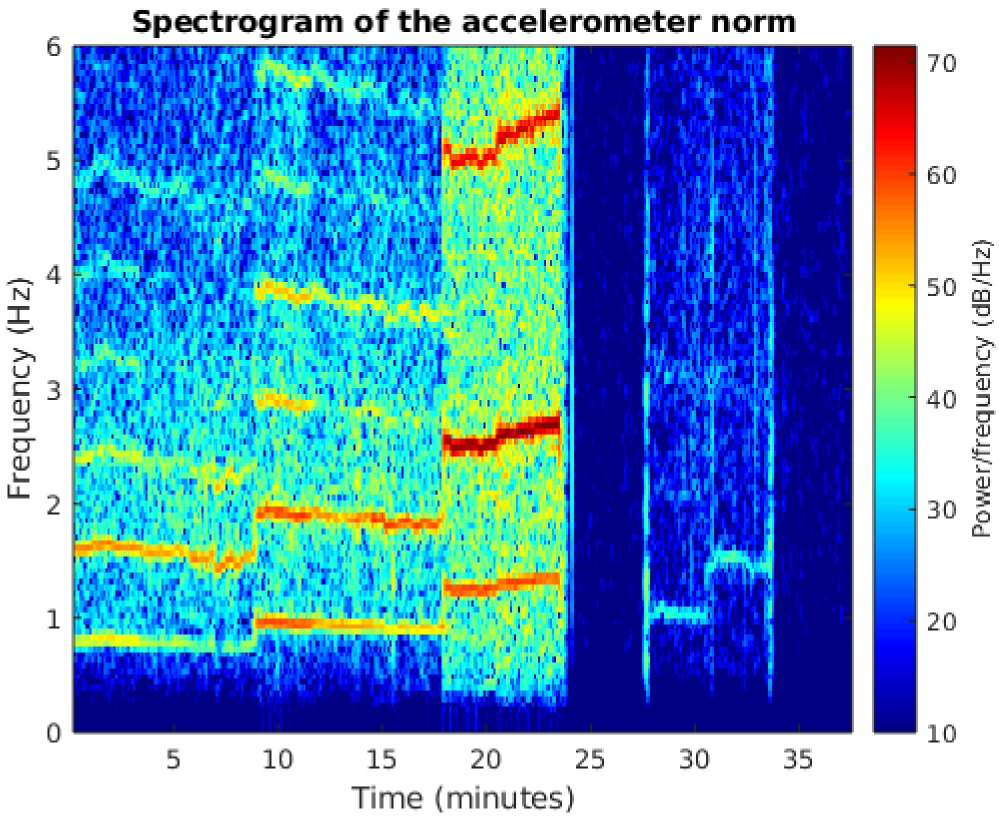
1. Heart rate estimation from a smartwatch-derived PPG signal during exercise

In [9]:

```
clear;
close all;
clc;

%% Load the raw data
load('ppg_acc.mat');

%% Baseline attenuation: Highpass filter on the PPG and accelerometer signals
% For the PPG signal we do not want to filter out the heart rate. Considering
% a minimal physiological heart rate of 30 bpm (0.5 Hz), we can use a highpass
% filter at 0.5 Hz. For the accelerometer norm signal, we do not want to filter
% out the frequencies of rhythmic motion. Considering a very slow walking pace
% of 1 step/s (1 Hz), the frequency of the arm swinging movement is half of
% that frequency, i.e. 0.5 Hz, and therefore we can use the same filter as for
% the PPG signal.
fs = 25;
[b,a] = butter(2, 0.5/(fs/2), 'high');
ppg = filtfilt(b, a, ppg);
accn = filtfilt(b, a, accn);

%% Spectrogram of the PPG & accelerometer norm signals
% When running, or when suddenly stopping an intense exercise, the heart rate
% can change quite fast in matter of a few seconds. A window of 10 seconds
% would be short enough at all times to consider the signal stationary in the
% window. However, a slightly longer window, e.g. 20 seconds, will also be fine
% the vast majority of the time, with the advantage of improving the frequency
% resolution of our spectrogram. It is therefore a good choice.
window = round(20*fs);          % Windows of 20 seconds
noverlap = round(0.95*20*fs);   % Overlap of 95%

figure('Units','centimeters','Position',[0,0,25,11],'Color','w');
spectrogram(ppg, window, noverlap, [], fs, 'yaxis');
ylim([0,6]);
colormap('jet');
set(gca, 'clim', [40, max(get(gca, 'clim'))]);
title('Spectrogram of the PPG signal');

figure('Units','centimeters','Position',[5,5,25,11],'Color','w');
spectrogram(accn, window, noverlap, [], fs, 'yaxis');
ylim([0,6]);
colormap('jet');
set(gca, 'clim', [10, max(get(gca, 'clim'))]);
title('Spectrogram of the accelerometer norm');
```

