

Relation between respiratory rate and heart rate – A comparative study

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Abstract

Background: Activity of many physiological subsystems has a well-developed rhythmic character. Often a dependency between physiological rhythms is established due to interaction between corresponding sub-systems. A well-known feature of oscillatory systems and biological oscillators in particular, is their ability to synchronize. The cardiac and respiratory systems each function in an oscillatory manner, providing a nice example of coupled biological oscillators. The present study has been conducted to evaluate the relation between Respiratory rate and Heart rate and comment upon frequency coupling involved in cardiovascular and Respiratory systems.

Materials and Methods: 40 conscious healthy adults belonging to both sexes were screened using standardized digital physiograph. Piezoelectric respiratory belt was used for respiratory recording. A bipolar limb lead ECG was used for cardiac activity.

Results: The data of healthy subjects showed strong variability in heart rate and respiratory rate in a 15 minute recorded segment and subjected to fast Fourier Transforms.

Conclusion: We thereby conclude that frequency coupling is the important aspect of cardio-respiratory interaction as we detected the presence of several different n: m epochs within one record.

Keywords: Coupled biological oscillators, heart rate, respiratory rate, cardio-respiratory interaction, physiography, frequency coupling.

Introduction

Both respiratory and cardiac rhythms have been extensively examined with regard to their ability to detect pathological conditions. Different tools of linear and nonlinear univariate time series analysis have been used in numerous attempts to quantify the state of either cardiovascular or respiratory systems and to reveal malfunction.¹⁻⁵

First approaches for the study of cardiorespiratory synchronization have been undertaken by the analysis of the relative position of inspiration within the corresponding cardiac cycle⁷. More recently, phase synchronization between heartbeat and breathing has been studied during wakefulness using the synchrogram method.⁸⁻¹⁰

Heart is the main pump in the cardiovascular system; consist of a large network of vessels that can be regarded as resistances or conductance. The ultimate goal of the circulation is to supply all cells with oxygen and nutrients. Therefore the optimal control of the amount of blood and thus of oxygen and nutrients, is needed. This is performed by controlling the cardiac frequency and the stroke volume, the amount of blood expelled by the heart in each cycle. The cardiac frequency and stroke volume adapt to variations in the conductance of the vascular network.

In addition the conductance is regulated by local mechanisms such as the endothelial, neurogenic and myogenic activities. The other generator in the network

is the respiratory systems, which not only takes care of the oxygen, but also modulates the heart rate has long been known as respiratory sinus arrhythmia.

In a study conducted by Kiyoshikotani published in May, 2002 in Japan developed a physiologically plausible model for this cardio respiratory synchronization and numerically shown that model can exhibit stable synchronization against given perturbations. In this model, in addition to the well-known influence of respiration on heartbeat, the influence of heart beat on respiration is also important for cardio respiratory synchronization¹¹.

In a study conducted and published in May 2010 aimed to quantify cardio respiratory phase locking in obstructive sleep apnea. Having investigated polysomnography data of 248 subjects cardio respiratory phase coupling was computed from the R-R intervals of body surface ECG and respiratory rate, calculated from abdominal and thoracic sensors, using Hilbert transform observed significant reduction in phase coupling in patients with severe OSA compared to patients with no or mild OSA cardio respiratory phase coupling was also associated with sleep stages and was significantly reduced during rapid – eye movement sleep compared to slow wave sleep. There was, however no effect of age and BMI on phase coupling. Study suggested that the assessment of cardio respiratory phase coupling may be used as an ECG

based screening tool for determining the severity of OSA¹².

In a study conducted by Carsten Schafer et al published in 1998 in Germany used newly developed data analysis technique which observes interaction that does occur in even weakly.

Six different methods have been used to analyze cardiorespiratory coordination and have been quantitatively compare with respect to their performance. The methods were applied to the simultaneous recording of electrocardiogram and a respiratory trace of 20 healthy subjects during night time sleep. The study concluded that the method of phase recurrences to be the method of choice since it offers best temporal resolution and the highest number of coordinated sequences and heart beats¹³.

