Calculating Metrics of Cardiac Chronotropy: A Pragmatic Overview

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Abstract

Many metrics have been used to assess sympathetic and parasympathetic contributions to cardiac chronotropy. This poster reviews the logic of and the procedures for calculating many of the more popular metrics derived from a single electrocardiographic channel: mean interbeat interval (IBI), mean heart rate, respiratory sinus arrhythmia (RSA), total heart rate variability (HRV), Toichi's cardiac vagal index (CVI) and cardiac sympathetic index (CSI), the proportion of consecutive IBI differences > 50 ms, the standard deviation of IBIs, the root mean square difference between IBIs, and mean absolute successive IBI difference . A computer program (CMet) that calculates all metrics is described, and made available by the author. Convergent validity of the metrics calculated by the CMet program has been assessed in a sample of 98 healthy college students, with measures of RSA and HRV correlating .99 with the respective values obtained from Porges' MXEdit program.

Introduction

- Numerous measures reflecting cardiac variability have been used in the literature to index sympathetic and parasympathetic activity.
- Although some metrics depend on the simultaneous recording of respiration and electrocardiographic channels, many metrics can be derived from the electrocardiographic channel alone.
- Given the plethora of metrics, and few systematic attempts to compare the various metrics (Friedman & Thayer, 1998; Grossman, Van Beek, & Wientjes, 1990), it would be of pragmatic value to have a way to quickly and easily calculate these commonly used metrics, so that subsequent studies might systematically examine the discriminant, convergent, and predictive validity of these various measures.
- This poster therefore overviews the rationale for the more popular metrics of cardiac variability that can be derived from a single electrocardiographic channel, and describes a program freely available from the author that can calculate these metrics from an interbeat-interval series.

Metrics

Metrics of Rate, which are influenced by both Parasympathetic (PNS) & Sympathetic (SNS) influences

- Mean interbeat interval (IBI)
- Mean heart rate (HR)

Metrics Summarizing Total Heart Rate Variability, which are influenced by both SNS & PNS

- Heart rate variability (HRV)
  - Operationalized as the log of the variance of the IBI series
- Standard deviation of IBI series (SDNN)
  - NN in the acronym SDNN is the abbreviation for "normal-to-normal intervals," which is the artifact-free IBI series
- Root mean square of successive differences between IBIs (RMSSD)

Putative Sympathetic Metric

- A cardiac sympathetic index (CSI; Toichi et al, 1997, see Figure 4)

Putative Parasympathetic Metrics

- Mean absolute successive IBI difference (MSD)
- Proportion of consecutive IBI differences > 50 ms (PNN50)
- Respiratory sinus arrhythmia (RSA)
  - Defined as Log of Band Limited (.12-.40 Hz) Variance of IBI series
- A cardiac vagal index (CVI; Toichi et al, 1997, see Figure 4)

Overview of CMet Program

Cardiac Time Versus "Real" Time

- An IBI series in not, strictly speaking, a time series, as the data occur at uneven intervals, provided that there is variability in cardiac chronotropy, the very phenomenon of interest!
- An IBI series can be converted to a time series by interpolating data points at a fixed sampling rate. The Cardiac Metric program implements a 10 Hz Sampling Rate with linear interpolation.

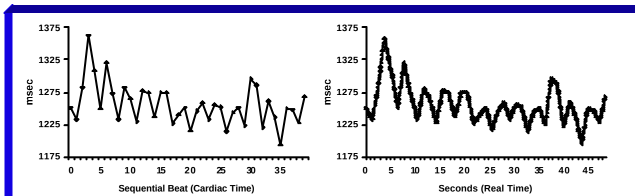


Figure 1 The first 40 IBIs in Cardiac Time (left) and Real Time sampled at 10 Hz (Right)

- Many metrics are calculated on the raw IBI values, as they involve the standard deviation, the variance, or a root mean squire of the raw IBI values (or difference between successive values). Others, such as RSA – which involves the extraction of specific frequencies of variability – require series in real time.

Filtering and the Loss of Data Points

- In the process of convolving a filter over a time series, data points at the beginning and end of the series will not be filtered, and are thus "lost."
- Whereas MXEdit uses a polynomial filter, the Cardiac Metric program uses an optimal finite impulse response digital filter using FWTGEN V3.8 from E.W. Cook III and detailed in Cook & Miller (1992), Psychophysiology, 29, 350-367.