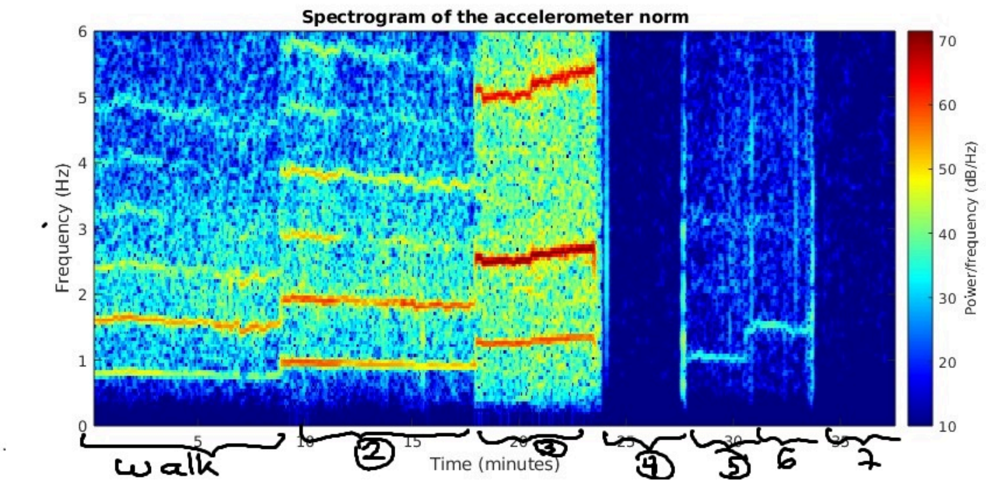




Question 1 :

The walk occured during 0 to around 9 minutes, the slow pace run during 9 to 18 minutes, the fast pace run during 18 to 24 minutes, the first rest during 24 to 27 minutes, the slow pace bike during 27 to 31 minutes, the fast pace bike during 31 to 34 minutes and the second recovery from 34 minutes to the end of the recording.

It was easy to spot the rest phase as no motion appears in them. Changes between phases are obvious because the frequency difference define them clearly.



Question 2 :

Knowing that the motion frequency appears on the PPG signal as well, it is easy to isolate the heart rate signal. The minimal heart rate should be around 2Hz (end of graph) and the maximal around 3Hz (end of fast running).

Question 3 :

While biking, the hand movement is very low and pedaling induces less acceleration in wrist than running (feet impact) or walking. The biking sessions, thus, correspond to the part of the spectrogram where the power at motion frequency is hardly distinguishable (~30dB/Hz) but not nonexistent.

Question 4 :

In the beginning of the fast running section, the heart rate frequency overlaps with the arm motion frequency's second harmonic, making it hard to distinguish one from the other. Trying to cancel the motion noise from the PPG signal could lead to the loss of the heart rate information.

