

Sport?Sicuro! A Graphical User Interface for Continuous Cardiovascular Monitoring while Playing Sport Based on Heart Rate and Heart-Rate Variability

Sofia Romagnoli¹, Agnese Sbroliini¹, Ilaria Marcantoni¹, Micaela Morettini¹, Laura Burattini¹

¹Università Politecnica delle Marche, Ancona, Italy

Abstract

Heart rate (HR) and heart-rate variability (HRV) are increasingly used to assess the body response to heavy physical effort and to define cardiovascular risk indices for sport related sudden cardiac death. The complexity of physiological phenomena affecting HR and HRV makes difficult the interpretation of measures provided by commercial wearable technologies for athletes and trainers. Availability of interactive applications for analysis of HR series can optimize continuous cardiovascular self-monitoring while training. This paper proposes Sport?Sicuro!, a graphical user interface that allows automatic computation of prevention and performance indexes from HR series for cardiovascular monitoring while practicing sport. This tool is an interactive instrument to support self-monitoring of athletes as well as the work of sport medicine clinicians. Sport?Sicuro! was developed under MATLAB®. Automatic analysis of HR series is based on some unchangeable features definitions provided in literature, and other arbitrary settings, the default values of which can be changed by the user. Eventually, Sport?Sicuro! provides a report file listing all the quantitative results of the HR analysis. Thus, Sport?Sicuro! represents a potentially useful graphical tool for automatic and objective analysis of HR series in sport.

1. Introduction

The use of wearable devices for continuous cardiovascular monitoring while playing sport is spreading [1-3]. Heart rate (HR, bpm) can be non-invasively and efficiently measured by wearable devices directly on field [4-5]. HR is derived from the time intervals among consecutive heart beats. This time series varies continuously under the control of autonomic nervous system on cardiovascular system generating heart-rate variability (HRV). Measures of HR and HRV reflect the organism's reaction to psychophysical stress and metabolic-request changes [6]. Thus, HR and HRV are increasingly used to define performance indexes, assessing

the response to physical exercise in terms of fatigue and fitness level, and prevention indexes assessing the risk for sport related sudden cardiac death (SrSCD) [1-3,6].

HR series can be analysed in time domain, frequency domain and with non-linear methods. The analysis of HR and HRV while training requires several information among which demographic data, anthropometric data and the training context [1,3]. Further highly trained athletes suffer exercise-related physiological adaptation which could lead to different normative values for interpretation of HR and HRV parameters compared to general population [7]. Due to the complexity of physiological phenomena affecting HR and HRV during physical exercise with different level of psychophysical stress, it is difficult for athletes and trainers to interpret measures provided by commercial wearable technologies. The computation and interpretation of HR and HRV parameters is related to sport medicine clinician's experience and the great intra- and inter-observer variability negatively affects sensitivity and specificity. Availability of interactive computerized tools in support of sport medicine clinicians, trainers and athletes can optimize cardiovascular monitoring with wearable technologies.

The aim of this work is the design and the implementation of a graphical user interface, called Sport?Sicuro!, that allows automatic cardiovascular monitoring while practicing sport. This tool is an interactive instrument to support sport medicine clinicians and self-monitoring of athletes.

2. Sport?Sicuro!

Sport?Sicuro! was developed under MATLAB® GUI and provides a user-friendly computerized tool in support to cardiovascular monitoring while practicing sport. Sport?Sicuro! displays two panels: an input panel and a heart rate analysis panel (Fig. 1). The input panel includes the "Load" button for selecting HR recording; the "Age" box for showing age, which is a fundamental parameter to compute the estimated maximum HR and relative indexes; the ID box for inserting subject's identifier; the "Athlete's Data" button for inserting demographic, anthropometric and clinical information; the "Training Note" button for

inserting training information; the “Parameter Settings” button for changing processing parameters; the “Analysis” button for analysing HR series. The interaction with the input panel drive HR series representation and report of results by automatic analysis in the heart rate analysis panel. Eventually, a “Report” button is present in the HR analysis panel to save quantitative results in an output file.

2.1. Data loading

After having started Sport?Sicuro!, the user can select the HR series to load (file extension supported by MATLAB® may be used). Raw HR series in its entire length is displayed contextually to data loading in the HR analysis panel. The user needs to insert athlete’s data (sex, birthday date, height, weight, smoking habits, alcohol consumption and relevant clinical information) and training notes (date, time, caffeine consumption 6 h before training, alcohol consumption 24 h before training and exercise phases) (Fig. 1). After having inserted these data,

the user can update them by pushing the “Update” button present in each panel.

