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KARDIA: A Matlab software for the analysis of cardiac interbeat intervals

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ABSTRACT

This article presents KARDIA, a Matlab (MathWorks Inc., MA) software developed for the analysis of cardiac interbeat interval (IBI) data. Available functions are called through a graphical user interface and permit the study of phasic cardiac responses (PCRs) and the estimation of time and frequency domain heart rate variability (HRV) parameters. Scaling exponents of heartbeat fluctuations are calculated with the detrended fluctuation analysis (DFA) algorithm. Grand average and individual subject results can be exported to spreadsheets for further statistical analysis. KARDIA is distributed free of charge under the terms of GNU public license so that other users can modify the code and adjust the program's performance according to their own scientific requirements.

1. Introduction

Time intervals between successive heartbeats are obtained from electrocardiographical (ECG) recordings and provide a way to measure heart rate patterns, either in resting states (heart rate variability; HRV) or as response to external stimuli (phasic cardiac responses; PCRs). Many commercial data acquisition programs provide algorithms to subtract interbeat intervals (IBIs) from ECG recordings and to calculate some of the most common HRV parameters. The problem of PCR analysis, however, is not addressed by these programs and most researchers depend on custom software to calculate heart rate changes in response to experimental stimuli. In addition, HRV analysis is a field that has gained considerable interest in recent years and a significant number of new metrics deriving from statistical physics have been proposed as complementary to traditional time and frequency domain measures [1]. At the same time, older algorithms are continuously being refined, and advanced methods are being tested in order to further improve the assessment of autonomic function in health and disease [2].

As an alternative to commercial software, several free HRV analysis programs are also available to cardiovascular researchers. Two of the most sophisticated and user-friendly are Ecglab [3] and POLYAN [4]. Ecglab is a Matlab toolbox that performs not only HRV analysis, but also R-wave peak detection from raw ECG recordings. HRV analysis functions

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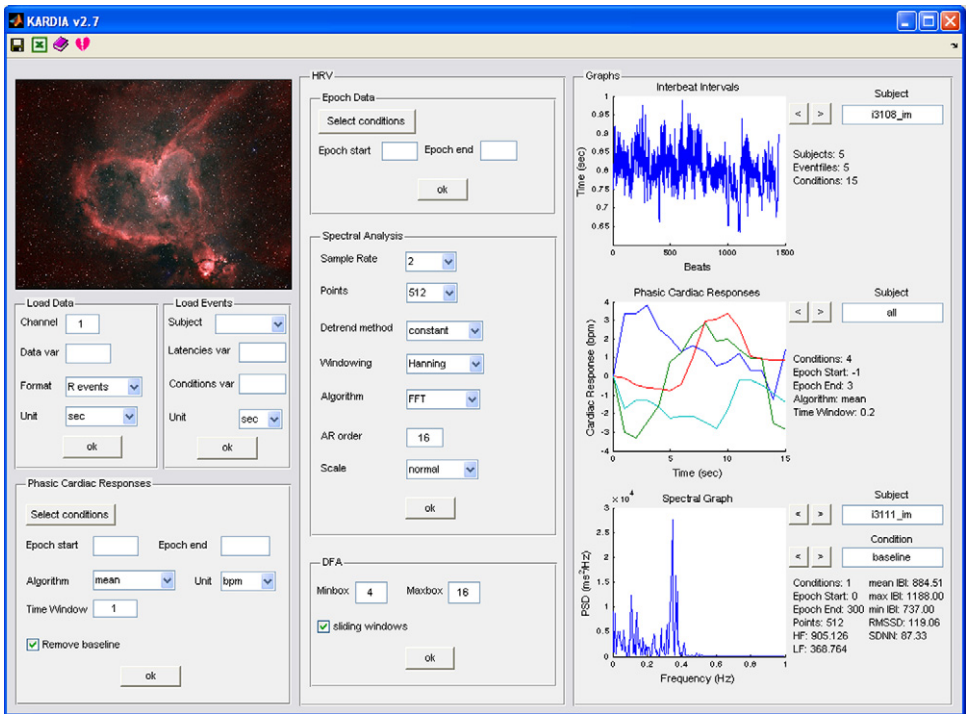

Fig. 1 – The graphical user interface of KARDIA.

calculate most common time domain measures, spectral analysis parameters and also present time–frequency graphs and metrics. Importantly, its open source philosophy allows users to modify the existing algorithms according to their specific needs. POLYAN is another open source Matlab software designed for the simultaneous analysis of several recording signals for the assessment of autonomic regulation. Its HRV analysis algorithms calculate both time and frequency domain metrics and provide elaborate graphs that facilitate the understanding and interpretation of numerical results. Another useful, and freely available HRV analysis program [5], also provides common estimates of time and frequency domain measures.

In this article we present KARDIA ("heart" in Greek), a Matlab software designed for the analysis of PCRs and HRV. Kardia is an open source project hosted by sourceforge, which means that it is subjected to continuous development by an increasing number of researchers [6]. Its main advantage compared to the programs presented above is its capacity for simultaneous analysis of multiple datasets, calculation of grand average statistics across subjects and experimental conditions and generation of analytic spreadsheets that can be directly subjected to further statistical analysis by related software.

Furthermore, KARDIA performs PCR analysis based on event codes corresponding to external stimuli presented under specific experimental conditions. These phasic responses are calculated by coherent averaging which provides a valid estimation of event-related changes as unrelated fluctuations are cancelled out. Results are compared to a baseline period prior to the stimulation where nonspecific fluctuations are expected [7]. The assessment of phasic heart rate responses is a fundamental index of emotional modulation during affective picture processing [8] or an important measure of orienting and attention [9], just to cite two examples.

2. Program description

KARDIA is intended to be a useful tool for researchers with no specific programming skills and therefore all functionalities are directly available from an intuitive graphical user interface (GUI).

PCRs time-locked to specific events may be calculated using either weighted averages or a range of interpolation methods. Common time and frequency domain HRV statistics are also estimated. The power spectrum is calculated using either fast Fourier transform or parametric methods, and scaling exponents of IBI fluctuations are computed using DFA [10]. Individual subject results and grand average statistics can also be exported to Excel spreadsheets for further statistical analysis.

KARDIA was entirely written in Matlab scripting language. All functions are contained within a single m-file (*kardia.m*), although the complete software package includes the software logo, a matrix with GUI-related information, documentation and sample data stored in different subfolders. The open access policy, guaranteed through the General Public License (GPL), allows more experienced users to adapt the code to address their own specific needs.

2.1. *The graphical user interface*

KARDIA's GUI is divided into four different panels (Fig. 1): the load data and event information panel (top-left), the PCR analysis panel (bottom-left), the HRV analysis panel (center) and