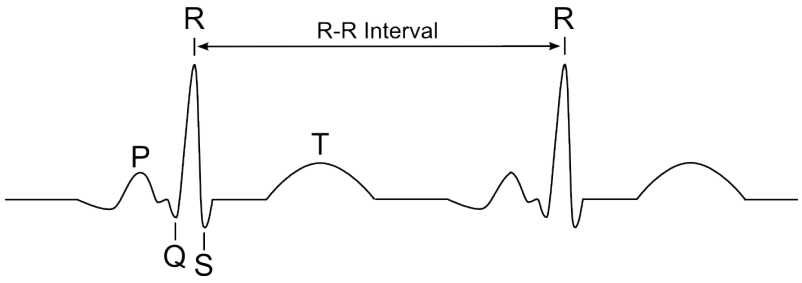
EE3518 RESPIRATORY AND CARDIOVASCULAR MEASUREMENT
Lecture 1 – Heart rate variability analysis 1

Introduction
Heart rate variability (HRV) refers to the natural variation in the time interval between heartbeats.

Methods used to detect beats include: ECG or the pulse wave signal derived from the arterial blood pressure or photoplethysmograph (PPG). ECG is considered superior because it provides a sharply defined 'landmark' within the cardiac cycle, i.e. the R-wave, and is not influenced by other variables (e.g. depolarisation latency period, pulse wave velocity) etc.

The R-R interval is usually calculated for each beat, which provides the raw data for HRV analysis. Note: The term "NN" is used in place of RR to emphasize the fact that the processed beats are "normal" beats.



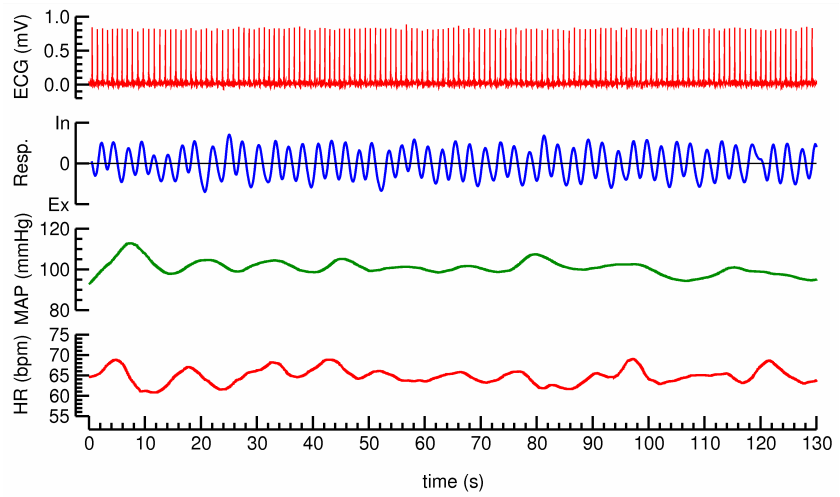
Clinical significance
Variability of heart rate is perfectly normal in healthy people. A range of outcomes/conditions may be associated with abnormal (usually lower) HRV, including congestive heart failure, diabetic neuropathy, depression post-cardiac transplant, susceptibility to SIDS, poor survival after myocardial infarction and poor survival in premature babies.

In the field of psychophysiology, there is interest in HRV. For example, HRV is related to emotional arousal. High-frequency (HF) activity (see later) has been found to decrease under conditions of acute time pressure and emotional strain and elevated state anxiety. HRV has been shown to be reduced in individuals reporting a greater frequency and duration of daily worry. In individuals with post-traumatic stress disorder (PTSD), HRV and its HF component is reduced compared to controls whilst the low-frequency (LF) component is elevated.

Modulation by Sympathetic and Parasympathetic Nervous System
Variation in the beat-to-beat interval is a physiological phenomenon. The sinoartrial (SA) node receives several different inputs, so the instantaneous heart rate or RR interval and its variation are the results of these inputs.

