

# Kubios HRV Scientific - How to analyze Empatica E4 measurements

Empatica E4 is a wrist-worn measurement device capable of recording long-term PPG (blood volume pulse) data. Empatica E4 has a built-in pulse detection algorithm, which detects pulse waveforms from the PPG data and extracts interbeat interval (IBI) time series (time intervals between successive pulse waveforms). Empatica E4 produces the following files, which can both be used for HRV analysis.

- BVP.csv** Raw PPG signal, compatible with Kubios HRV Scientific
- IBI.csv** IBI data, compatible with Kubios HRV Scientific and Standard

If you have Empatica E4 and plan to make scientific publications, we at Kubios strongly recommend you to use Kubios HRV Scientific for HRV analysis because

1. In many situations, the pulse detector algorithm of Kubios HRV Scientific software is better than the E4 detector.
2. Having the raw PPG signal in Kubios HRV Scientific, you can easily edit pulse detections if necessary, mark noisy PPG data segments and select good quality data samples for HRV analysis.
3. The automatic beat correction available in Kubios HRV Scientific corrects accurately missed, extra and misaligned (including ectopic) beats<sup>1</sup>.

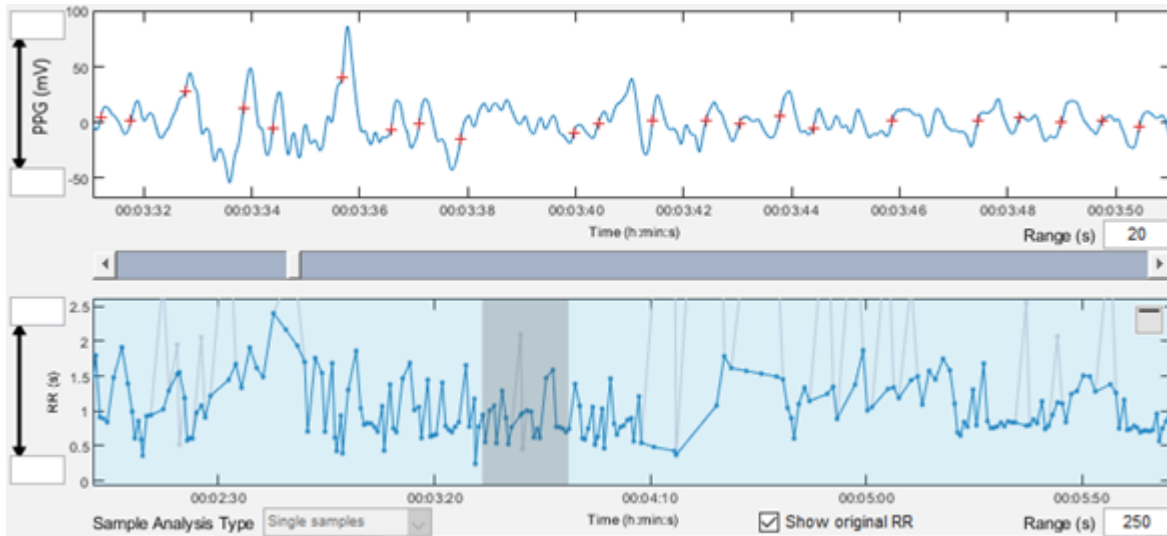


**Figure 1:** An example of high-quality PPG recording with periodic pulse waveforms of similar morphology. RR-interval series has no irregularities and all beat-to-beat intervals are physiologically realistic (in this case 0.7–1.1 sec).

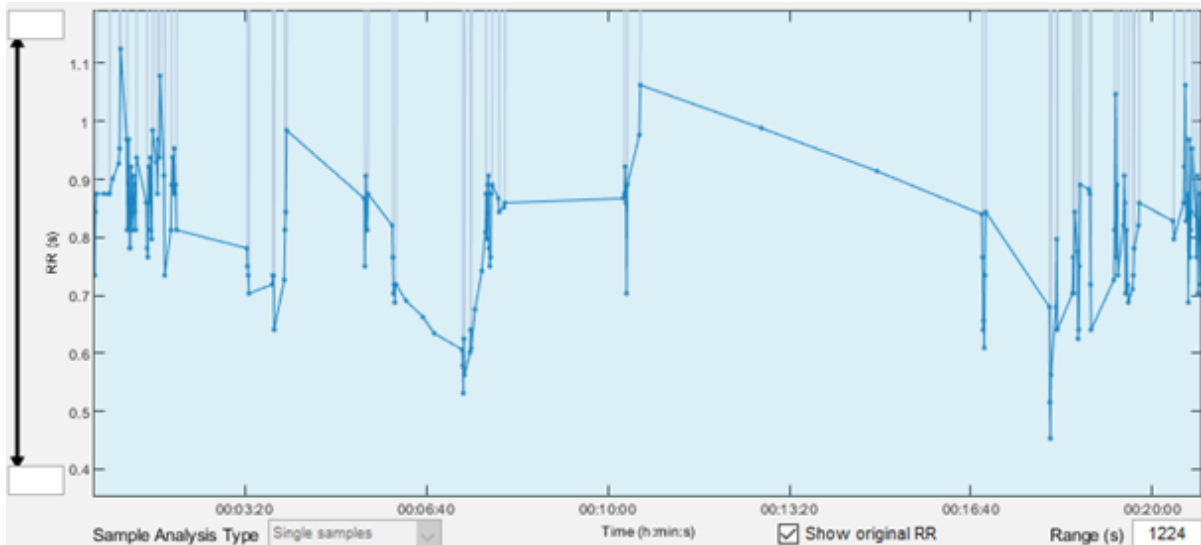
<sup>1</sup> Lipponen JA and Tarvainen MP. A robust algorithm for heart rate variability time series artefact correction using novel beat classification. J Med Eng & Technol, 43(3):173-181, 2019.

