A Nonlinear Analysis of respiration rate and heart rate during continuous incremental exercise test

Giovanna Zimatore[a], Dafne Ferrari [b], Gian Pietro Emerenziani [c], Lorenzo Innocenti [b], Valerio Bonavolontà[b]
Marco De Spirito[d], Laura Guidetti [b]
[a] eCampus University, Novedrate (Co), 22060, Italy
[b] University of Rome "Foro Italico", 00135, Italy
[c]Department of Experimental and Clinical Medicine, University of Magna Græcia of Catanzaro, 8810, Italy
[d]Institute of Physics, Fondazione Policlinico Universitario A. Gemelli IRCCS, Università Cattolica del Sacro CuoreRome, 00168, Italy
e-mail: giovanna.zimatore@uniecampus.it

Keywords: Heart rate variability, individual metabolic threshold, recurrence quantification analysis;
nonlinear dynamics;

In this preliminary work we compare the deterministic pattern of respiration frequency (RF), heart rate (HR) and tidal volume (VT) during the execution of cardiopulmonary exercise test (CPET). This test is executed in order to estimate individual metabolic threshold (IVT). In particular, IVT is the point after which ventilation begins to increase disproportionately relative to oxygen uptake so that it was called "point of optimal ventilatory efficiency" [1]. It is considered a useful submaximal breakpoint for optimal moderate exercise intensity prescription for health. The transition from aerobic to anaerobic metabolism during incremental exercise is deeply studied and different protocols to measure (from gases exchange) or estimate (from HR) where the transition occurs are proposed [1-2]. During a continuous incremental exercise test, the individual ventilatory threshold (IVT) is determined analysing the ventilatory equivalent (VE/ VO_2) as a function of VO_2 where it reaches its lowest value in this curve.
In this preliminary work we suggest innovative method to observe the transition. A volunteer underwent to incremental exercise test on a treadmill (Woodway PRO, Woodway, Waukesha, WI, USA). VO_2, carbon dioxide production (VCO_2), and ventilation (VE) were measured by an automatic gas analyzer (Quark RMR-CPET CosmedTM, Rome, Italy). The test started at 3 km/h; the speed was increased by 1 km/h every three minutes until 5 km/h was reached and then the slope was increased by 3% every three minutes until one of the following conditions was reached: a value of 10 on RPE-OMNI-Walk/Run Scale [3-4] or the subject's HR reached a value of 90% of their predicted HRmax. HR (beats/min) was continuously recorded before and throughout the trial using a HR monitor (RS 400, Polar ElectroTM, Kempele, Finland). The individual ventilatory threshold (IVT) for this volunteer is at time t=900 sec as mean of previous 30 seconds. The basically stochastic nature of heart rate dynamics, probably reflecting the continuous adjustments to an unpredictable internal environment well suited for recurrence quantification analysis (RQA). The ability of RQA to predict catastrophic changes and phase transitions is in line with the fact that RQA is based upon the change in correlation structure of the observed phenomenon that is known to precede the actual event in many different systems ranging from physiology and genetics to economics. Before obvious symptoms of crisis appear, correlation increases, and, at the same time, variance (and volatility) increases too [5-6]. We have studied different patterns of Recurrence Plot (RP) and the change of percent of determinism along time in time series 24 minutes long, recorded during an incremental exercise test. In Fig1-2 is possible observe the unthreshold recurrence plot of the period between consecutive heartbeat (RR interval, obtained from heart rate) and of RR interval detrended; in Fig3-4 the unthreshold recurrence plot of tidal volume (VT) and of respiration frequency (RF), respectively (by VRA, E. Kononov) (emb=7;radius=50; line=4). Comparing the RP, percent of determinim and percent of recurrence epoch by epoch we found a transition at the same time at which the IVT was detected from ventilatory equivalent curve: see point i=350 that corresponds to time t=909 sec and it corresponds to the same workload. Future applications of this work regard the realization of mobile and wearable system for realize individual training and monitoring fatigue and stress during the execution of a physical exercise.

