

Application Note 233 Heart Rate Variability—Preparing Data for Analysis Using AcqKnowledge

This Application Note explains how to optimize ECG R-R interval data for Heart Rate Variability studies by using a template matching approach. It also explains how to identify erroneous R-R interval values caused by signal artifact and shows methods for correcting the errors by using the tools in the AcqKnowledge software. The note explains how to:

- A. Record good ECG data
- B. Prepare data for the tachogram
 1. Filter the ECG data
 2. Transform the data using Template Correlation function
- C. Create a tachogram
- D. Identify problems with the tachogram data
- E. Correct tachogram data

Recording good data is essential for performing HRV analysis. The following protocol for data acquisition, filtering, artifact detection and correction results in great improvements in HRV analysis.

“Results reveal that even a single heart period artifact, occurring within a 2-min recording epoch, can lead to errors of estimate heart period variability that are considerably larger than typical effect sizes in psychophysiological studies.”

—Berntson & Stowell, 1998

A. Record good ECG data

1. Hardware Setup—ECG100C amplifier settings:

- i. Gain:1000
- ii. Mode: NORM
- iii. LPN Filter: 35Hz LPN ON
- iv. HP Filter: 0.5Hz HP ON

2. Software Setup

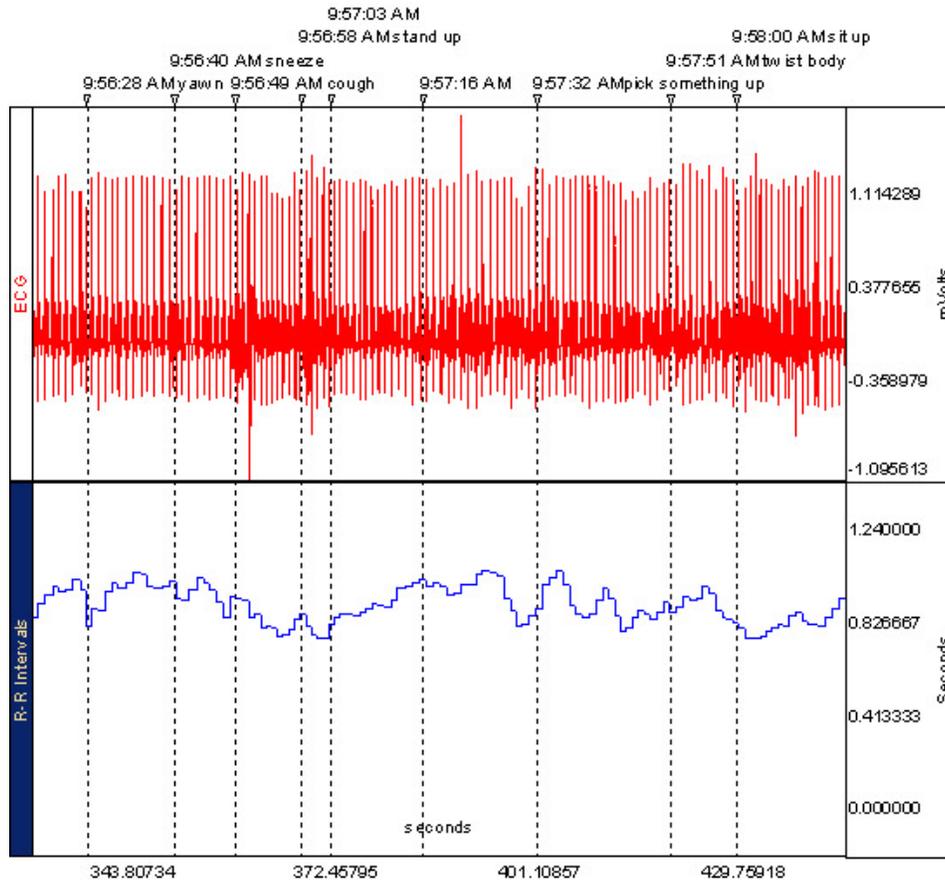
- i. Set the acquisition sample rate to 1000 Hz (MP menu > Set Up Data Acquisition > Length/Rate)