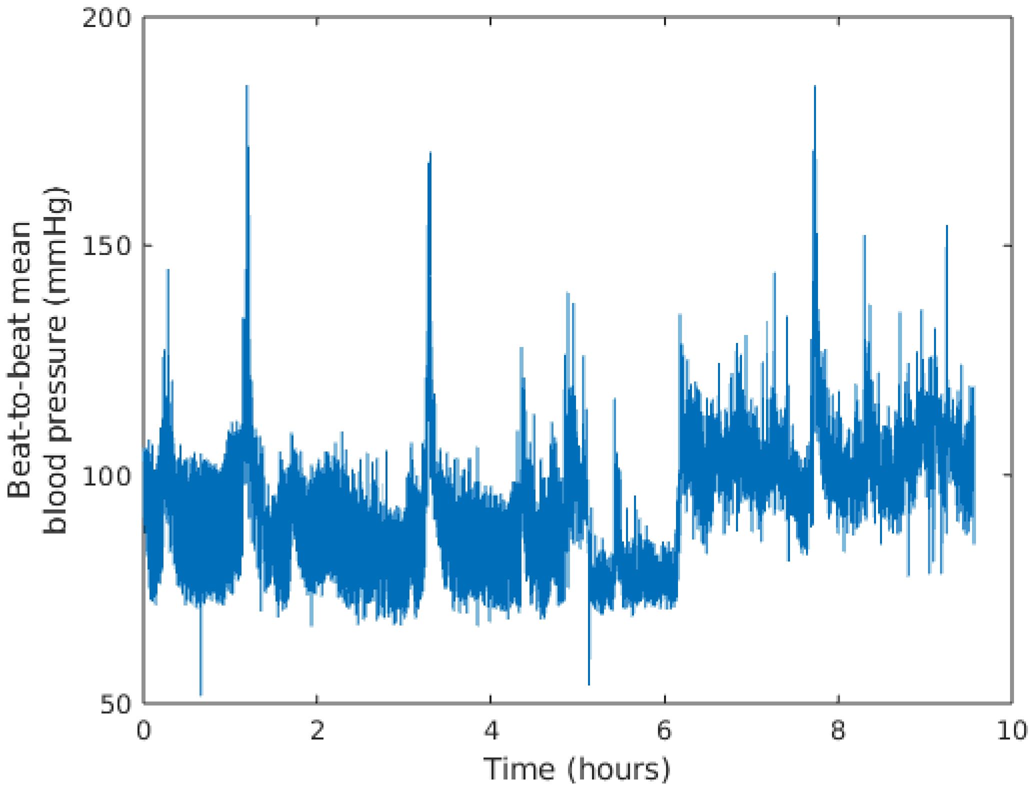
Question 5 :