2.2. Parameter settings

“Parameter Settings” button allows to fix sampling frequency, which is set at 1 Hz by default (Fig. 1). For the correction of HR series, “Settings” button allows to fix the percentage of acceptable data loss, which is set at 10% by default. After having changed parameter settings, the user can update them by pushing the “Update” button.

2.3. Data analysis

Data analysis consists in three subsequent steps: pre-processing, HR and HRV parameters computation and results visualization. HR series is pre-processed in order to remove data loss consisting of samples in HR series wrongly equal to zero. If data loss is lower than the acceptable percentage of data loss (set at 10% by default),

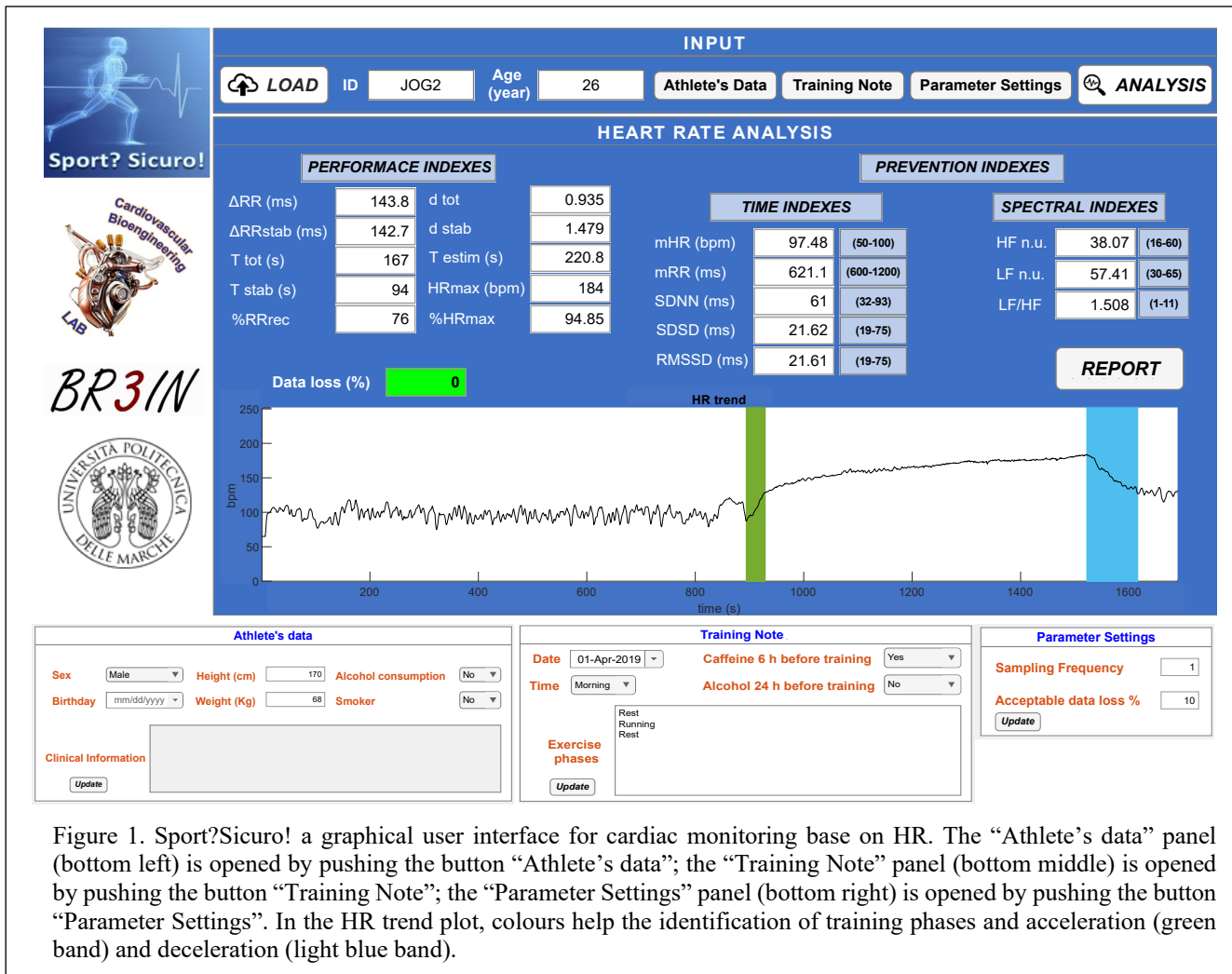


Figure 1. Sport?Sicuro! a graphical user interface for cardiac monitoring base on HR. The “Athlete’s data” panel (bottom left) is opened by pushing the button “Athlete’s data”; the “Training Note” panel (bottom middle) is opened by pushing the button “Training Note”; the “Parameter Settings” panel (bottom right) is opened by pushing the button “Parameter Settings”. In the HR trend plot, colours help the identification of training phases and acceleration (green band) and deceleration (light blue band).

