**OOFOS HRV ANALYSIS READ-ME**

**Intro to HRV:**

**What is HRV:** Heart rate variability (HRV) consists of changes in the time intervals between consecutive heartbeats called interbeat intervals (IBIs). Autonomic efferent neurons and circulating hormones modulate SA node initiation of heartbeats. The interdependent regulatory systems that generate the complex variability of a healthy heart operate over different time scales to achieve homeostasis and optimal performance. Circadian oscillations in circadian variations in core body temperature, metabolism, sleep-wake cycles, and the renin angiotensin system contribute to 24 h HRV measurements. The complex dynamic relationship between the sympathetic and parasympathetic branches, and homeostatic regulation of HR viarespiration and the baroreceptor reflex are responsible for short-term and ultra-short-term HRV measurements. Slower regulatory mechanisms contribute to HRV metrics recorded over longer measurement periods.

(Shaffer et, al. 2017)

**How is HRV Measured:** Time domain indices quantify the amount of HRV observed during monitoring periods that may range from <2 min to 24 h. Frequency-domain values calculate the absolute or relative amount of signal energy within component bands. Non-linear measurements quantify the unpredictability and complexity of a series of IBIs.

(Shaffer et, al. 2017)

**Length of Observation:** The length of the recording period significantly affects both HRV time domain and frequency domain measurements. Since longer recordings are associated with increased HRV, it is inappropriate to compare metrics like SDNN when they are calculated from epochs of different length. Generally, resting values obtained from short-term monitoring periods correlate poorly with 24 h indices and their physiological meanings may differ.Longer recording periods provide data about cardiac reactions to a greater range of environmental stimulation. In addition to cardiorespiratory regulation, extended measurement periods can index the heart’s response to changing workloads, anticipatory central nervous activity involving classical conditioning, and circadian processes, including sleep-wake cycles. Twenty-four-hour recordings reveal the SNS contribution to HRV**.**

(Shaffer et, al. 2017)

**Using the HRV analysis code:**

This code utilizes the hrv-analysis library developed for python. Documentation and a link to their git-hub can be found using the below link.

<https://pypi.org/project/hrv-analysis/>

1). Open *oofos\_hrv\_analysis.py* [Spyder/Jupyter NB or use the Terminal]

2). Check to see the heart rate exports are correctly named

3). Check to see the heart rate exports are in the correct folder path

4). This code isolates the heart rate variability for one 24 h period based upon the selected date. It is important that you reference the data using the *ACTi-life* software in order to identify the correct date. The SOP requires as close to a full 24 h period as possible. HR is recorded for 36h starting before bed on day 1 (Bedtime-11:59pm) and ending the morning of day 3 (12:01am-Wakeup). This should allow for a complete 24 h period of day 2 (12:00am – 12:00am). \*\*\*\*Check to make sure participant did not go to bed after 12:00 am \*\*\*\*

5). Using the date of day 2 input this into the python script.

**BELOW:** This is the section of code where the date should be changed for each subject. Note that the date is as follows ‘year\_month\_day’. It is important to maintain any leading zeros for single digit months or days.

Text

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6). Now you are ready to run the code

7). Run the code

8). You will be prompted with a subject ID input prompt. Enter the subject info as follows: OP3\_S#\_V#

- S# is the subject number

- V# is the visit number

9). Notice in the screenshot below the section of code contains the cut points for what is identified as an outlier currently the lower bound sits at 300ms and the upper bound is at 2000ms or 2 seconds. This can be changed.



10). At this point the code should run completely WARNING: THIS TAKES SOME TIME THERE IS A LOT OF DATA

\*\* If the code is being run on a computer with a GPU it is possible in one or two lines of code to have the computer run the code on the GPU for a faster run time.\*\*

11). The code will generate three plots for each day which will be saved AUTOMATICALLY to one collective pdf labeled by subject and visit #. This will also save in the same folder the hrv analysis code is kept. Additionally, the time domain and frequency domain metrics will be appended to an excel sheet which will be AUTOMATICALLY saved in the same folder.

12). Upload the information into the correct folder structures on one drive.

13). The information below explains the resultant metrics that the code will spit out

**Time Domain Metrics:**

**NN Interval vs. RR Interval:** The RR interval represents the time between each detected heartbeat, measured from peak (R) to peak (R) on the QRS complex. The NN interval represents the RR interval data but with added filtering to remove artifacts and noise present in the data making some RR intervals unreliable.