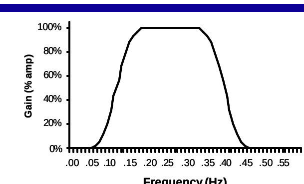


Figure 2 Transfer function of filter used by Cardiac Metric computer program, a 241-point FIR filter with a .12-.40 Hz bandpass, constructed using a Hamming windowing option.

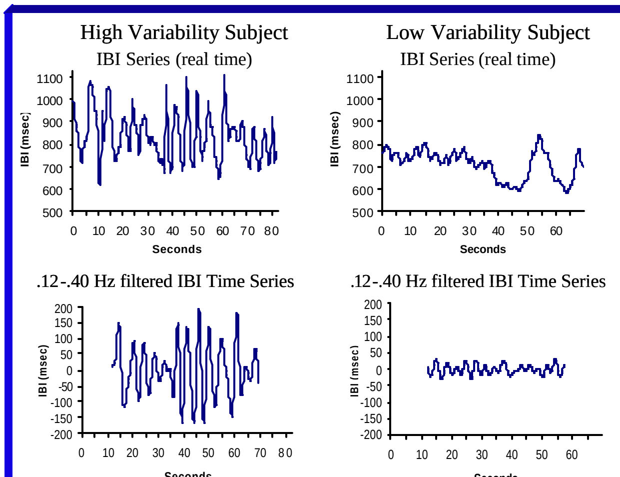


Figure 3. Time-series representation of IBI series for two subjects (top panels), and the filtered versions of those series (lower panels), resulting in a loss of 12 seconds of data at both ends of the series. The variability in the lower panel represents that potion of the total variability that reflects vagal influence.

Rationale for Toichi Metrics

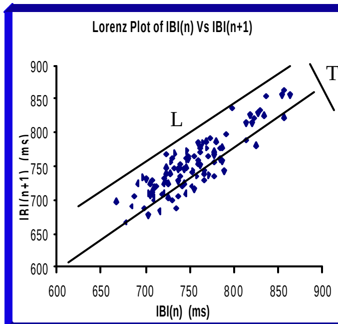
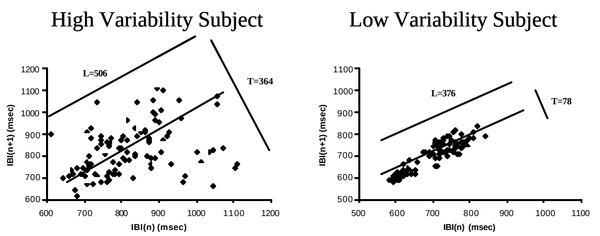


Figure 4 Toichi et al. (1997) describe the Lorenz plot of each IBI (x axis) plotted against the subsequent IBI (y axis). Deviations in the direction transverse to the line $IBI_n = IBI_{n+1}$ reflect high beat-to-beat variability and putatively reflect parasympathetic influences. Axes were rotated –45° so that L was now parallel to the X axis. After rotation L and T were estimated as four times the standard deviation of points along the respective axes (4 s.d.'s reflecting a truncated normal distribution). Finally, two indices were calculated:

- ❑ Cardiac Vagal Index: CVI=Log(L*T)
- ❑ Cardiac Sympathetic Index: CSI= L/T



	Rate	
73.3	HR	85.7
832.3	IBI	707.7
	Total Variability	
9.2	HRV	8.3
112.4	SDNN	66.3
132.8	RMSSD	27.7
	"Sympathetic"	
1.4	CSI	4.7
	"Parasympathetic"	
57.1	PNN50	10.8
97.6	MCD	22.0
5.3	CVI	4.5
8.8	RSA	5.3

Figure 5 Lorenz plots for the two subjects depicted in Figure 3. Values for various metrics are provided in tabular format to provide a sense of how each metric may vary in two very different cases

Validation Sample

Subjects and Tasks

- ❑ 98 college students (female=51)
- ❑ EKG recorded for five minutes under three conditions: Resting baseline, Serial paced arithmetic , Recovery.

Recording Specifications

- ❑ Sample rate 500 Hz.
- ❑ Interbeat Interval (IBI) series extracted via computer peak detection, and then hand corrected for artifacts
- ❑ This IBI series formed the basis for the calculation of various metrics, using the Cardiac Metric (CMet) program.

