

DynaScope: a Software Tool for the Analysis of Heart Rate Variability During Exercise

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Abstract

Heart Rate Variability is usually studied using spectral analysis in stationary conditions, but this kind of study cannot be applied during exercise tests where stationarity decays.

To study dynamic situations a software tool has been designed to evaluate HR changes during non stationary conditions.

We introduce DynaScope a Windows-based C++ software containing algorithms developed to analyse RR variability where spectral analysis cannot be applied.

1. Introduction

Heart Rate Variability (HRV) reflects the regulation of heart-rate (HR) by the autonomic nervous system and has a clinical relevance as a predictor for mortality in presence of cardiovascular pathologies [1,2].

Beyond the pathologic field, HRV analysis can be used on athletes as a tool for the identification of the success of any training program aimed at performance optimization [3].

To evaluate HR changes, the HRV has been analysed in dynamic situations (e.g. prior, after and during exercise) and with different techniques [3] (e.g. Poincaré plots [4], analysis of HR sudden increase and reduction [6]).

The aim of this paper is to present DynaScope, a Windows-based computer program designed to estimate RR changes during physical onset and offset of activity, inclusive of the initial recovery stage. These two stages are defined as HR increase (HRI) and HR recovery (HRR) respectively.

2. Methods

The study of HR changes is based on the analysis of the tachogram of the RR-series, automatically extracted from the ECG tracing by HeartScope [5] (AMPS llc, New York, NY).

ECG signal must be continuously recorded for the entire exercise test, so that uninterrupted RR-series are available before the beginning of exercise throughout the recovery phase.

The recording may contain one or more exercise-recovery episodes.

2.1. Program description

Once the RR-series file to open is selected, a window designed to insert subject demographic information is shown, the user is called to choose whether calculate the maximum HR Reserve (difference between maximum and minimum HR) by inserting nominal maximum HR and minimum HR; this value is used by DynaScope to evaluate relative HR Reserve (% of maximum HR Reserve) for each episode of exercise.

Before closing the window, the tool prompts the user to select if the RR series represents a recording of a test in a suitable standardized structure (i.e. following a specific protocol) or represents a recording during random training situation (e.g. a team training), from this choice the appropriate detection algorithm will be used.

The tool indistinctly works with two modalities of recording: single bout (the RR file represents a recording containing a single episode of exercise) and multiple bouts (the recording contains two or more episodes of exercise).

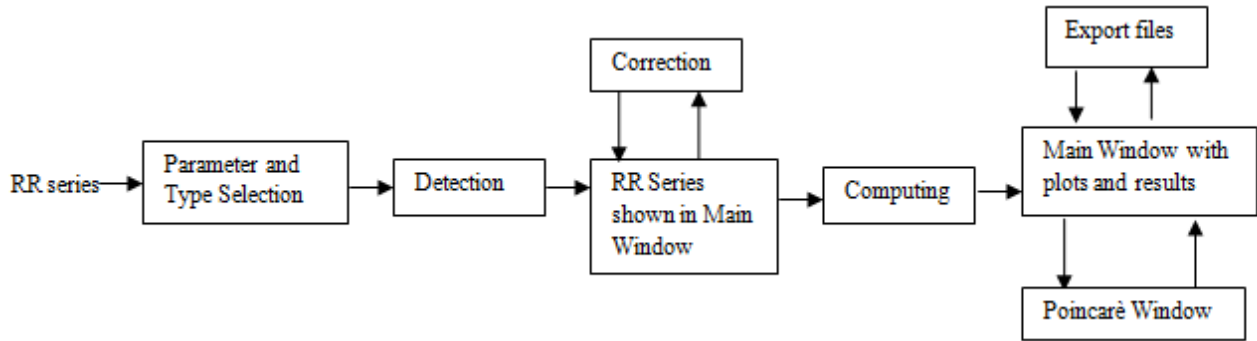


Fig 1. Flowchart of DynaScope tool.

When the file is opened, the program automatically detects all exercise episodes, dividing them in HRI and HRR phases.

User can check the accuracy of detection/division, shifting boundaries of the exercise phases; in addition editing of the RR series is allowed by cutting or correcting wrongly detected RR intervals; then, by pressing a dedicated button, the analysis is performed.