[1] JS. Skinner, TH. Mclellan Exercise Physiology (1980) 234-248.
[2] G.P. Emerenziani et al PlosOne (2018) 1-13.
[3] L. Guidetti,et al. J Aging Phys Act (2011) 19: 214–224. PMID: 21727302
[4] A.C. Utter et al. Med Sci Sports Exerc (2004) 36: 1776– 1780. PMID: 15595300
[5] G. Zimatore et al. Chaos (2017) 27, 043101; doi: 10.1063/1.4979351
[6] G. Zimatore et al. Chaos, Solitons and Fractals (2018) 110, 82–94.

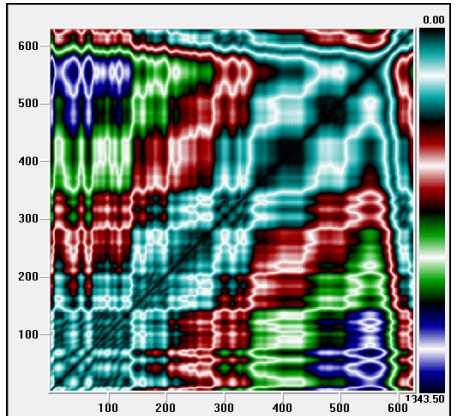

Figure 1. Unthreshold Recurrence plot of RR (Rec=30,.2%, Det=99.72%; see trend effect in colored regions and point i=350)

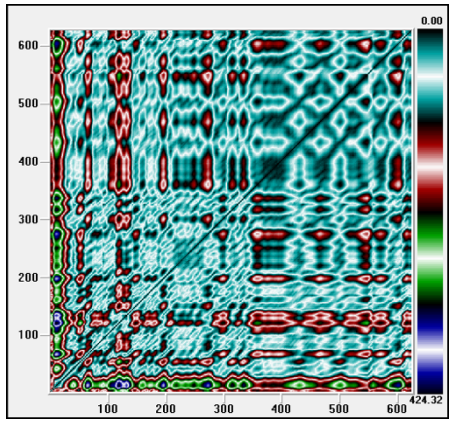

Figure 2. Unthreshold Recurrence plot of RR detrended (Rec=23.378%, Det=95.57%; see point i=350)

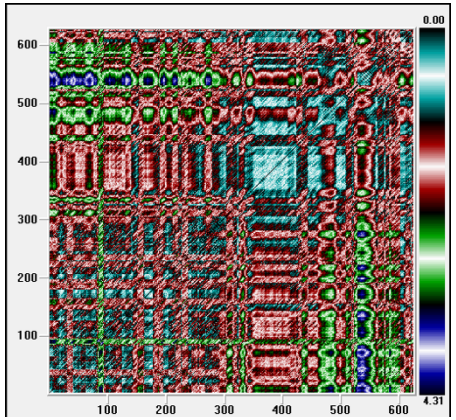

Figure 3. Unthreshold Recurrence plot of tidal volume (VT) (Rec=6.44%, Det=76,26% see point i=350)

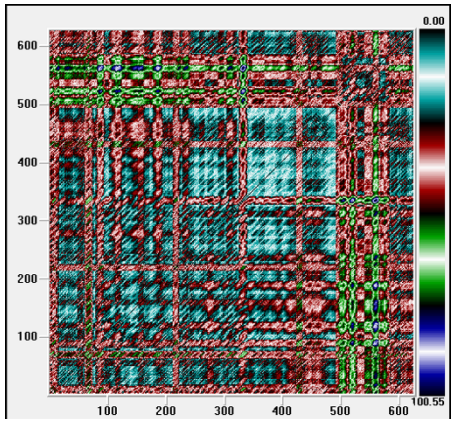

Figure 4. Unthreshold Recurrence plot of respiration frequency (RF) (Rec=5.71%, Det=70.68% see point i=350)