- *“The sampling rate must be properly chosen. A low sampling rate may produce a jitter in the estimation of the R-wave fiducial point, which alters the spectrum considerably. The optimal range is 250 to 500 Hz or perhaps even higher”*—Guidelines: HRV

3. Subject Preparation

- i. If the subject has to move to perform a task, place the electrodes away from the limbs being used. The cleanest ECG signals will come from the chest, but this might not always be convenient for subjects.
- ii. Always prepare the electrode site by removing dead skin using an ELPAD and cotton swabs with water.
- iii. Apply gel to the electrodes (even for disposable ones, when they look dry) but not so much as to spread and prevent it from sticking well.
- iv. To help prevent movement artifacts, use tape to attach the electrode leads to the skin as well. Making a loop with the electrode lead cable under the tape will reduce the chance of dislodging the electrode due to a sudden pull.
- v. **Wait** at least 5 minutes before recording so that the gel can be absorbed into the skin. This will reduce the impedance.

If all of these guidelines are followed and subject movement is minimized, it is reasonable to expect virtually no artifacts in the data. The following screenshot is taken from a 9 min ECG recording where the subject sneezed, moved in the chair, twisted his body, stood up and sat down, moved his hands, etc., all with no artifact (observe the consistent R-R interval waveform on the bottom).



Good ECG and R-R tachogram data with subject activity marked

B. Prepare the data for the tachogram

This process is only required if the raw ECG data has artifacts that the tachogram is unable to interpret correctly. If the ECG data looks good, this step can be skipped and the HRV tachogram can be created from the raw ECG data.

If the ECG signal has artifacts and the interval tachogram is displaying erroneous values it is possible to clean the data using the following techniques. Filter the data and use template matching to identify QRS complexes (hint: to guarantee that all transformations are applied on the entire waveform, select all the data from Edit > Select all before running any given transformation. Even though all the data will be highlighted, only the selected channel will be affected by the transformation). Template matching is one of the recommended techniques for obtaining the R-R tachogram.

“The fiducial point recognized on the ECG tracing that identifies a QRS complex may be based on the maximum or baricentrum of the complex, on the determination of the maximum of an interpolating curve, or found by matching with a template or other event markers.”—Guidelines: HRV.

1) Filter the ECG data

- Select the ECG waveform and then select Edit > Duplicate waveform (this preserves the original ECG).
- This step is optional; if the data is already quite clean this step can be skipped. Select Transform > Digital filters > FIR > Band Pass and apply a filter between 0.5 and 35 Hz, using 8000 coefficients.

- For data recorded at 1000 Hz; the optimal number of coefficients is 4 times (sample rate/lowest frequency), as illustrated here: $4*(1000/0.5) = 8000$. This will remove baseline drift and high-frequency noise.

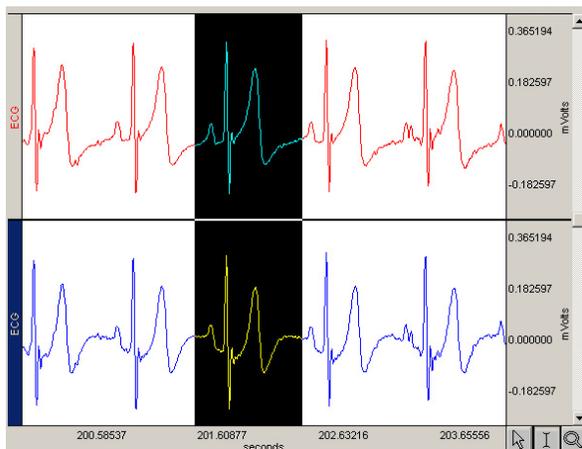
Note This filter is computationally intensive. Effect of the filter on the data: Heart rate detection with 1 msec accuracy is obtainable with an analog band pass filter at 0.5-35 Hz (*Ruha et al, 1997*) and the filter recommended here is a digital filter with optimized frequency response. A 1 Hz or 2 Hz frequency is suggested because then the number of coefficients used will be 4000 and 2000 respectively (which will cause the filter to compute faster), and this should not affect the QRS detection significantly. Note that *Hejzel and Kellenyi, (2005)* claim that high-pass filtering at 0.5 Hz does not cause significant changes in the shape of the ECG; at 1 Hz and 2 Hz cutoffs, considerable alterations can be seen in the ST segment and the T-wave, but not the QRS.

