Biomedical Signal Processing and Control 40 (2018) 156–162

Contents lists available at ScienceDirect

Biomedical Signal Processing and Control

journal homepage: www.elsevier.com/locate/bspc

ECG response to submaximal exercise from the perspective of Golden Ratio harmonic rhythm

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ARTICLE INFO

Article history:
Received 20 November 2016
Received in revised form 2 August 2017
Accepted 16 September 2017

Keywords:
Electrocardiography
Fibonacci series
Golden Ratio
Exercise
Cardiovascular adaptation

ABSTRACT

Background: The Golden Ratio (GR), derived from the Fibonacci sequences, has multiple representations in nature, as expressions of the repetition of specific geometric shapes called fractals.
Methods: The aim of the study focused on investigation of the cardiovascular homeostasis, at rest and during effort testing, with determination of the validity of the GR at the level of variables extracted from serial ECG. We used a group of 230 young subjects (average age 19.21 ± 1.87), each subject performing a 6 min submaximal exercise ergometer test (Astrand & Rhyming Protocol). We were interested in estimate the ratio between the electrical diastole and electrical systole (TQ/QT) and between the cardiac cycle and electrical diastole (RR/TQ), which has been much discussed as being related to GR value.
Results: We proposed using a new synthetic fractal indicator (SFI), with dynamic nonlinear evolution and we determined the intervals of acceptability for SFI. The mean values of the SFI of our subjects were significantly close to GR value, aspect that suggests the presence of harmonic rhythm, under different conditions of existence and adaptation of the human organism (rest and submaximal effort). The SFI and the heart rate values had very strong correlations, at rest ($R = 0.88$, $p < 0.001$, CI 95% 0.83–0.91) and postexercise ($R = 0.91$, $p < 0.001$, CI 95% 0.87–0.94).
Conclusions: Our results show a fractal dimension of the ECG interval dynamics for the study group. The proposed SFI imposes itself as a relatively simple parameter for assessing heart's electrical functionality during cardiac cycle that can be applied both at rest and exercise.

1. Introduction

The Golden Ratio (GR), represented by the Greek letter Phi (φ), is known since ancient times also as the Golden Ratio, Golden Number, Golden Proportion, Golden Mean, Golden Section, Divine Proportion and Divine Section as a mathematic parameter with important symmetric and harmonic properties [1].

The Golden Ratio, as an irrational, continuous and non-repeating number [2], with the value of 1.61803398 . . .., can be considered as the first member of a family which can generate a set of generalized Fibonacci sequences [3].

The Fibonacci numbers is a series of terms $\{F_n\}^{\infty}_{n=1}$ wherein each term (except the first two) is the sum of the two previous terms, according to the following linear recurrence equation:

$$F_n = F_{n-1} + F_{n-2}$$

This results in a series of terms of the type 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144 .. . ., in which the ratio of two consecutive terms tends to the Golden Ratio value, as stated in the formula $\varphi = F_n/F_{n-1} = 1.61803398\ldots\ldots$.

The Fibonacci sequence is also defined by the quadratic equation $x^2 - x - 1 = 0$ which has two solutions: $x_1 = \varphi = 1.618\ldots$ and respectively $x_2 = -1/\varphi = -0.618\ldots$. [4].

The Golden Ratio, the Fibonacci sequence and also its q-deformed or "quantum" extension [4] are widely applied in modern sciences, particularly in theoretical physics, mathematics and computer science, but also in art, architecture, economics and natural sciences [5]. The multiple connections of these mathematical concepts with our life environment it led to their labelling with the term of "divine aesthetics" [6].

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http://dx.doi.org/10.1016/j.bspc.2017.09.018
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It seems that the Golden Ratio has multiple representations in nature, as expressions of the repetition of specific geometric shapes called fractals, resulting at the biological level an interesting manifestation of the phenomenon of phyllotaxis.

In medicine, the applications of Golden Ratio are also very diverse, especially in Anatomy and Physiology, e.g. human body measurements (human face, human hand, other anthropometric parameters), lungs and bronchial divisions, hearing and vestibular functions, brain and cardiovascular rhythms, human genome DNA [7–9], biomechanical analysis on human gait [10,11].

Some researches focused on determining correlations between GR and the variations in systolic and diastolic blood pressure, induced by cardiac cycle, as a marker of health status [8,12,13].

Another special interest has been represented by the investigation of GR applicability to ECG testing. The results of several studies converge towards the idea of the existence of a ratio with φ value between the diastolic and systolic phases of the cardiac cycle, measured on the ECG [8,14–17]. According to some scholars, this harmonic rhythm of heart functioning is valid only during rest state and it represents a manifestation of phylogenesis, under the principle of physiological adaptation of the organism to an operating regime in conditions of maximum energy efficiency [18].