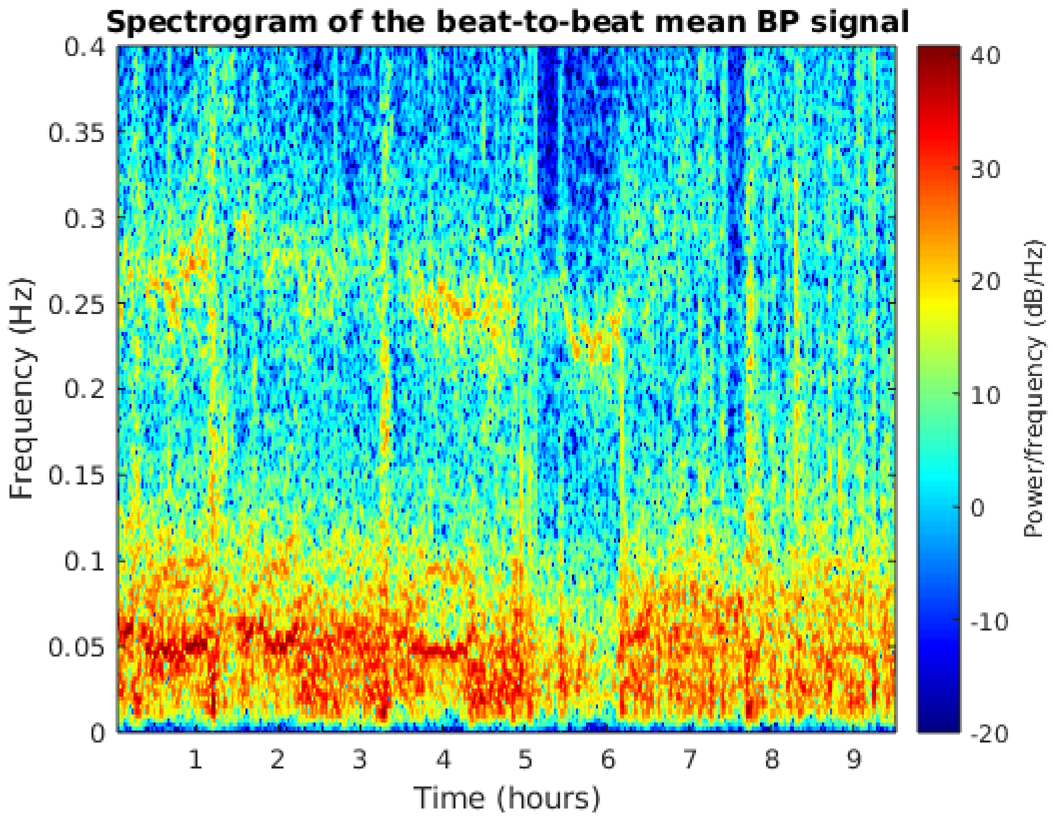
As we seem to have an arm swinging frequency around 0.8Hz, the subject was walking 1.6Hz (96 steps per minute). This explains why the second harmonic of arm swinging frequency in running and walking is more powerful as it also corresponds to the dominant leg motion frequency.

2: Sympathovagal balance estimation from blood pressure variability during sleep

In [10]:
```
clear;
close all;
clc;
```

```matlab
%% Load the raw data
load('bp.mat');

%% Plot the raw time signal
fs = 20;
t = (0:length(bp)-1)'/fs;
figure('Units','centimeters','Position',[0,0,25,11],'Color','w');
plot(t/3600, bp);
xlabel('Time (hours)');
ylabel({'Beat-to-beat mean','blood pressure (mmHg)'});

%% Baseline attenuation: Highpass filter on the BP signal
% The lower limit of the LF range is 0.04 Hz. With a cut-off frequency at 0.01
% Hz, one can check (with the freqz function for instance) that we do not
% attenuate significantly any frequency component >= 0.04 Hz. Therefore, 0.01
% Hz is a good trade-off between effective baseline cancellation and
% preservation of the frequency bands of interest.
[b,a] = butter(2, 0.01/(fs/2), 'high');
bp_filt = filtfilt(b, a, bp);

%% Spectrogram of the BP signal
% Adjust the window duration below to a better value and explain your choice.
winduration = 300;     % Window duration in seconds: Find a better suited value
window = round(winduration*fs);
noverlap = round(0.95*winduration*fs);  % Overlap of 95%

figure('Units','centimeters','Position',[0,0,30,11],'Color','w');
spectrogram(bp_filt, window, noverlap, [], fs, 'yaxis');
ylim([0,0.4]);
colormap('jet');
title('Spectrogram of the beat-to-beat mean BP signal');

% Adjust the lower limit of the colormap to a better value to improve the
% readability of the spectrogram.
cmaplowlim = -20; % Lower colormap limit: Find a better value
set(gca, 'clim', [cmaplowlim, max(get(gca, 'clim'))]);
```





Question 1 :

To choose the better suited duration of windows, we first check the lowest value of the signal which is : 1/0.04 = 25. Then to be sure that the length is long enough to include a few periods of the lowest frequency, we choose 300s (12 cycles) being carefull to not loose the stationarity assumption (5 minutes is a reasonable duration for this assumption). We can see on the graph that it allows us to see the lowest frequencies.

Question 2 :

At the beginning, most of the color we see is red/orange and there are a few yellowish tones (around -20 dB/Hz), therefore we need to rise up the limit of the color map. By checking the balance between window length and color map, we arrive at the following value : -20. We can see on the graph that the map is readable to extract information.