Not enough information was found in the literature at the time of this application note release for the effect of 1 Hz and 2 Hz FIR high-pass filtering.

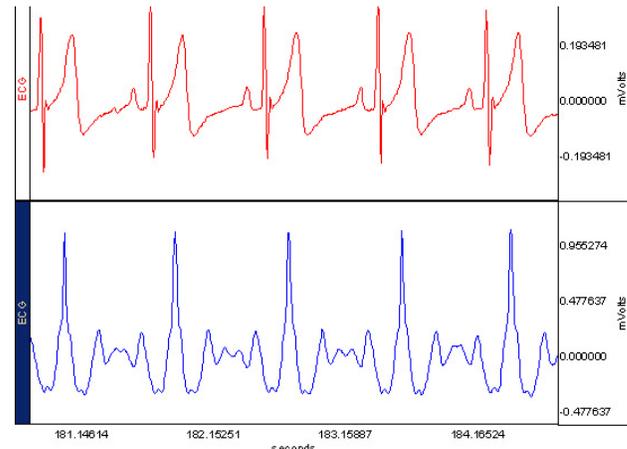
- The researcher should test the effect of these filters on good data (data for which the R-R tachogram shows no abnormalities) by running HRV analysis before and after filtering.

2) Transform data using the Template Correlation function

- Transform the data using the Template Correlation function by following these steps.
- Highlight a representative ECG cycle from the recording.



Highlighting a representative ECG cycle

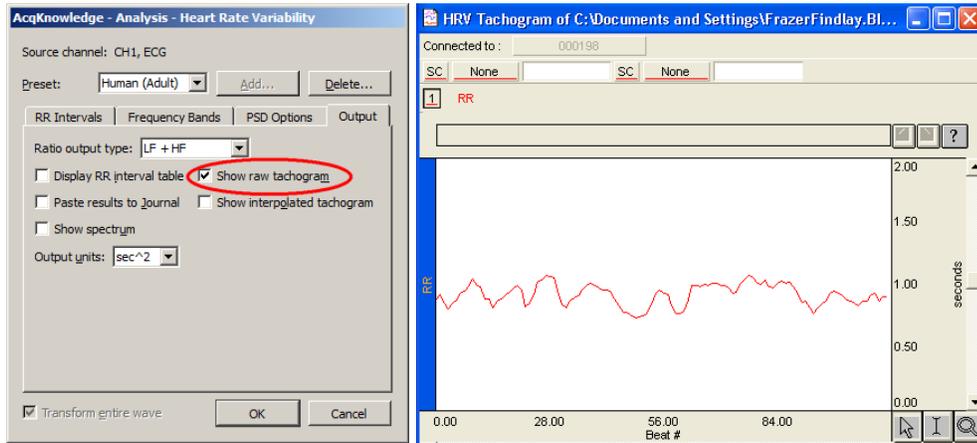


Transformed data

- Select Transform > Template Functions > Set Template.
- Select Edit > Select All.
- Select Transform > Template Functions > Correlation.
 - This operation will take some time if the file is long. The transformed waveform should resemble the graph shown above right (observe the waveform on the bottom; note the time scale when comparing to the data)
- Rename the new channel “Template” (double-click the channel label on the left edge for label dialog).