It is worth mentioning here the interesting studies by Svetskov on the symmetry and spatial organization of the heart cycle in mammals, in conditions of rest and physical exercise [19], used later as a reference by other authors [20].

These studies have highlighted the existence of certain biophysical parameters (temporal, volumetric, mechanical and coronary flow related), that have an invariant dynamics during cardiac cycle, which can be correlated with the Golden Ratio value.

Many recent studies documented that Golden Ratio and the Fibonacci sequence are strongly linked to hemodynamic variables [21,22], but we consider these data as being still controversial. In addition, most research especially focused on cardiovascular investigations at rest, mathematical modelling being less applied in exercise testing in human subjects.

2. Material and methods

2.1. Aim of the study

The practical objective of this research focused on the investigation of the cardiovascular homeostasis at rest and during effort testing, with determination by means of descriptive statistics (univariate and bivariate analysis) and inferential statistics of the validity of the GR harmonic rhythm at the level of a set of variables, which was extracted from serial ECG.

2.2. Participants

Basically, we used a group of 230 young subjects, with an average age of 19.21 ± 1.87 years, age range 18–22 years old and sex ratio 0.437 (70 men/160 women). The subjects are students in Physical Therapy at the University of Pitesti who are clinically healthy, without significant cardiovascular pathological history and who were declared apt for physical effort following a medical examination.

According to the most cited models in the specialty literature that can generate experimental variables in the cardiovascular field, which are possibly correlated with GR and Fibonacci sequence, we designed a double assessment of subjects, at rest (r) and after the effort (e).

2.3. Data acquisition

The assessments were carried out between 8 am and 12 am, with the same type of protocol, with the following sequence: at rest (after a 5 min rest) and during a 6 min exercise test. The exercise testing was performed according to the protocol of the Astrand & Rhyming Submaximal Bicycle Test, a classical, accurate and largely used standardized tool to estimate maximal oxygen consumption (VO_2 max) [23].

In practice, the ergometric bicycle test or the treadmill test are commonly used to assess the cardiovascular adaptability to effort, as there are various standard load protocols for ECG recording.

These protocols are based on a metered load of physical effort, with the recording of serial ECGs at rest and during effort, as well as during the recovery period after the effort. These tests are very useful for the diagnosis of ischemic heart disease, but especially for the exclusion of this type of pathology [24].

Considering that the physical effort represents a variant of the body's homeostasis, it becomes interesting to investigate the presence of the harmonic rhythm (or another type of derived rhythm) during physical exercise.

That's why we opted for the protocol of the Astrand & Rhyming Submaximal Bicycle Test. This test estimates the VO_2 max using a single-stage, six-minute submaximal cycling protocol, by recording the subject's heart rate at rest and at minute six, when usually subject is reaching a steady state. The test predicts the VO_2 max, based on the linear relationship between VO_2 max and heart rate, by reference to a nomogram [25].

Since the effort testing offers the possibility to dynamically investigate the electrophysiological systolo-diastolic activity of the heart, superimposable with myocardial mechanical activity, we proposed this model of experimental design of evaluation of the group of subjects.

Therefore, each subject performed a test of 6 min submaximal exercise ergometer test, cycling with a load of 150 W for males and 100 W for females, with a settled speed of 60 rotations per minute [26].

We recorded the ECG for all subjects in the mentioned circumstances by using a computerized protocol (Ergoline ergometer exercise bike – Ergoselect 200, with Cardimax FX-7402, Fukuda Denshi Co. Ltd., with 12 derivations).

Within the electrocardiogram, we were interested in conducting specific measurements on the duration of the heart systole and diastole in order to estimate the ratio between the two intervals, which has been much discussed as being related to a harmonic rhythm with φ value.

For the delimitation of the systolic component from the diastolic one of the cardiac cycle, we turned to the interpretation of consecrated authors, who define the electrical systole as the time between the start of the Q (by case R) wave and the end of the T wave (meaning the QT interval). On the other hand, the electrical diastole is described as the remaining period, from the end of the T wave to the beginning of the Q (by case R) wave of the next cardiac cycle (namely the $RR - QT = TQ$ segment, where $RR = QQ$) [27–30].

The TQ on ECG represents a segment, because does not include waves. In the same time, for an easier understanding of the series of data, we will use further the appellative "interval" for the ST segment, taking into consideration his algebraic sense, as equivalent of the diastolic interval of the cardiac cycle [31–33].

As the heart rate increases, the dynamic of QT interval follows that of the ventricular systolic ejection (the mechanical systole), and the one of the TQ interval follows that of the ventricular filling (the mechanical diastole). As a result, the two mentioned intervals can be considered as electrical parameters of cardiac mechanical phenomena [28].