The RR-series (expressed in milliseconds) of HRI and HRR are filtered (FiltRR) using a median-filter (with a window length of 15 beats), used both for filtering the series and calculating the variance of RR (VarRR).

Applying the least squares method to FiltRR, taking the time as X axis, the slopes of HRI (TachySlope1 and TachySlope2) and HRR (BradySlope) can be estimated.

HRI has two different descending phases, the first one synchronized with the beginning of the physical activity

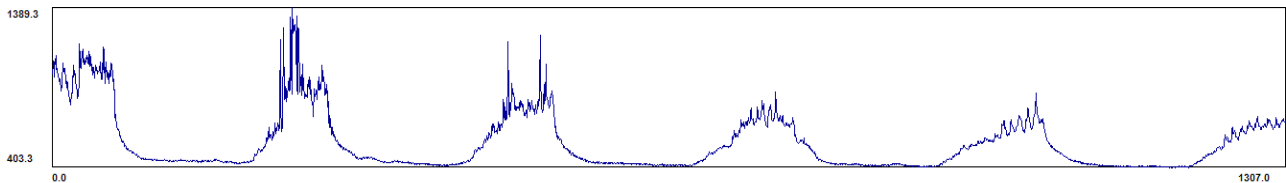


Fig 2. View of a five-bouts RR series in DynaScope.

2.2. Analysis of RR series

The program initially divides each episode in HRI and HRR, which are analysed independently.

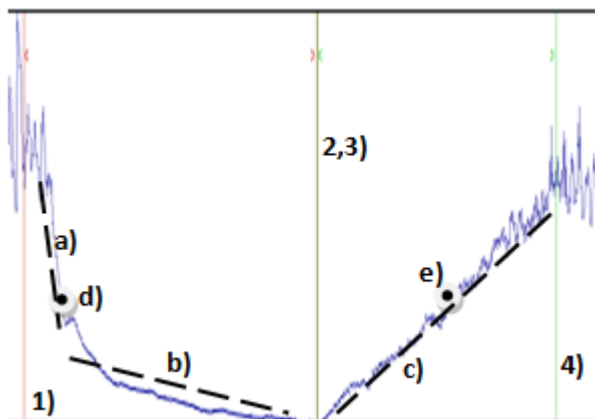


Fig 3. Representation of several parameters detected by DynaScope: 1) HRI start; 2) HRI end; 3) HRR start; 4) HRR end; dashed lines represent the slopes, respectively a) TachySlope1, b) TachySlope2, c) BradySlope; d) and e) are the points where TachySpeed and BradySpeed were detected.

is of higher magnitude and is followed by a second of lower gradient, as shown in Figure 3.

Filtering further FiltRR with a mean-filter and deriving the resulting signal (DRR), the maximum speed for exercise (TachySpeed) and recovery (BradySpeed) phase can be estimated with accuracy.

Starting from the original RR-series, the part preceding the first exercise (Baseline) and all recovery phases are extracted. These series are associated with corresponding RR_{N+1} series to construct Poincaré plots, one representing the Baseline and one for each recovery episode.

From these series polygons to represent Poincaré plots area are computed, using an asymmetric method instead the more commonly used ellipse which cannot correctly represents Poincaré plots generated with the presence of a deceleration of HR.[7]

The area and the length of the major axis of polygons are computed.

2.3. Program views

DynaScope allows the visualization of graphs and results of the RR-series analysis.