C. Create a tachogram

- Select the Correlation Template channel.
- Select Edit > Select All.
- Select “Analysis > HRV and RSA > Single-epoch HRV-Spectral.”
 - Enable (check) the “Show raw tachogram” Output option and click OK.
 - Click OK to close the dialog that is generated to display the results of the HRV analysis.



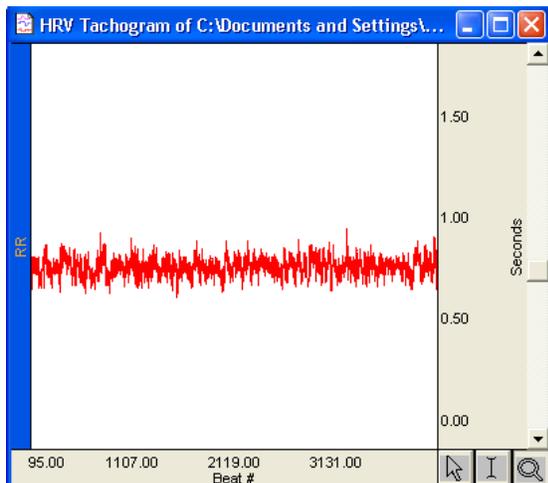
Heart Rate Variability dialog and R-R tachogram data

c. A new graph window will open to display the R-R interval tachogram.

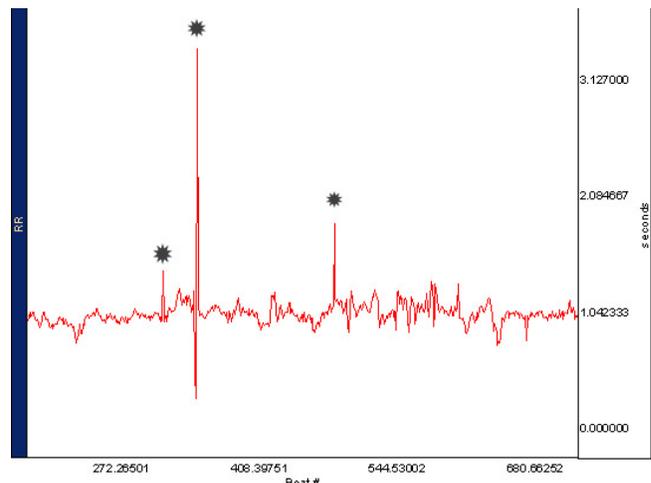
Note The HRV analysis QRS detector uses a modified Pan and Tompkins algorithm. The algorithm normalizes the ECG data to 1 whereby the peak amplitude of the highest R-wave represents 1. The default threshold level of .5 should place the threshold in the middle of the R-wave. If the R-wave amplitude varies a lot, it might be necessary to adjust the threshold level.

D. Identify problems with the tachogram data

Apart from visually checking the R-R tachogram, it may be helpful to define a set of rules to determine what R-R intervals will be considered artifacts. Become comfortable visually inspecting a data record for artifacts as no set of rules or algorithms will be perfect. Below, see an example R-R tachogram that is artifact-free and an R-R tachogram with some possible artifacts (marked with a starburst).