Question 3 :

At 2 hours, the HF-to-LF ratio is the higher which means sympathetic activity is at his peak and demonstrating a low sympathovagal balance. On the other hand we find at 6 hours, the HF-to-LF ratio has considerably decreased, meaning that the parasympathetic system has taken over. At 4 hours, it is between the two previous ones which can act as a transition between the two types of activity.

If chronic, this increase of the sympathovagal balance can be a signal/indicator of cardiovascular or autonomic disease.

Question 4 :

Yes, we could have concluded the same from the time signal; however, this method would be much more tedious and less evident. Indeed, to observe this, we had to zoom in on the time signal by restricting the x-axis to ±0.05 hours at the three specified points (t = 2h, t = 4h, t = 6h) and made slight adaptations to the y-axis to visualize the signal properly. This is likely due to the fact that both of those frequencies are quite close to each other.

Subsequently, in the t = 2 graph, the signal maxima and minima appear to be quite spaced apart, indicating a predominance of the lower frequencies (sympathetic activity). However, we can still see the presence of the higher frequencies, albeit with a significantly smaller amplitude compared to the lower ones. This suggests a low sympathovagal balance (HF to LF ratio).

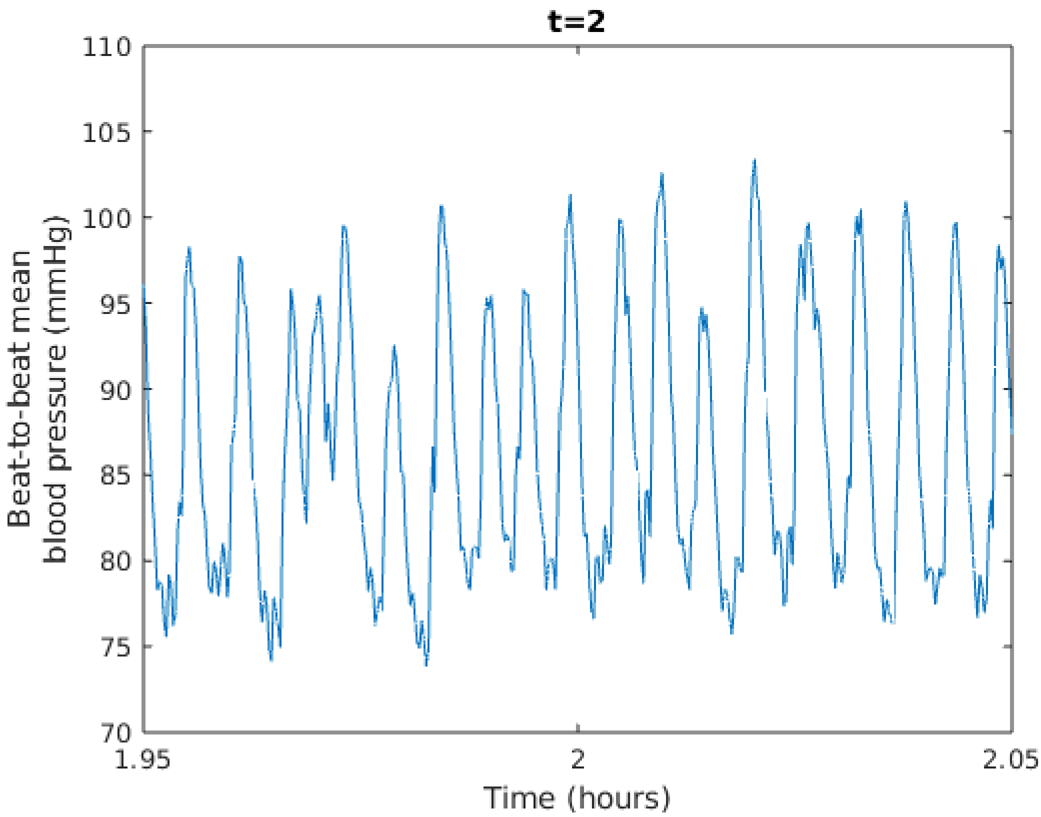
In the t = 4 graph, we observe a slight change between the two frequencies. Just as in the spectrogram, there is an increase in the presence of the higher frequencies in the time signal, accompanied by a slight decrease in the lower frequencies. This leads to an increase in the sympathovagal balance (an increase in the ratio).