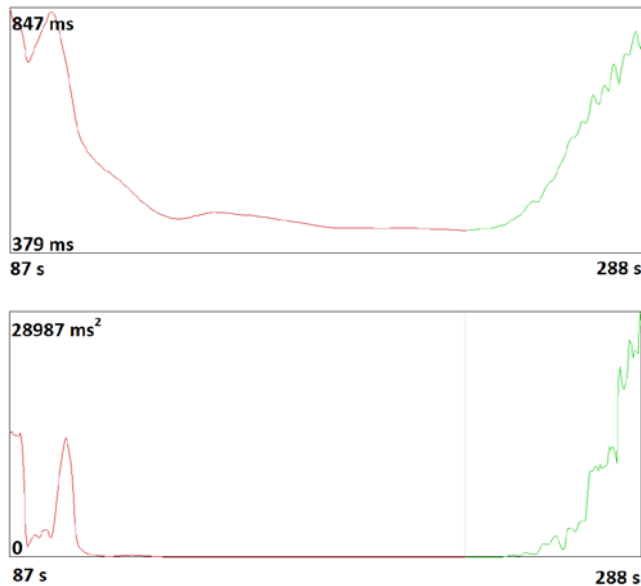


Fig 4. t-FiltRR (on top) and t-VarRR(on bottom) plots, HRI on the left side and HRR on the right side.

The RR-series and all detected exercise-recovery episodes are visible on the tachogram.

The user can move through episodes with a button and time-FiltRR or time-VarRR plot related to the selected episode are shown.

By pressing a button, on FiltRR plot are shown the points which represent the begin and the end of the slopes, and the points in correspondence of maximum speeds.

If these points have been wrongly detected, the user can change their position, and the value of slopes and speed is recomputed.

The visualization of plots gives a qualitative analysis of the trend of RR series, supported by the values of computed measurements which are shown on the right of the graph. Pressing the corresponding button, Poincaré plots window pops up, showing Baseline and recovery graphs, and the parameters of the displayed figures (refer to Figure 4).

The polygon detected to represent the area, are shown on Poincaré plots.

The scale of all graphs can be modified in the settings window.

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2.4. Exporting files

Once the computation/editing ends, results can be exported in a CSV file, which may contain other analyses performed with DynaScope (i.e. each analysis fills (i.e. appends) a number of rows related to the number of bouts

in the RR file).

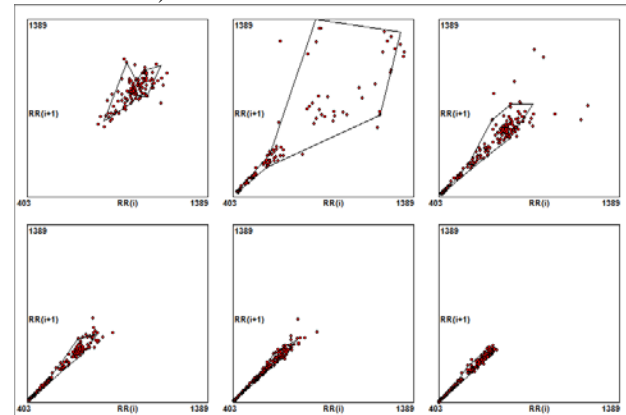


Fig 4. Poincaré plots view of a 5-bouts recording. The upper-left corner plot represents the Baseline, the other plots represents (from left to right) the Poincaré plots of recovery phases.

The printing procedure consists in a report containing the RR-series, the graphs (t-FiltRR and t-VarRR) of each episode, a page with Poincaré plots (Baseline and recovery phases) and the summary table with the results of the analysis.

3. Program validation

The parameters extracted by DynaScope describe the quality of the response to an exercise evaluating HRI (“Tachy” parameters) and HRR (“Brady” parameters) phases.

“TachySlope” and “TachySpeed” parameters were designed to estimate the speed of the simultaneous vagal deactivation and sympathetic activation, combined, when the heart is under stress.

The “slope” parameter indicates the speed whereby the HR increase and “speed” parameter indicates the maximum speed of this process.

The same assumption can be made for BradySlope and BradySpeed, which describe the quality of recovery and the speed of the vagal tone reactivation.

Poincaré area estimates the quality of the vagal recovery, its value depending on variance and RR changes.

To validate the plausibility and the usefulness of these parameters a small study is needed.

3.1. Study population

To validate the newly developed tool, we conducted a small study on 10 healthy subjects (mean age 23.1 ± 2.5 years) undergoing three subsequent 5 minutes bouts of exercise on a supine-bicycle with three different loads (50-100-150 W), separated by 5 minutes rest phases.

We wanted to evaluate how DynaScope may estimate different response to exercise between different bouts.

3.2. Results

DynaScope automatically calculates several parameters, which describe the RR changes in dynamic conditions, where spectral analysis cannot be used.