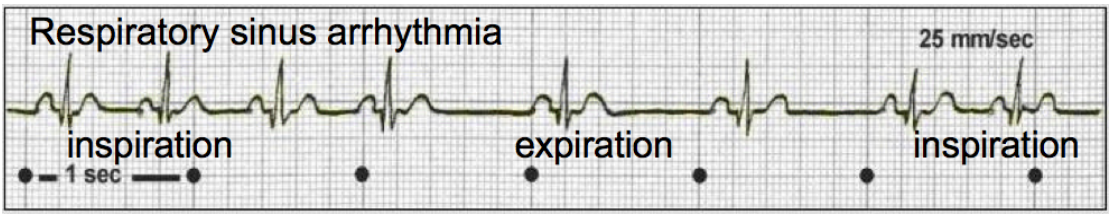
Parasympathetic "Rest & Digest"	Sympathetic "Fight or Flight"
Decrease Heart Rate	Increase Heart Rate
Decrease Force of Contraction	Increase Force of Contraction
Decrease Blood Pressure	Increase Blood Pressure
Miosis (Pupil Constriction)	Mydriasis (Pupil Dilation)
Spasm of Accommodation	Paralysis of Accommodation
Bronchoconstriction	Bronchodilation
Increase Gut Activity	Decrease Gut Activity
Increase Secretions	Decrease Secretions
Vasoconstriction	Vasodilatation
No innervations to Sweat glands	Increase Sweating

The main inputs are the sympathetic and the parasympathetic nervous system (PSNS) and humoral factors. Respiration gives rise to waves in heart rate mediated primarily via the PSNS, and it is thought that the lag in the baroceptor feedback loop may give rise to 10 second waves in heart rate (associated with Mayer waves of blood pressure), but this remains controversial.



Factors that affect the input are the baroreflex, thermoregulation, hormones, sleep-wake cycle, meals, physical activity, and stress.

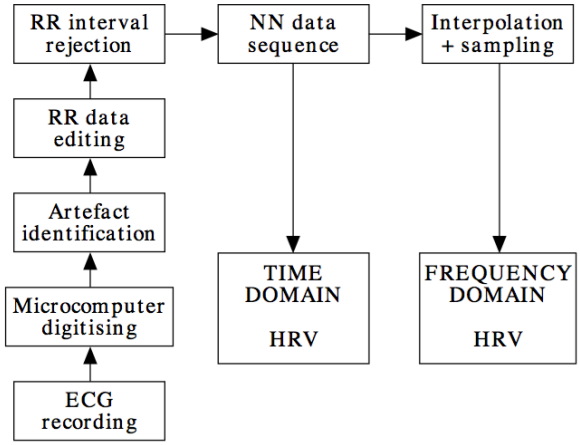
Decreased PSNS activity or increased SNS activity will result in reduced HRV. High frequency (HF) activity (0.15 to 0.40 Hz), especially, has been linked to PSNS activity. Activity in this range is associated with the respiratory sinus arrhythmia (RSA). RSA is the acceleration of HRinst on inspiration, and its deceleration on expiration. The magnitude of the effect is highly variable and tends to be larger the slower and deeper the breathing.



Less is known about the physiological inputs of the low frequency (LF) activity (0.04 to 0.15 Hz). Though previously thought to reflect SNS activity, it is now widely accepted that it reflects a mixture of both the SNS and PSNS.

HRV Analysis

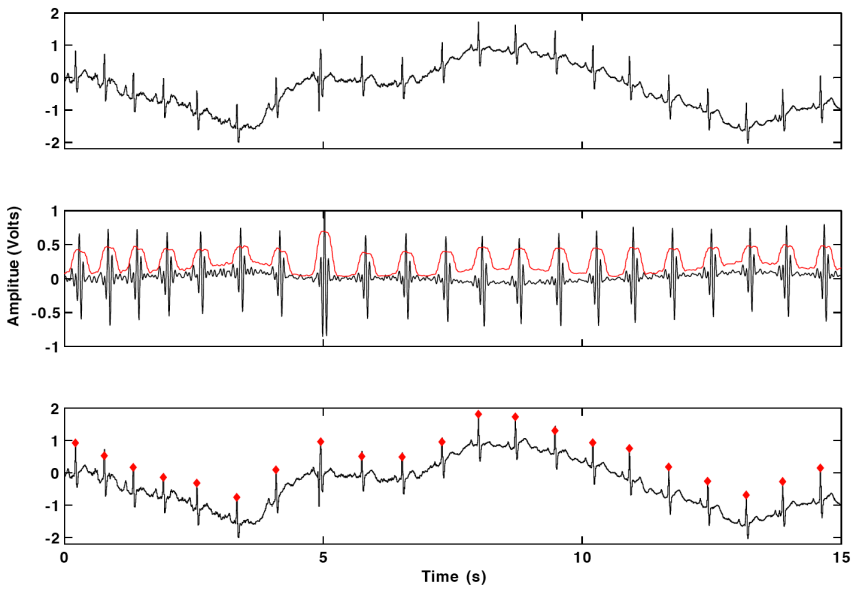
The method of analyzing HRV data may be summarized by the schematic below.