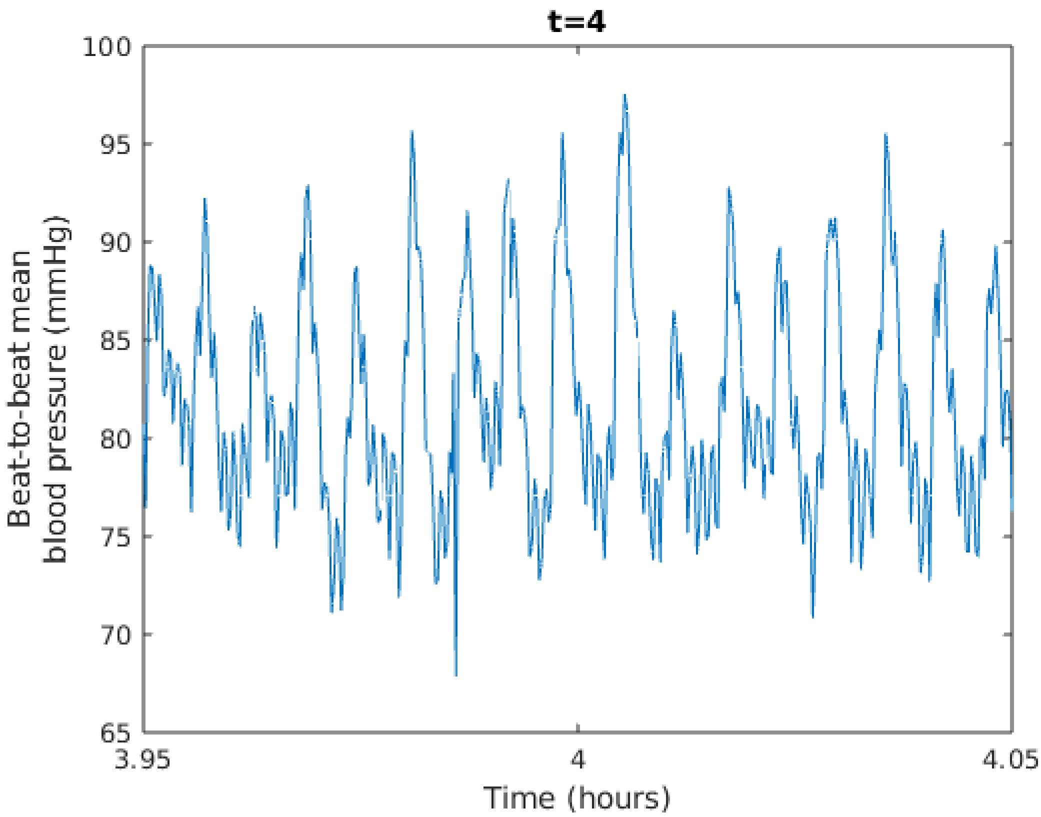
This increase is even more pronounced at t = 6, where, similar to the spectrogram, we see a significant loss of the lower frequencies, which are overtaken by the higher frequencies.