the algorithm shows a green light and detects and replaces such data loss with a linear interpolation between stable HR segments immediately before and after data loss. Otherwise, the algorithm shows a red light and the analysis cannot be performed. Further, outlier values of HR series deviating by more than $\pm 10\%$ from the running median of HR series computed over 40 beats were replaced with the corresponding median value. Finally, an algorithm for automatic detection of training phases is applied to

segment HR series in resting and exercise phases [3]. HR and HRV parameters are extracted and assessed from the HR series according to [1,6-8]. Table 1 shows prevention indexes along with their definition and range of normality; Table 2 shows the performance indexes along with their definition. Sport?Sicuro! visualizes the processed HR series and the results of automatic analysis in the heart rate analysis panel.

Table 1. Definition of prevention indexes in time and frequency domains. The last two columns show the training phase in which each index is computed and the range of normality (min - max) respectively.

Prevention indexes (unit)	Definition	Training phase	Normality range
Time domain	mHR (bpm)	Mean HR	resting 50-100
	mRR (ms)	Mean of RR intervals	resting 600-1200
	SDNN (ms)	Standard deviation of all normal-to-normal RR intervals It reflects global HRV	resting 32-93
	SDSD (ms)	Standard deviation of the successive differences between adjacent normal-to-normal intervals	resting 19-75
	RMSSD (ms)	Root mean square of the sum of the squares of differences between adjacent normal-to-normal RR intervals	resting 19-75
Frequency domain	HF Power (n.u.)	Integration of HR-power spectrum in the 0.15 - 0.4 Hz frequency range It mainly reflects the vagal activity	resting 16-60
	LF Power (n.u.)	Integration of HR-power spectrum in the 0.04 - 0.15 Hz frequency range It reflects both sympathetic and vagal activities	resting 30-55
	LF/HF ratio	Ratio between HR-power spectrum in LF and HR-power spectrum in HF It quantifies the balance between sympathetic and vagal systems	resting 1-11

Table 2. Definition of performance indexes. Last column shows the training phase in which each index is computed.

Performance indexes (unit)	Definition	Training phase
Δ RR (ms)	Delta of increase between the average RR interval during exercise and the mean RR interval in the recovery phase	exercise recovery
Δ RRstab (ms)	Delta of increase between the average RR interval during exercise and the RR interval of the re-establish HRV index	exercise recovery
T tot (s)	Time between the end of exercise and the end of the recording	exercise recovery
T stab (s)	Time between the end of the exercise and the re-establish HRV instant	exercise recovery
%RRrec	Percentage value of RR interval evaluated in the recovery phase compared with the mean RR interval detected at rest	rest recovery
d tot	Derivative that quantifies the recovery times, calculated from the end of the exercise	recovery
d stab	Derivative that quantifies the recovery times, calculated from the end of the exercise	recovery
T estim (s)	Estimated time for a complete recovery, <i>i.e.</i> , the time that the subject would needed for his/her mean RR in the recovery phase to become equal to that in the resting phase	recovery
HRmax (bpm)	Maximum HR reached	exercise
%HRmax	Ratio between the estimated maximum HR (220-age) and reached maximum HR	exercise

These results can be saved through the “Report” button, which allows to save a report in .txt format relative to the performed analysis. The report includes prevention indexes and performance indexes along with athlete and training information.

3. Discussion

This work proposes Sport?Sicuro!, a graphical user interface for automatic analysis of HR series for cardiovascular monitoring while practicing sport.

Sample runs refer to SportDB database, specifically subject 2 of Jogging dataset [9]. Colours help the identification of training phases and acceleration (green band) and deceleration (light blue band) on the HR series plot [3]. Automatic analysis is based on feature definition provided in literature [1,6-8], and thus cannot be changed by the user. Parameter settings can be changed according to user’s preference or to acquisition settings of wearable HR recorders. The value of percentage of acceptable data loss should not overcome 15% to enable a reliable computation and interpretation of HRV indexes.