R-R interval measurement

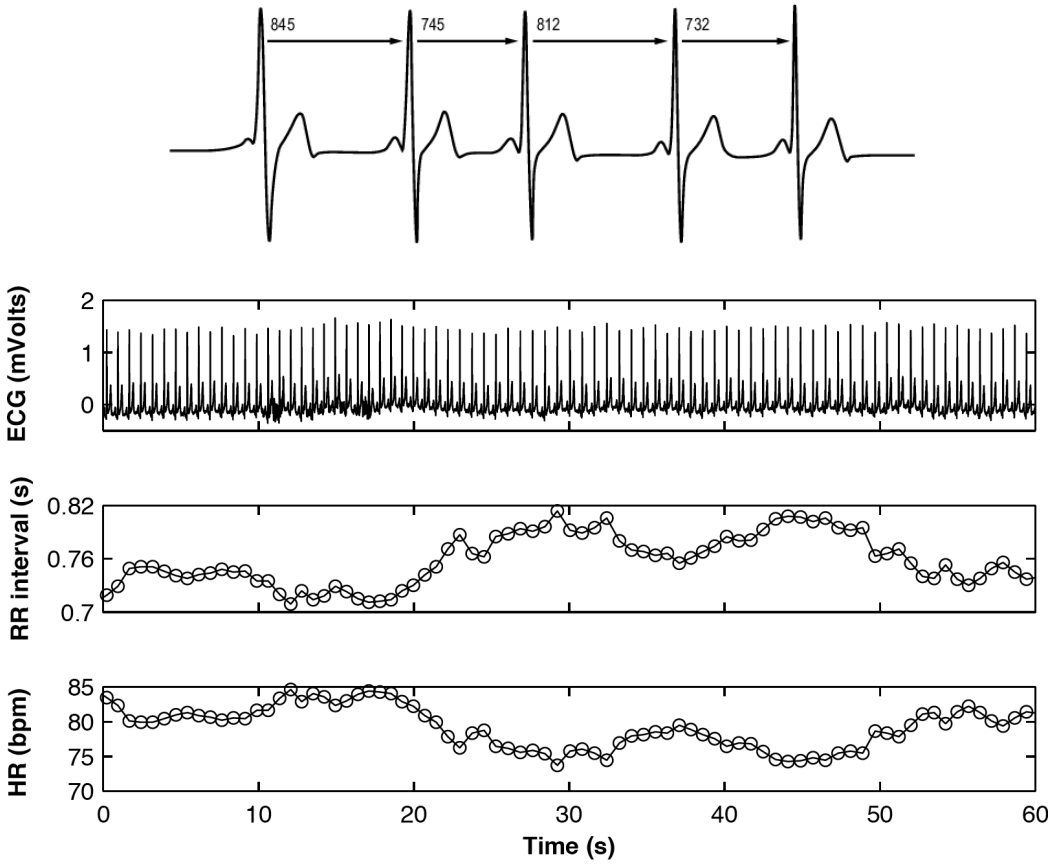
R wave detection

For HRV analysis the raw signal should be sampled at a high sample rate (e.g. 1 kHz or greater). Artefacts (physiological and instrumentation) should be removed. R-wave detection is achieved using peak detection, or threshold-crossing detection. A fixed or variable (adaptive) threshold may be implemented to improve discrimination of R-waves from background noise (i.e. to avoid false positive or false negative detection).



guidelines.