Materials and Methods

The present study was undertaken in Upgraded Department of Physiology, OMC, during the period of July, 2010 to Sept. 2010.

Total population of 50 people in the age group of 20-40 was studied, taking their consent after explaining the whole procedure. Approval from the ethical committee was also obtained in advance.

A non-invasive method of simultaneously estimating heart rate and respiratory rate was done using standardized digital physiographs supplied by AD instruments.

Pulse rate, respiratory rate and ECG of total population were recorded for an interval of 15 minutes (heart rate was derived from the recorded pulse).

For the assessment of respiratory rate and heart rate following devices were used attached to the power lab of the physiographs:

1. Pulse transducer: pulse transducer uses a piezoelectric element to convert force applied to the active surface of the transducer into an electrical signal. To produce a signal, a change in force must be applied to the active surface of the transducer. Expansion and contraction of the finger circumference, due to changes in blood pressure, can be detected by the transducer. A typical output is 50-200 mv but can reach as high as 500mv transducer is kept in place using a Velcro strap around the finger. The index finger is usually best for pulse measurement.
2. Piezoelectric respiratory belt: generates a voltage when there is a change in thoracic or abdominal circumference due to respiration. It contains a piezoelectric device that requires no excitation and connects directly to power lab transducer contains a sensor placed between two elastic strips. Stretching the elastic places a strain or changes in length, such as period of no breathing, the signal returns to zero. The device should be placed around the body at the level of maximum respiratory expansion at maximum inspiration the belt should

be stretched almost too maximum extension this allows the recording of respiratory changes with maximum sensitivity and linearity.

Signal source: piezoelectric

Output range: 20 mv to 400 mv

3. ECG electrodes – are a set of gold plated, cup shaped electrodes suitable for recording ECG. These electrodes have a diameter of 9 mm. they feature a hole in the top for injection of conductive paste or gel and lead wires of 185 cm, fitted with 1.5 mm sockets for bio-amp cables of physiograph.

The subject is made to sit comfortably on a chair and the above mentioned electrodes are attached at appropriate places. Pulse rate, Respiratory rate and ECG are recorded for a period of 15 minute duration in a quiet, cool environment of Electrophysiology lab. Heart rate was derived from the pulse rate signal simultaneously.

Results

Table 1: Heart Rate (HR) per minute of 15 minutes duration Mean HR Values (for 40 cases)

Maximum (HR)	106.33
Minimum (HR)	65.40

Table 2: Respiratory Rate (RR) per minute of 15 minutes duration Mean RR values (for 40 cases)

Maximum (RR)	28.73
Minimum (RR)	14.73

Table 3: RSA amplitude (for 40 cases) Mean Values

Maximum RR	Minimum RR	Difference
1.829	0.408	1.421
0.705	0.6245	0.08

Table 4: Respiratory and Non-Respiratory components of FFT Frequencies of ECG signal (for 40 cases)

Maximum Value of CVS/R	18.14
Minimum value of CVS/R	0.72

Discussion

We have investigated simultaneous wave recordings of cardiovascular and respiratory systems in the 40 healthy individuals including males and females and obtained non-stationary bivariate irregular data of both systems of 15 minute duration.

All the 40 subjects showed strong variability of respiratory rate and heart rate per minute in 15 minute recorded data, which is presented in Table 1 and Table 2. Maximum and Minimum values are shown.

RSA amplitude for maximum RR and minimum RR and the difference is presented in Table 3. The maximum value of ratio of CVS/R and the minimum value of ratio of CVS/R is shown in Table 4.

We have investigated the synchronization between the cardiovascular and respiratory system in the healthy individuals in both male and female in resting state conditions. We got non-stationary bivariate irregular data of namely cardiovascular and respiratory system in a time series for a period of 15 minutes. We have tried to evolve the phase and frequency locking process involved in the cardio respiratory coupling.

As biological systems are open system and far from equilibrium, their general behavior is characterized by intrinsic oscillation in the background of stability obtained and stratified during its evolution for simple to complex. Every process in biological system from subcellular to macroscopy level of a complex organism like human beings is studied theoretically in the frame work of interplay of stochastic and deterministic methods.