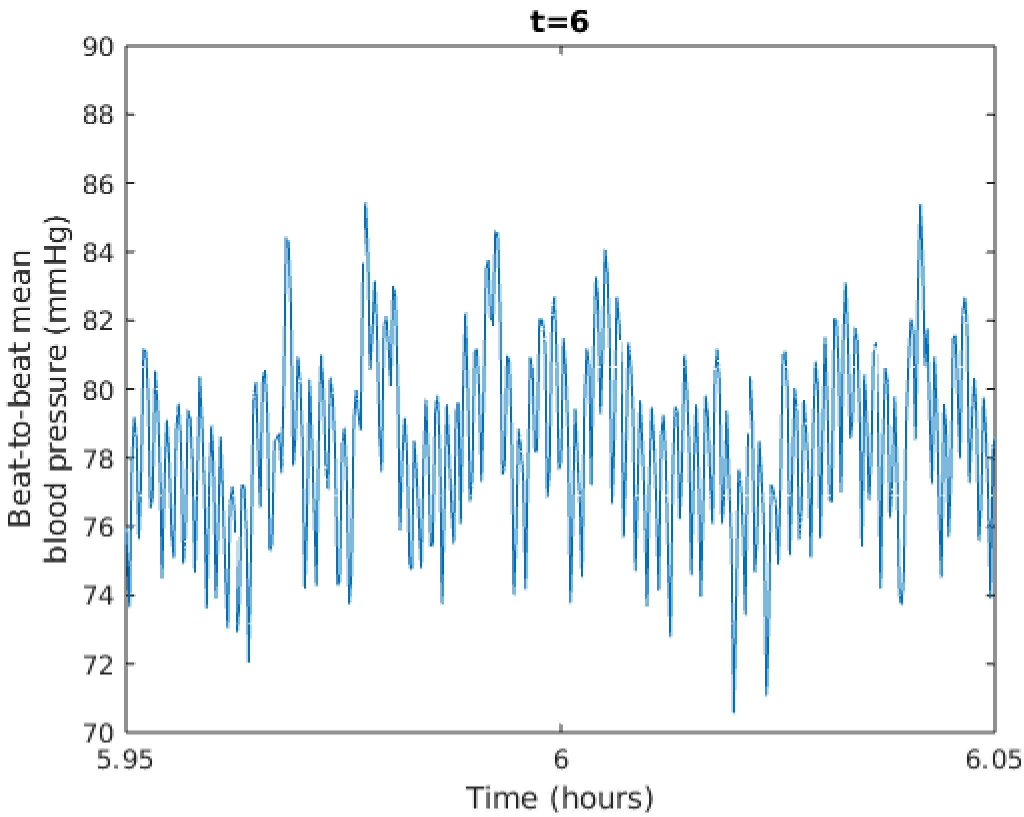
Therefore, as mentioned previously, the sympathovagal balance can indeed be assessed in the time domain; however, quantifying it is more challenging and less obvious than with the spectrogram.

In [11]:
```
figure('Units','centimeters','Position',[0,0,25,11],'Color','w');
plot(t/3600, bp);
xlabel('Time (hours)');
ylabel({'Beat-to-beat mean','blood pressure (mmHg)'});
```

```
xlim([1.95 2.05]);
ylim([70 110]);
title('t=2');

figure('Units','centimeters','Position',[0,0,25,11],'Color','w');
plot(t/3600, bp);
xlabel('Time (hours)');
ylabel({'Beat-to-beat mean','blood pressure (mmHg)'});
xlim([3.95 4.05]);
ylim([65 100]);
title('t=4');

figure('Units','centimeters','Position',[0,0,25,11],'Color','w');
plot(t/3600, bp);
xlabel('Time (hours)');
ylabel({'Beat-to-beat mean','blood pressure (mmHg)'});
xlim([5.95 6.05]);
ylim([70 90]);
title('t=6');
```







3: Respiration signal of a patient suffering from sleep apnea

Question 1 :

The ideal value is the apnea time period (assuming it is bigger than the ventilation period). The minimal value is around 7.5s (60/8 = 7.5) - period of a breathing cycle-. This is because we want to be sure that the window contains the signal fully constructed. Moreover, practically, the minimum value would be more around 10 since the period cited before is an average of the cycle and we should then take in consideration that some cycles may take longer. Plus, the maximal value is as said before, 20s (minimal period of apnea). The reason for the later would be as to ensure that the apnic event are included in the analysis.