### PPG recording is sensitive for movement

In general, PPG devices can be used for HRV analysis only in the measurement setups where subject movements are minimal (such as nighttime recordings). When the subject is moving around, Empatica E4 records PPG signal (it's a continuous measurement), but pulse intervals may not be properly detected, and therefore, data stored in the IBI.csv file can be much shorter than the actual duration of the recording. See Figures 2 and 3 for examples of low quality PPG and IBI data. For recordings where HRV analysis is required also during periods of activity and subject movements, we recommend using an electrocardiogram (ECG) device or a good quality heart rate (HR) monitor with chest strap for HRV recordings.



**Figure 2:** Example of low-quality PPG measurement, which can not be used for HRV analysis. Pulse waveform morphology varies (upper panel), pulse interval data includes abnormally long intervals (RR > 1.5 sec) and pulse interval variability is abnormal (lower panel).



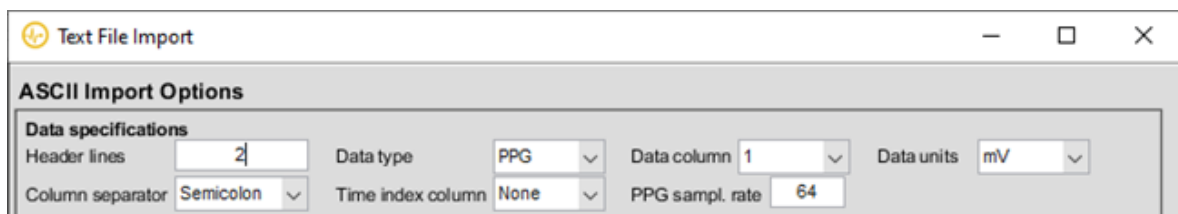
**Figure 3:** Example of low quality IBI recording, which can not be used for HRV analysis. Long segments without beat detections shown as long straight lines (without data points).

## Importing Empatica E4 files in Kubios HRV Scientific

### Importing BVP.csv file into Kubios HRV Scientific

Kubios HRV Scientific includes a built-in beat detector for PPG data and we recommend using the BVP.csv file, which contains the raw PPG signal. To import the BVP.csv file into Kubios HRV Scientific, use the Custom ASCII files import tool:

1. From Preferences set “Default input data type” to “Custom ASCII files”
2. Open the file and use data import settings presented in Figure 4
3. Sampling rate of the PPG signal is 64Hz



ASCII Import Options					
Data specifications					
Header lines	2	Data type	PPG	Data column	1
Column separator	Semicolon	Time index column	None	PPG sampl. rate	64
				Data units	mV

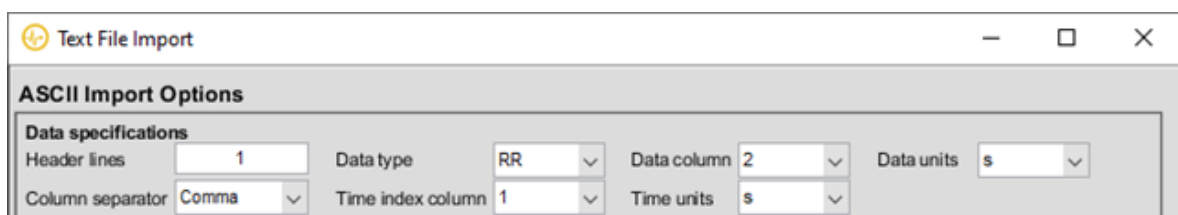
**Figure 4:** Settings for importing Empatica E4 BVP.csv file into Kubios HRV Scientific.

### Importing IBI.csv file into Kubios HRV Scientific or Standard (not recommended):

To import the IBI.csv file into Kubios HRV Scientific or Standard, use the Custom ASCII files import tool:

1. From Preferences set “Default input data type” to “Custom ASCII files”
2. Open the file and use data import settings presented in Figure 5

NOTE: Empatica E4 beat detector does not detect beats if signal quality is too low, typically this happens when the subject is moving (movement artefacts). Therefore, IBI.csv files can be much shorter than the actual recording duration.



ASCII Import Options					
Data specifications					
Header lines	1	Data type	RR	Data column	2
Column separator	Comma	Time index column	1	Time units	s
				Data units	s

**Figure 5:** Settings for importing Empatica E4 IBI.csv file into Kubios HRV Scientific or Standard.