Good (artifact free) tachogram data



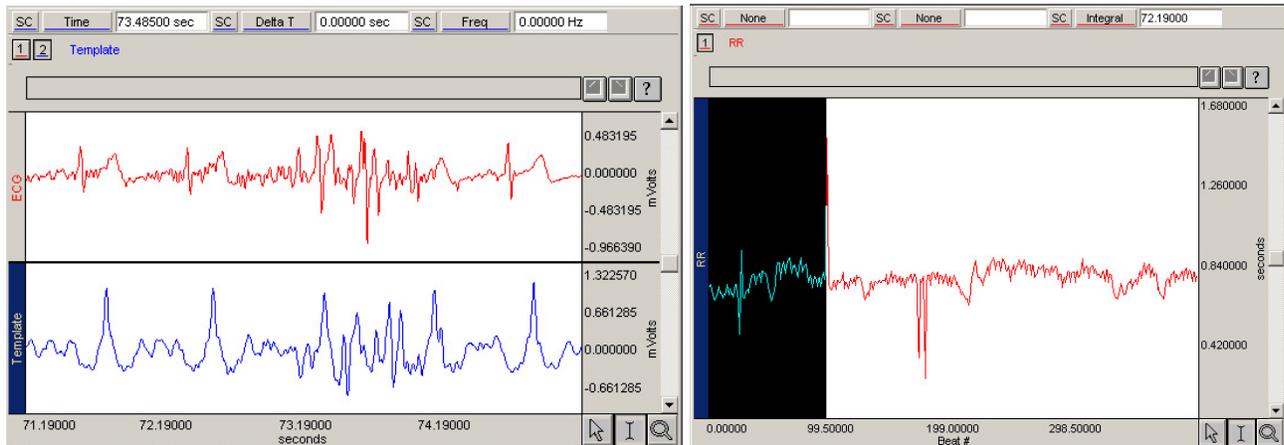
Tachogram data with artifacts marked

The tachogram is displayed with the beat # along the horizontal axis and R-R time interval on the vertical scale. A good R-R interval will have variability within a physiological range. In the preceding left screen shot, all of the results fall somewhere between ~.7 and .9 seconds (700-900 msec). That means the subject's heart rate range was ~60-90 BPM, which is quite normal for a human subject. However, in the preceding right screen shot, there are some values that are significantly higher. In the case of the higher spike, the subject's heart rate would have dropped rapidly from ~60 BPM to ~20 BPM before settling back to ~60 BPM.

1. Inspect the R-R tachogram for artifacts.
2. If an artifact is identified:
 - a. Highlight all the data from the beginning of the tachogram to the artifact R-R interval.
 - b. Set a measurement to Integral in the tachogram graph; the Integral result will indicate the time in the ECG and Template graph where the artifact occurred (72.19 in this example).

c. Set a Time measurement on the template channel in the ECG and Template graph. Use the cursor to locate the time value in the template data that matches the integral result.

- Click once in the data and then use the right and left arrow keys to move the cursor location.



Raw ECG data with artifact

Tachogram artifact

E. Correct tachogram data

After identifying the time of the artifact in the tachogram, go to the data file and zoom in on the appropriate time period of the template data. Typically, a problem will be immediately apparent and one of the following examples can be used to correct the problem. Repeat the above process for all artifacts and check the data manipulations by producing a new R-R tachogram. Run the HRV analysis on the corrected R-wave waveform.

- Example 1: Template peak too low or too high for threshold (page 6)
- Example 2: Artifact between cycles (see page 7)

If artifact prevents identification of the ECG cycle, these additional guidelines might be useful.

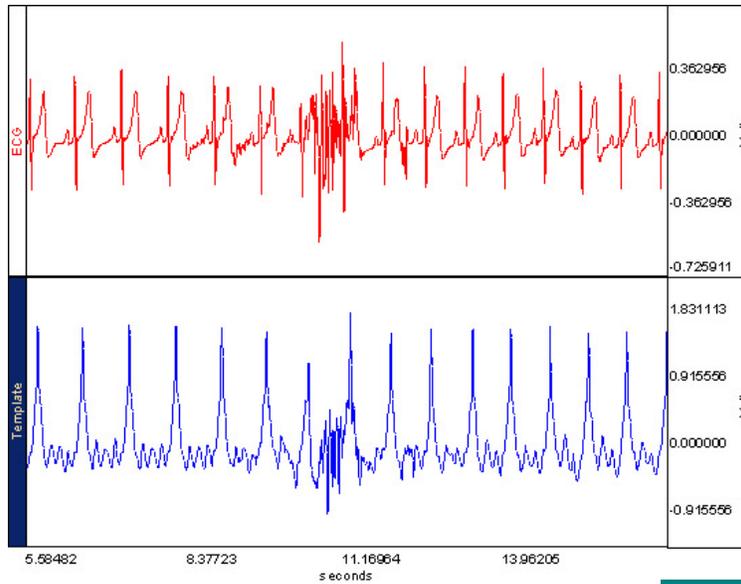
“There are several approaches to the resolution of missed beats. In order of preference, these are (a) measuring the actual R-R intervals, if identifiable, from the ECG record; (b) interpolating the missing R-waves from surrounding beats; and (c) splitting the spuriously long beat into two (or more) equivalent R-R intervals...such approaches should be expected to introduce minimal distortion in estimates of heart rate variability, although validation studies are needed to formulate specific guidelines”

