HRV Analysis

* Abnormal beats and noise: Detection and Handling
  + Affect geometric/time-domain metrics the most
    - Especially SDNN/SDANN
  + Ectopic beats – arrhythmic beats (unexpected times)
    - Occur when RR intervals differ by more than certain amount (20%, 32.5% increase/24.5% decrease, depending on source)
      * Is there an objective standard we should use?
    - How do you recognize them?
      * Useful to have *automatic system of classification* (requires deep learning)
    - If infrequent: Remove ectopic beats; normal beats interpolated
    - If frequent: Segment with high occurrence removed
  + Artefacts – Jumps in signal caused by electrode pops, etc.
    - Arbitrary threshold for how many NN beats required for analysis (i.e. 1000)
    - Visual identification and exclusion of artefacts
      * Again, useful to automatize this
  + Robust techniques for ectopic/artefact exclusion
    - Upper limits for high-frequency power (arbitrary)
    - Parseval’s Theorem
      * Power in frequency domain ~ power in time domain
      * Parseval index, should be close to 1; exclude major deviations
    - Blind source separation/Independent component analysis (ICA)
      * Multiple observations; identification of independent components through minimizing cost function (mutual information, kurtosis, etc.)
      * Involves non-linear transform –> may distort signal
      * Criteria: No correlation between components, high signal/noise ratio, requires 3 channels of ECG
  + Adaptive algorithm for identifying normal beats
    - Previous methods
      * Hidden Markov Models
      * Pattern recognition
    - Algorithm steps
      * Template creation
      * QRS detection
      * Ectopic identification
        + If RR-interval deviates from median of last nine NNs by >10%
  + Other techniques for denoising
    - Singular spectrum analysis (SSA)
      * Decomposition
        + Embedding: one dimensional time series 🡪 multidimensional (trajectory matrix); window length parameter
        + Singular value decomposition: trajectory matrix as sum of bi-orthogonal elementary matrices
      * Reconstruction
        + Grouping: Split elementary matrices into groups
        + Diagonal averaging: Transform to Hankel matrix, then time series
    - Multivariate singular spectrum analysis (MSSA)
      * Extends SSA to multivariate time series
      * Algorithm: Separate and process twice, reconstruct
    - Wavelet transforms can also be used for denoising (described later)
* Resampling
  + RR tachogram (RR interval time vs. time of sample) is non-uniformly distributed
  + Often needed to define instantaneous heart rate (IHR) on tachogram
    - Not always, however (see FMPI below)
  + Many subsequent spectral analyses require uniform distribution
    - Not all, however (see Lomb periodogram)
  + Sampling is a function of number of beats
    - Can approximate spacing to be mean RR interval 🡪 only good for small deviations
  + Piecewise-constant resampling
    - Rate assumed constant within event-interval
    - ωSCT(t) = (tn − tn−1)−1 : t ∈ (tn−1, tn]
  + Polynomial techniques
    - Linear are most common
    - Cubic approximations match Taylor approximation of sinusoid
  + Several different accepted resampling frequencies (e.g. 2, 3, 4 Hz)
    - Low sampling frequency ~ loss of information
    - High sampling frequency ~ lower analysis speed
  + Frequency-Modulated Phase-Interpolation (FMPI)
    - Defines continuous phase function, from which IHR is deduced (derivative)
* Time-Domain analysis – Quantify variability in IHR measurements
  + Geometric metrics – Insensitive to outliers, scale dependent
    - HRV triangular index – Integral of density of RR interval histogram divided by height, based on 24 hr recordings
    - TINN
    - Differential index
    - Logarithmic index
  + Geometric metrics – Scale independent
    - Fano Factor
    - Wavelet-transform standard deviation
    - Allan factor
    - Detrended Fluctuation Analysis
  + Statistical metrics
    - SDNN – Standard dev. of NN interval; more accurate over 24 hrs, “gold standard” for identifying cardiac risk
    - SDANN (5 min segments)
    - RMSDD – Root mean square of successive differences between NN; reflects beat-to-beat variance
    - SDNN index
    - SDSD
    - NN50 and pNN50
* Frequency-Domain analysis 🡪 Power spectrum density (PSD), distribution of absolute and relative power
  + Fourier techniques
    - Most common technique of analyzing PSD
    - Require resampling so that time intervals can be assessed
    - PSD assessed in terms of different frequency bands
      * Ultra-low-frequency (ULF): <0.003 Hz
      * Very-low-frequency (VLF): 0.0033-0.04 Hz
      * Low-frequency (LF): 0.04-0.15 Hz
      * High-frequency (HF): 0.15-0.40 Hz
        + Note: LF/HF is indicator of sympathovagal imbalance
        + LF generated by SNS (not really), HF by PNS
  + Auto-regressive spectral estimations
    - Constructing PSD from only original points
    - Less accurate than PSD produced from FFT and linear resampling (loss of information)
  + Lomb periodogram
    - Does not require resampling, but equally effective as cubic resampling method (when no noise)
    - Power spectrum weighted on point by point basis, not interval
  + Wavelet transforms
    - Allow for analysis of non-stationary signals and better assessment of instantaneous changes
      * Fourier transforms make use of infinite sinusoids; wavelets are localized
    - Based on scaling and transposition
    - Also has been used for denoising
* Nonlinear Analysis
  + Poincare plot
  + Entropy
  + Total HRV ellipse
* Stochastic Processing