1. **mean\_nni** = The average of every NN-interval duration (ms)
2. **sdnn** = Standard Deviation of every NN-interval (ms)
3. **sdsd** = The standard deviation of the differences between adjacent NN-intervals (ms)
4. **nni\_50** = The number of interval differences of successive NN intervals greater than 50 (ms)
5. **pnni\_50** = The proportion of nni\_50 divided by the total number of NN intervals (%)
6. **nni\_20** = The number of interval differences of successive NN intervals greater than 20 (ms)
7. **pnni\_20** = The proportion of nni\_20 divided by the total number of NN intervals (%)
8. **rmssd** = The square root of the mean of the sum of the squares of differences between adjacent NN-intervals (ms)
9. **median\_nni** = Median of the absolute values of the successive differences between every NN-interval (ms)
10. **range\_nni** = Difference between the maximum and the minimum NN-intervals (ms) (Max of 1700 based on outlier bounds)
11. **cvsd** = Coefficient of variation of the successive differences equal to the rmssd divided by the mean\_nni
12. **cvnni** = Coefficient of variation equal to the ratio of sdnn divided by mean\_nni
13. **mean\_hr** = Average Heart Rate
14. **max\_hr** = Maximum Heart Rate
15. **min\_hr** = Minimum Heart Rate
16. **std\_hr** = Standard Deviation of Heart Rate

Contains some age/gender/healthy ranges:

<https://www.sciencedirect.com/science/article/pii/S0735109797005548>

**SDNN (SD2):** The standard deviation of the IBI (Inter Beat Intervals) of normal sinus beats (SDNN) is measured in ms. "Normal" means that abnormal beats, like ectopic beats (heartbeats that originate outside the right atrium’s sinoatrial node), have been removed. The SDNN is more accurate when calculated over 24 h. than during the shorter periods monitored during biofeedback sessions. The SDNN is the "gold standard" for medical stratification of cardiac risk when recorded over a 24 h period. SDNN values predict both morbidity and mortality. Based on 24 h monitoring, patients with SDNN values below 50 ms are classified as unhealthy, 50–100 ms have compromised health, and above 100 ms are healthy. Heart attack survivors, whose 24 h measurements placed them in a higher category, had a greater probability of living during a 31-month mean follow-up period. For example, patients with SDNN values over 100 ms had a 5.3 times lower risk of mortality at follow-up than those with values under 50 ms.

(Shaffer et, al. 2017)

**RMSSD (SD1):** The root mean square of successive differences between normal heartbeats (RMSSD) is obtained by first calculating each successive time difference between heartbeats in ms. Then, each of the values is squared and the result is averaged before the square root of the total is obtained. The RMSSD reflects the beat-to-beat variance in HR and is the primary time-domain measure used to estimate the vagally mediated changes reflected in HRV. The RMSSD is identical to the non-linear metric SD1, which reflects short-term HRV. Twenty-four-hour RMSSD measurements are strongly correlated with pNN50 and HF power.

**Interpreting HRV Measures:**

Awareness of the context of recording and subject variables can aid interpretation of HRV measurements. Important contextual factors include recording period length, detection or recording method, sampling frequency, removal of artifacts, respiration, and whether or not there is PB. Important subject variables are age, sex, HR, and health status. In addition, influences of position, movement, recency of physical activity, tasks, demand characteristics, and relationship variables can all affect measurements subtly or even greatly by changing ANS activation, breathing mechanics, and emotions.

**Frequency Domain Metrics:**

**VLF Band:** The VLF band ranges from (0.0033–0.04 Hz). Low VLF power has been shown to be associated with arrhythmic death and PTSD. Low power in this band has been associated with high inflammation in several studies. Finally, low VLF power has been correlated with low levels of testosterone, while other biochemical markers, such as those mediated by the hypothalamic–pituitary–adrenal axis (e.g., cortisol), have not. Very-low-frequency power is strongly correlated with the SDNNI time-domain measure. There is uncertainty regarding the physiological mechanisms responsible for activity within this band. The heart’s intrinsic nervous system appears to contribute to the VLF rhythm and the SNS influences the amplitude and frequency of its oscillations.

**LF Band:** The LF band ranges from (0.04–0.15 Hz). This region was previously called the baroreceptor range because it mainly reflects baroreceptor activity during resting conditions. LF power may be produced by both the PNS and SNS, and BP regulation viabaroreceptors, primarily by the PNS, or by baroreflex activity alone. The SNS does not appear to produce rhythms much above 0.1 Hz, while the parasympathetic system can be observed to affect heart rhythms down to 0.05 Hz (20 s rhythm). In resting conditions, the LF band reflects baroreflex activity and not cardiac sympathetic innervation.

**HF Band**: The HF or respiratory band ranges from (0.15–0.40 Hz). The HF band reflects parasympathetic activity and is called the respiratory band because it corresponds to the HR variations related to the respiratory cycle. These phasic HR changes are known as RSA and may not be a pure index of cardiac vagal control. Heart rate accelerates during inspiration and slows during expiration. During inhalation, the cardiovascular center inhibits vagal outflow resulting in speeding the HR. Conversely, during exhalation, it restores vagal outflow resulting in slowing the HR *via* the release of acetylcholine. Total vagal blockage virtually eliminates HF oscillations and reduces power in the LF range. HF band power may increase at night and decrease during the day. Lower HF power is correlated with stress, panic, anxiety, or worry. The modulation of vagal tone helps maintain the dynamic autonomic regulation important for cardiovascular health. Deficient vagal inhibition is implicated in increased morbidity.