For practical purposes the first step in HRV analysis is to convert the raw biosignal (e.g. ECG) into a R-R interval 'signal'.



This may be represented as an array of R-R (NN intervals). There are two methods of representing this information:

Unevenly sampled
The NN interval is calculated for each heartbeat, so one array element is produced for each heart beat. In other words each element represents a different period of time, depending on the length of the RR interval. In other words the data in the array is not evenly spaced in time.

Evenly sampled
A sample rate is chosen (e.g. 1 kHz), then the time series is repeatedly sampled, so one array element is produced for each sample interval. The NN interval is written to the data file a number of times so that each heart beat is represented by a number of samples proportional to the NN interval. In other words the data in the array is evenly spaced in time.

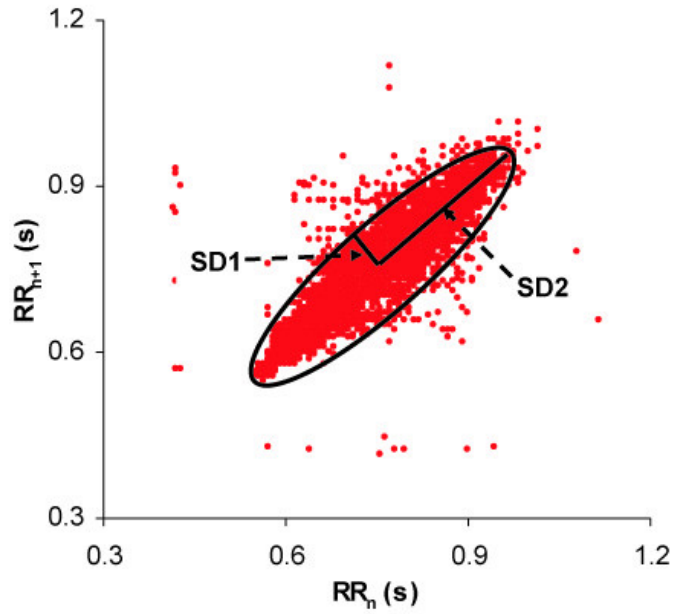
Time domain methods
The following is a summary of the five most commonly used time domain HRV measurements (there are many more!).

- SDNN, the standard deviation of NN intervals. Often calculated over a 24-hour period.
- SDANN, the standard deviation of the average NN intervals calculated over short periods, usually 5 minutes. SDANN is therefore a measure of changes in heart rate due to cycles longer than 5 minutes.
- RMSSD, the square root of the mean squared difference of successive NNs.

- NN50, the number of pairs of successive NNs that differ by more than 50 ms.
- pNN50, the proportion of NN50 divided by total number of RRs.

A geometric method - Poincaré plot

Poincaré plots are also used to analyse heart rate variability. A typical Poincaré plot is shown below. The *x*–axis represents the RR interval of the current normal beat and the *y*–axis represents the RR interval of the succeeding normal beat. An ellipse is fitted to the data points and the Poincaré plot indices are calculated by estimating the short diameter (SD1), the long diameter (SD2) and the ratio of the short and long diameters (SD1/SD2 ratio) of the fitted ellipse.



SD1 represents the dispersion of points perpendicular to the line of identity and it seems to be an index of instantaneous recording of beat-to-beat variability; the SD2 represents the dispersion of points along the line of identity and represents the longer term HRV the relationship of both (SD1/SD2) shows the ratio between the short- and long-term variations of the RR intervals.

Frequency domain methods

Frequency domain analysis allows identification of periodic components of the HRV signal, especially over long time periods (e.g. several minutes or even several hours).

The spectral power density is the most widely used. This is obtained using a discrete Fourier transform of the HRV signal (not the raw biosignal). The time series must be evenly sampled, i.e. the NN interval appears in the time series not once, but a number of times proportional to the NN interval value itself.