Validation with MXEdit

- ❑ Log of total variance in IBI series, and the log of the variance in the .12-.40 Hz band-limited series were extracted with the Cardiac Metric (CMet) program and also with Porges' MXEdit (Delta-Biometrics, Inc, 1988-1993)
- ❑ Correlations were obtained between the metrics from the Cardiac Metric (CMet) program (v2.32) and those from MXEdit (v2.21) on this sample under the three tasks

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Convergent Validity with MXEdit

Table 1. Correlations between measures obtained by the Cardiac Metric (CMet) program and by MXEdit.

	Task		
Metric	Baseline	Arithmetic	Recovery
HRV	.994	.996	.993
RSA	.992	.995	.988
MeanIBI	1.000	1.000	1.000

Convergent and Discriminant Validity

Table 2. Correlations Between Various Metrics obtained by Cardiac Metric (CMet) Program

Baseline, Stress, and Recovery tasks

	IBI	HR	HRV	SDNN	RMSSD	CSI	MSD	PNN50	RSA
HR	-0.98								
	-0.97								
	-0.98								
HRV	0.59	-0.58							
	0.49	-0.45							
	0.44	-0.44							
SDNN	0.57	-0.54	0.95						
	0.54	-0.48	0.97						
	0.48	-0.45	0.96						
RMSSD	0.63	-0.59	0.85	0.93					
	0.74	-0.67	0.74	0.82					
	0.61	-0.56	0.79	0.89					
CSI	-0.57	0.57	-0.34	-0.40	-0.64				
	-0.65	0.73	-0.31	-0.31	-0.61				
	-0.51	0.50	-0.11	-0.21	-0.58				
MSD	0.65	-0.61	0.79	0.88	0.98	-0.65			
	0.78	-0.71	0.71	0.80	0.99	-0.61			
	0.65	-0.61	0.74	0.84	0.98	-0.60			
PNN50	0.74	-0.72	0.74	0.76	0.87	-0.75	0.91		
	0.79	-0.72	0.71	0.78	0.96	-0.60	0.97		
	0.72	-0.70	0.69	0.73	0.88	-0.68	0.92		
RSA	0.59	-0.56	0.90	0.90	0.91	-0.61	0.88	0.85	
	0.67	-0.66	0.84	0.83	0.88	-0.71	0.86	0.87	
	0.49	-0.49	0.87	0.88	0.90	-0.50	0.88	0.85	
CVI	0.69	-0.68	0.96	0.94	0.92	-0.58	0.88	0.86	0.95
	0.69	-0.68	0.92	0.91	0.89	-0.63	0.87	0.87	0.96
	0.59	-0.58	0.95	0.94	0.91	-0.42	0.88	0.86	0.94

Predictive Validity

Metric	F	P	Eta
IBI	314.2	<.001	0.76
HR	214.8	<.001	0.69
HRV	21.3	<.001	0.18
SDNN	7.0	<.01	0.07
RMSSD	26.7	<.001	0.26
CSI	90.0	<.001	0.48
MSD	39.8	<.001	0.29
PNN50	57.1	<.001	0.37
RSA	7.9	<.001	0.08
CVI	0.6	>.52	0.01

Table 3. Ability of Metrics to Discriminate Between Tasks
All metrics except Toichi's CVI discriminated robustly between the stressor task and both baseline and recovery phases. In all cases of significant tests, follow-up contrasts verified that only the stressor task differed from the baseline and the recovery tasks.

Discussion

- ❑ The Cardiac Metric (CMet) Program calculates a variety of metrics of cardiac chronotropy given in IBI series as input.
- ❑ Values obtained by the Cardiac Metric (CMet) Program are very highly correlated with those obtained by Porges' MXEdit software, but the latter requires substantially greater user intervention to obtain the output, and to organize the output.
- ❑ Hand editing is still essential, as missed or extra beats can create a large artifactual increase in variability, especially in metrics that use variance as their basis.
- ❑ It remains an empirical question whether the polynomial filter (MXEdit) or the finite impulse response filter (CMet program) is more susceptible to artifacts in the IBI series.
- ❑ Further research may benefit from the examination of various metrics.

To obtain the Cardiac Metric software or copy of the handout, please go to
http://apsychoserver.psych.arizona.edu