**Visualizing HRV:**

**Poincare Plot:** The Poincare ́ plot is a scatterplot of the current N-N interval plotted against the preceding N-N interval. Poincare ́ plot analysis is a quantitative visual technique, whereby the shape of the plot is categorized into functional classes. The plot provides summary information as well as detailed beat-to-beat information on the behavior of the heart. Points above the line of identity indicate N-N intervals that are longer than the preceding N-N interval, and points below the line of identity indicate a shorter N-N interval than the previous. Accordingly, the dispersion of points perpendicular to the line of identity (the “width”) reflects the level of short-term variability. This dispersion can be quantified by the standard deviation of the distances the points lie from the line of identity. This measure is equivalent to the standard deviation of the successive differences of the N-N intervals [standard deviation of successive differences (SDSD) or root-mean-square of successive differences (RMSSD)]. The standard deviation of points along the line of identity (the “length”) reflects the standard deviation of the N-N intervals (SDNN). The length reflects the contribution of non-respiratory components to the total HRV.

The Poincaré plot is analyzed by fitting an ellipse to the plotted points. Three non-linear measurements, S, SD1, and SD2 can be derived. The area of the ellipse which represents total HRV (*S*) correlates with baroreflex sensitivity (BRS), LF and HF power, and RMSSD. The standard deviation (hence SD) of the distance of each point from the *y* = *x* axis (*SD1*), specifies the ellipse’s width. SD1 measures short-term HRV in ms and correlates with baroreflex sensitivity (BRS), which is the change in IBI duration per unit change in BP, and HF power. The RMSSD is identical to the non-linear metric SD1, which reflects short-term HRV. SD1 predicts diastolic BP, HR Max − HR Min, RMSSD, pNN50, SDNN, and power in the LF and HF bands, and total power during 5 min recordings. The standard deviation of each point from the *y* = *x* + average R–R interval (*SD2*) specifies the ellipse’s length. SD2 measures short and long-term HRV in (ms) and correlates with LF power and BRS. The ratio of *SD1/SD2*, which measures the unpredictability of the RR time series, is used to measure auto- nomic balance when the monitoring period is sufficiently long and there is sympathetic activation.

Chart

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**Power Spectrum Plots:**

**Power Spectrum:**

The power spectrum of a time series describes the distribution of power into frequency components composing that signal. According to Fourier analysis, any physical signal can be decomposed into a number of discrete frequencies, or a spectrum of frequencies over a continuous range. The statistical average of a certain signal or sort of signal (including noise) as analyzed in terms of its frequency content, is called its spectrum.When the energy of the signal is concentrated around a finite time interval, especially if its total energy is finite, one may compute the energy spectral density. More commonly used is the power spectral density (or simply power spectrum), which applies to signals existing over all time, or over a time period large enough (especially in relation to the duration of a measurement) that it could as well have been over an infinite time interval. The power spectral density (PSD) then refers to the spectral energy distribution that would be found per unit time, since the total energy of such a signal over all time would generally be infinite. Summation or integration of the spectral components yields the total power.

**The Code Will:**

Compute a Power Spectral Density (PSD) estimation from the NNI series using the Welch’s & Lomb’s method and compute all frequency domain parameters from this PSD according to the specified frequency bands and export it to a subject specific excel sheet in the current folder path. Use : get\_frequency\_domain\_features to print out quantitative frequency values.

**Lombs Periodogram:**

This method uses the Lomb-Scargle Periodogram. This technique is based upon the same fundamental theory as the FFT but is superior in this context as it does not require an evenly sampled data set it allows for the inherent variability of the RR interval data and hence the tachogram can be transformed directly without an intervening approximation stage. Unlike the FFT, the Lomb method also allows for the exclusion of ectopic beats without requiring an approximated beat to be put in its place as it is perfectly capable of dealing with gaps in the data set, giving you a more accurate analysis that is less affected by ectopic or missing beats.

**Welch’s Periodogram:**

In the Welch’s periodogram method the HRV sample is divided into overlapping segments. The spectrum is then obtained by averaging the spectra of these segments, which decreases the variance of the FFT spectrum. The Lomb-Scargle periodogram differs from the Welch’s periodogram in the sense that it does not assume equidistant sampling and is thus computed directly from the non-interpolated RR interval time series.

Example Welch’s Periodogram with Frequency Domain Metrics:

Chart

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