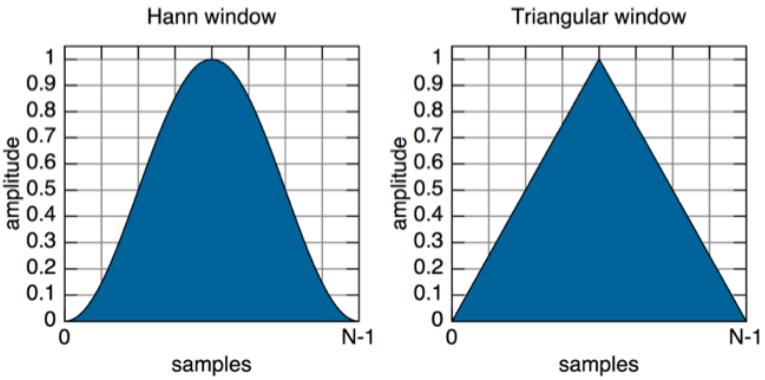
An evenly sampled time series can be produced from unevenly sampled data as follows. A sample interval is selected (e.g. 1 ms) then the time series is repeatedly sampled, so one array element is produced for each sample interval. The process is repeated *n* times for each heart beat i.e. *n* samples of each NN interval are produced, where

$$n = \text{NN interval} / \text{sample interval}$$

Thus, each datum in the time series represents a fixed period of time rather than a single heart beat.

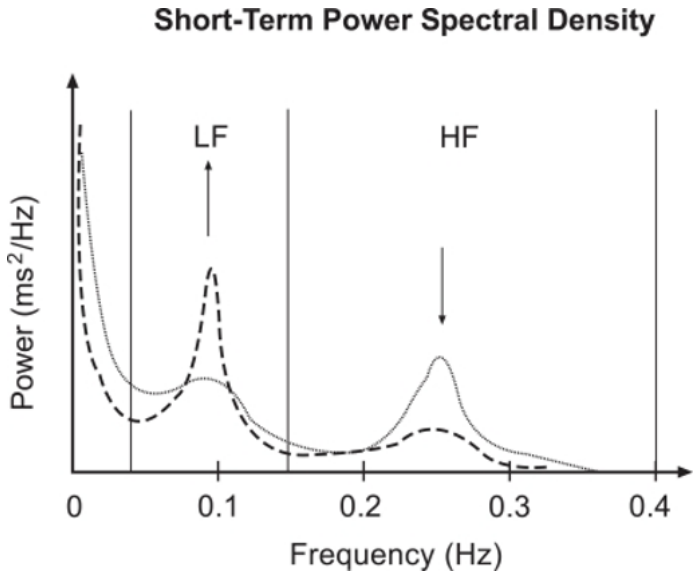
To reduce the amount of information, the array can be **downsampled**, e.g. to 100 Hz by deleting some samples and keeping every 10^{th} sample (a process known broadly as **decimation***)*. Evenly sampled data generally takes up more storage (unless it has been sufficiently downsampled).

The power spectrum functions (e.g. in LabVIEW) usually require the sample interval to be specified, and windowing should be used (e.g. Hamming, Hann, trapeziod etc). This ensures that no discontinuity is present at the beginning and ends of the time series, which would produce artefacts in the spectrum and produce erroneous results.



The following definitions are used for the four standard HRV frequency ranges:

Ultra Low Frequency (ULF):	0.000 Hz ≤ ULF ≤ 0.0003 Hz
Very Low Frequency (VLF):	0.0003 Hz ≤ VLF ≤ 0.04 Hz
Low Frequency (LF):	0.04 Hz ≤ LF ≤ 0.15 Hz
High Frequency (HF):	0.15 Hz ≤ HF ≤ 0.4 Hz



Several features may be identified from the spectra:

- Total power (PT) ≤0.4HZ

This is the area under the power spectrum and can be found by integrating the power spectrum (numerical integration).

Similarly, the following variables can be derived using integration between the relevant frequency limits:

- Power in ultra low frequency range (PULF: ≤ 0.0003 Hz)
- Power in very low frequency range (PVLF: 0.0003 – 0.04 Hz)
- Power in low frequency range (PLF: 0.04 – 0.15 Hz)
- Power in high frequency range (PHF: 0.15 – 0.4 Hz)
- Normalised power in low frequency range: PLF/(PLF+PHF)x100%
- Normalised power in high frequency range: PHF/(PLF+PHF)x100%
- PLF/PHF ratio