The reference ranges of normality relative to each index permit a first and rapid check of prevention indexes. These measures along with performance indexes can be examined in depth by including athlete’s data and training notes. When compiling the additional data on athlete and training, the user is inserting those variables affecting HR and HRV trend.

The existent commercial applications for HR monitoring are mainly finalized to assess athlete’s performances and their improvement. Whereas Sport?Sicuro! includes additionally cardiovascular risk indices for SrSCD, which is the leading medical cause of death across all sports and prevention by cardiac screening remains the primary weapon to contrast SrSCD [7].

Future works aim to integrate Sport?Sicuro! with CaRiSMA 1.0 [10], a software application for cardiac self-evaluation which uses QTc measures. The contextual analysis of QT interval, HR and their relation has the potential for giving a significant contribution in the development of new cardiac risk indexes. Further objective is to quantitatively compare Sport?Sicuro! against commercially available application for HR analysis.

Sport?Sicuro! was developed using MATLAB® 9.9 (R2020b): it is compiled as a standalone application using MATLAB® Compiler 6.3 and MATLAB® Runtime 9.9 is required for running it. For research purposes, Sport?Sicuro! can be obtained for free by contacting the research manager (Laura Burattini, l.burattini@univpm.it).

4. Conclusion

Sport?Sicuro! represents an interactive and useful GUI in support to sport medicine clinicians and automatic self-

monitoring of athletes while practicing sport. It is an instrument for cardiac screening, one of the primary weapons to contrast sport related sudden cardiac death.

References

- [1] M. Buchheit, “Monitoring training status with HR measures: do all roads lead to Rome?,” *Front Physiol.*, vol. 5, no. 73, Feb. 2014, doi: 10.3389/fphys.2014.00073.
- [2] M. Ludwig, K. Hoffmann, S. Endler, A. Asteroth, and J. Wiemeyer, “Measurement, prediction, and control of individual heart rate responses to exercise-basics and options for wearable devices,” *Front Physiol.*, vol. 9, n. 778, June 2018, doi:10.3389/fphys.2018.00778.
- [3] S. Romagnoli et al., “Signal Processing for Athletic Cardiovascular Monitoring with Wearable Sensors: Fully Automatic Detection of Training Phases from Heart Rate Data,” 2021 IEEE International Conference on Bioinformatics and Biomedicine (BIBM), Houston, Texas, USA, pp. 1491–1494, doi: 10.1109/BIBM52615.2021.9669408.
- [4] D. Nepi et al., “Validation of the heart-rate signal provided by the Zephyr bioharness 3.0,” *Computing in Cardiology Conference (CinC)*, Vancouver, Canada, pp. 361–364, 2016.
- [5] D. Hernando, N. Garatachea, R. Almeida, J. A. Casajús and R. Bailón, “Validation of heart rate monitor Polar RS800 for heart rate variability analysis during exercise,” *J Strength Cond Res.*, vol. 32, pp. 716–725, Mar. 2018, doi: 10.1519/JSC.0000000000001662.
- [6] E. Maranesi et al., “Health monitoring in sport through wearable sensors: a novel approach based on heart-rate variability,” *Mobile Networks for Biometric Data Analysis. Lecture Notes in Electrical Engineering*, Springer, vol. 392, pp. 235–246, Jan. 2016, doi: 10.1007/978-3-319-39700-9_19.
- [7] S. Romagnoli et al., “Initial investigation of athletes’ electrocardiograms acquired by wearable sensors during the pre-exercise phase,” *TOBEJ*, vol. 15, pp. 37–44, July 2021, doi: 10.2174/1874120702115010037.
- [8] D. Nunan, G.R. Sandercock, D.A. Brodie, “A quantitative systematic review of normal values for short-term heart rate variability in healthy adults,” *Pacing Clin Electrophysiol.*, vol. 33, pp. 1407–1417, Nov 2010, doi: 10.1111/j.1540-8159.2010.02841.x.
- [9] A. Sbröllini et al., “Sport Database: Cardiorespiratory data acquired through wearable sensors while practicing sports,” *Data Brief.*, vol. 27, 104793, Nov 2019, doi: 10.1016/j.dib.2019.104793.
- [10] A. Agostinelli et al., “CaRiSMA 1.0: Cardiac Risk Self-Monitoring Assessment,” *Open Sports Sci. J.*, vol. 10, pp. 179–190, Oct 2017, doi: 10.2174/1875399X01710010179.

Address for correspondence:

Department of Information Engineering,
Università Politecnica delle Marche,
via Brecce Bianche 12,
60131, Ancona, Italy.
E-mail address. l.burattini@univpm.it