—Berntson et al, 1997 p.631

If there are ectopic beats in the data it is better to avoid using that portion of the file for the analysis.

The Task Force Guidelines: HRV paper suggests that in case the researcher decides to use only epochs that contain no ectopic beats, the ECG or the tachogram could be modified using interpolation techniques (which are not currently a part of the AcqKnowledge software) to guard against the introduction of a bias in the signal. For example, see Solem et al (2006).

Example 1: In the following example, the peak of the template data is too low for the tachogram threshold. Use the Waveform Math feature to add a value to the waveform and increase the value.



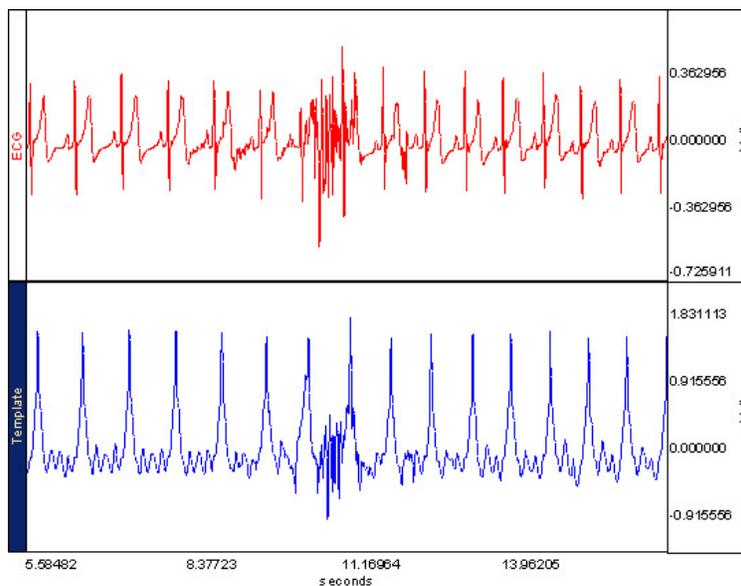
Waveform Arithmetic

Source 1	Operand	Source 2	Destination
Channel: CH 2	+	K	= CH 2
Sample rate: 200.000		200.000	200.000 samples/sec
		Result sample rate: 200.000	samples/sec
Constant= 0.4			Scaling...

Transform entire wave

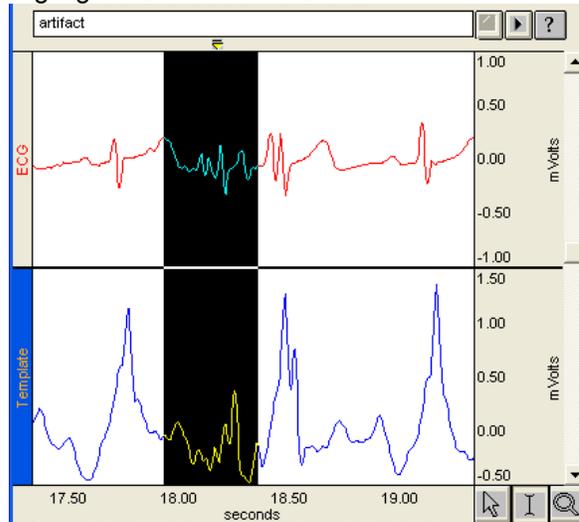
Use Waveform Math
(Transform > Waveform Math) to add a value to the waveform:

- Too low: add a value to increase the waveform
- Too high: subtract a value (negative constant)

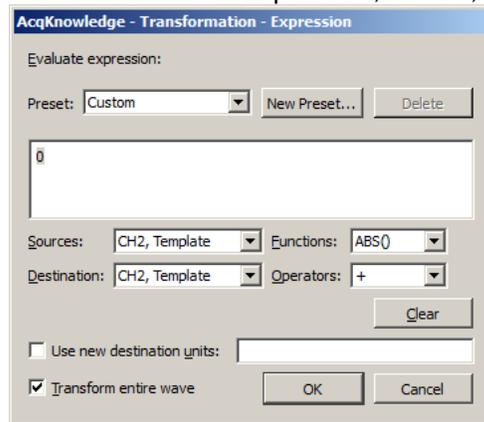


Example 2: The following example shows artifact between two cycles. The Expression transformation can be used to set the artifact to zero and eliminate the artifact from the record. To do this

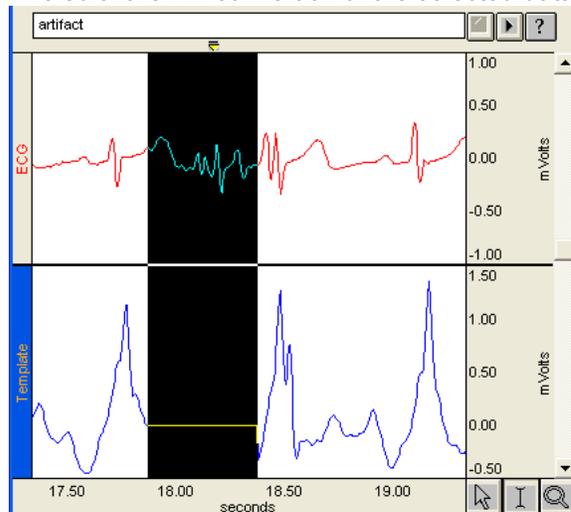
a) Highlight the artifact in the data:



b) Select Transform > Expression, enter 0, and click OK:



c) The software will convert all of the selected data to 0 and eliminate the artifact.



References

- Berntson G. G., Stowell JR, ***ECG artifacts and heart period variability: Don't miss a beat!*** Psychophysiology, 35 (1998), 127–132. Cambridge University Press.
- Berntson G. G., Bigger T. J., Eckberg D. L., Grossman P., Kaufmann P. G., Malik M., et al., ***Heart rate variability: Origins, methods, and interpretive caveats.*** Psychophysiology, 34 (1997), 623–648.
- Berntson G. G., Quigley K. S., Jang J., and Boysen S. T., ***An approach to artifact identification: Application to heart period data.*** Psychophysiology, 27 (1990), 586–598.
- Hejjeel L. and Kellenyi L., ***The corner frequencies of the ECG amplifier for heart rate variability analysis.*** Physiol. Meas. 26 (2005) 39-47.
- Ruha A, Sallinen S and Nissilä S, ***A real-time microprocessor QRS detector system with a 1-ms timing accuracy for the measurement of ambulatory HRV.*** IEEE Trans. Biomed. Eng. 44 (1997) 159–67.
- Solem, K.; Laguna P.; and Sörnmo, L., ***An Efficient Method for Handling Ectopic Beats Using the Heart Timing Signal.*** IEEE Transactions on Biomedical Engineering, Vol. 53, no. 1, January 2006 13.
- Task Force of the European Society of Cardiology and The North American Society of Pacing and Electrophysiology, ***Guidelines—Heart rate variability: Standards of measurement, physiological interpretation, and clinical use.*** *European Heart Journal* (1996) 17, 354–381.