Table 1. Several parameters computed by DynaScope for the study population. Results are given by mean \pm std. Kruskal-Wallis test:(*)significant, p-value<0.05 (N)non-significant, p-value>0.05.

	Exercise Load			P-value
	50W	100W	150W	
Max RR [ms]	948 \pm 56	853 \pm 60	735 \pm 52	*
TachySlope1 [ms/s]	1.74 \pm 0.52	1.59 \pm 0.37	1.64 \pm 0.23	N
BradySlope [ms/s]	4.94 \pm 0.69	3.51 \pm 0.53	2.51 \pm 0.51	*
TachySpeed [ms/s]	17.70 \pm 2.21	13.05 \pm 1.95	9.27 \pm 0.78	*
BradySpeed [ms/s]	12.53 \pm 1.18	10.08 \pm 1.37	7.35 \pm 1.63	*
TachyVar [ms ²]	12203 \pm 3679	8749 \pm 3413	2501 \pm 812	*
BradyVar [ms ²]	10281 \pm 5319	3583 \pm 1460	2508 \pm 1405	N
Poincaré Area [ms ²]	82047 \pm 33161	63430 \pm 30485	35309 \pm 23782	*

It is evident that all parameters decrease with increasing load and successive bouts of exercise.

The reduction of Max RR indicates an incomplete recovery of HR with successive bouts (suggesting an after effect as memory), BradySlope decreases with successive bouts linearly with increasing of recovery duration.

TachySpeed and BradySpeed have a significant reduction and this could indicate a reduced capacity of the HR control system (both autonomic and humoral) to respond to exercise.

TachyVar and BradyVar decrease, and this is likely and for the most part attributable to a vagal tone reduction caused by an incomplete recovery.

The significant decrease of Poincaré Area provides complementary information to HRV during the offset phases of rest after successive bouts: a greater value of this parameter could suggest a better vagal reactivation after exercise.

The trend of these results describes the effects of exercise within different loads and the subsequent series of exercises on HRV and reflects the dynamics of the

onset and offset of HR regulatory systems during subsequent bouts of submaximal exercise.

4. Conclusions

Human heart has memory of the preceding episodes of exercise and the developed tool can quantify it estimating HR changes between different episodes.

The analysis in dynamic conditions, and the estimation of the changes with DynaScope, can be useful both in healthy subjects, to evaluate exercise capacity and the efficiency of a specific training program and in patients to monitor clinical conditions and the efficacy of therapy.

References

- [1] Nissinen SI, Mäkikallio TH, Seppänen T, Tapanainen JM, Salo M, Tulppo MP, Huikuri HV. Heart rate recovery after exercise as a predictor of mortality among survivors of acute myocardial infarction. *Am J Cardiol* 2003;91:711-714.
- [2] Nanas S, Anastasiou-Nana M, Dimopoulos S, Sakellariou D, Alexopoulos G, Kapsimalakou S, Papazoglou P, Tsolakis E, Papazachou O, Roussos C. Early heart rate recovery after exercise predicts mortality in patients with chronic heart failure. *Int J Cardiol* 2005; 110:393-400.
- [3] Plews DJ, Laursen PB, Kilding AE, Buchheit M. Heart rate variability in elite triathletes, is variation in variability the key to effective training? A case comparison. *Eur J of Applied Physiol*, 2012, 1439-6327.
- [4] Paul M, Garg K. The effect of heart rate variability biofeedback on performance psychology of basketball players. *Applied Psychophysiology and Biofeedback*. 2012; 37/2(131-44): 1090-0586
- [5] Badilini F, Pagani M, Porta A. HeartScope: a Software Tool Addressing Autonomic Nervous System Regulation. *Computers in Cardiology* 2005;32:259–262.
- [6] Leeper NJ, Dewey FE, Ashley EA, Sandri M, Tan SY, Hadley D, Myers J, Froelicher V. Prognostic Value of Heart Rate Increase at Onset of Exercise Testing. *Circulation* 2007; 115:468-474.
- [7] Piskorsky J, Guzik P. Geometry of the Poincaré plot of RR intervals and its asymmetry in healthy adults. *Physiol. Meas* 2007;28:287-300.

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