The stability process in complex biological systems, i.e. in multicellular systems, express a series of stratified stability. These stratified stabilities are addressed from molecular level to complex organ system level within the framework of homogenous and heterogeneous integration in horizontal vertical and time coordinates.

From this theoretical prospective one can predict the existence of intrinsic oscillatory behavior in every component of complex biological system upon which it has been built up. So we also hypothesize that there should be intrinsic oscillatory behavior in the cardiovascular and respiratory systems independent of influence of one over the other.

A brief review of evolution of cardiovascular and respiratory systems is necessary to understand comprehensively the coupling of cardiovascular and respiratory systems. There are different phase in evolution of cardiovascular system. The first phase of evolution of cardiovascular system is said to be linked to address the overload of gastrointestinal system as extension of closed canal system, in order to meet the increasing demand of organism for digestion and absorption of more complex food materials. The second phase of cardiovascular system is said to be linked to meet the increasing demand for oxygen for addressing the overload of metabolic activity imposed upon organism during its evolution from aquatic to terrestrial environment.

Regarding evolutionary aspects of respiratory system it has many components. One among them is during evolution of Quadra pedal animals to bipedal animals which has introduced the inherent instability in stranding of animals. Second is the emergence of speech in the higher organisms. Third is optimization of exchange of gases required in the terrestrial animal during the increasing demand of metabolites. Hence we have planned to study the interaction of respiratory and cardiovascular system in a stationary sitting resting condition.

Interaction of cardiovascular and respiratory systems involves a large number of feedback and feed forward mechanisms. As a first approximation, one can record this coupling as uni-directional i.e. the respiratory system influencing the rhythm of cardiovascular system in resting conditions. This can be further substantiated on the basis of perfusion-limited process of exchange of pulmonary gases in a normal person where the exchange of process gets saturated during its normal one third of transit time of blood in the pulmonary capillaries. This is particularly more relevant in our study as we did it absolutely resting conditions where there is no load imposed on cardiovascular systems.

When we have recorded the pulse, ECG, and respiratory activity simultaneously and consistently observed the respiratory sinus arrhythmia in all cycles of respiration of all the subjects in the form of increase heart rate during inspiratory phase and decrease heart rate during expiratory phase.

When we subjected the same data for bi-spectral analysis with Hilbert transforms the power spectral density of FFTs of respiratory and cardiovascular system confirmed the same trend. Increased power spectral density during inspiration and decreased during expiration in all cycles of respiration of all the subjects.

The data also shows that when RR intervals are taken into account, the RSA amplitude varied strongly during longer length of recording.

Conclusion

We have subjected the non-stationary bivariate data to bispectral analysis, thereby obtaining frequencies of both the systems. We could conclude that there is an effect of respiratory rhythm on cardiovascular rhythm. FFTs of cardiovascular and respiratory systems are consistent with respiratory sinus arrhythmia (RSA) during each inspiratory and expiratory phase of one respiratory cycle, i.e. increased FFT power attenuation during inspiration and decreased FFT power attenuation during expiration. Ratios of cardiovascular and respiratory rate may vary in the range of 3:1 to 6:1 confirming the behavior of frequency coupling in the modulated effect of RSA and other external factors. All the respiratory components of FFTs fall below 0.6 Hz and the cardiovascular components between 1-2Hz. This is indicative of unidirectional coupling i.e. respiratory rhythm which is influencing the cardiac rhythm. Modulation of heart rate by respiration is done by mechanical means through baroreceptor mechanisms by altering blood pressure as is evident from the constancy of LF/HF ratio (autonomic tone) during a longer length of recording. Variation of coupling ratio is more in males than in females.

Future studies can be undertaken by subjecting the subjects to different degrees of exercise to study the bidirectional coupling i.e. to study the effect of

cardiovascular system on respiratory system and vice versa. Similar studies can be done in fasting and post-lunch conditions to study the interaction of gastrointestinal system with cardiovascular system. Similar studies can be undertaken in variable state of locomotory and speech components in the respiratory rhythm.

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