Quantitative analysis of the cardiorespiratory system during paced respiration

Heike Leutheuser1,3, Thorsten Schaffer1,3, Bernhard Hensel1, Christian Weigand3, Ju¨ rgen Schüttler2 and Christian Jeleazcov2,3

1Max-Schaldach Stiftungsprofessur fu¨ r Biomedizinische Technik, Universita¨t Erlangen-Nu¨ rnberg, Germany; 2Ana¨sthesiologische Klinik, Universita¨tsklinikum Erlangen, Germany; 3METEAN, Fraunhofer IIS, Erlangen, Germany; e-mail: Heike.Leutheuser@biomed.uni-erlangen.de

Abstract—The phase relationship between respiration and cardio- vascular system is investigated under the influence of paced respiration with respiratory rates from 4 to 25 breaths per minute. Particularly, the phase shift dependency on breathing rate as well as the correlation between respiratory sinus arrhythmia (RSA) and breathing frequency is examined. It can be shown that there is an increasing phase relationship between RSA and breathing frequency and that RSA diminishes with rising breathing frequency.

Keywords: respiratory sinus arrhythmia, paced respiration, cardiorespiratory system.

I Introduction

Respiratory sinus arrhythmia (RSA) is a common phenomenon of the interaction between respiratory and cardiovascular system. RSA is the breath-synchronous variation of the heartbeat and is defined as the difference between the maximum and minimum RR interval within one breath. Although this phenomenon is known for several years, the causes and underlying physiological processes are still not completely understood.
There are two possible explanations for the origin of RSA: central oscillator theory and baroreflex theory [1]. According to the central oscillator theory, RSA and respiratory frequency have the same car- diopulmonary oscillator which is influenced by brainstem structures and innervated by efferent and afferent nerves fibres [2, 3]. The other theory is that baroreflex mechanism officiates as opponent to intra- thoracic pressure fluctuations which are caused by respiration [4, 5]. Furthermore, cardiopulmonary receptors or lung stretch receptors may influence RSA.
In this work paced respiration is used to investigate the phase relationship between respiration and respiratory sinus arrhythmia.

II Methods

A. Data acquisition
25 (6 female) healthy volunteers (age: 25.9 ± 3.2, BMI: 24.0 ± 3.7, mean ± SD) were studied during paced respiration with breathing rates from 4 to 25 breaths per minute. The recorded biosignals were ECG, SpO2, etCO2, respiratory mechanics and CNAP (continuous non-invasive blood pressure).
B. Data analysis
R peak times were automatically detected from raw ECG recordings and manually corrected if necessary. Expiratory and inspiratory onsets of each breath were extracted from respiratory flow signals and mean lengths of inspiration and expiration periods were calculated by averaging over all breaths within one record.
Frequency of respiration was estimated using Fourier transformwith weighted mean [6].

$$f = \frac{\sum_{i=-1}^{1} X_{f_{k+i}} \cdot f_k}{\sum_{i=-1}^{1} X_{f_{k+i}}} = f_k + \frac{X_{f_{k+1}} - X_{f_{k-1}}}{\sum_{i=-1}^{1} X_{f_{k+i}}}$$

where Xfk is the Fourier transform of respiratory flow and fk is the
frequency belonging to the k-th peak of the power spectra.
Since it is assumed that the frequency of respiration f equals the frequency of RSA, a sinusoidal fit to respiration and RR intervals was used to calculate the phase shift between the time series. The fit function is composed of a sine wave with frequency f and phase shift φ

$$x(t) = A \cdot \sin(2\pi f t + \varphi) + c$$

$x(t)$ was calculated using least squares approximation. Then, the phase shift was defined as difference between phase of respiration and phase of RR intervals $\Delta\varphi = \varphi_{resp} - \varphi_{rr}$.
To obtain the RSA dependency on breathing frequency, the maximum
and minimum RR intervals within one breath were calculated. The difference between these two values was computed to estimate a quantitative value of RSA for this breath. The overall RSA was determined by averaging RSA values for all breaths in one record.

III Results

A. Variation of RR intervals within one breath

The duration of RR intervals decrease during inspiration and increase during expiration. This phenomenon can be seen in breathing frequencies from 0.06 to 0.26 Hz. At higher breathing frequencies (0.32–0.42 Hz), this aspect cannot be displayed in a proper way because of the small number of RR intervals within on short breath.

B. Phase shift dependency on breathing frequency

The phase shift $\varphi = \varphi_{resp} - \varphi_{rr}$ rose continuously with increasing breathing frequency in all 25 volunteers, see Fig. 1. The solid line displays the mean behavior for all volunteers. A polynomial of second order was fitted to the mean phase values for each breathing frequency.

C. RSA dependency on breathing frequency

RSA declines with rising breathing frequency, see Fig. 2. The indi- vidual RSA of a certain breathing frequency was averaged and a

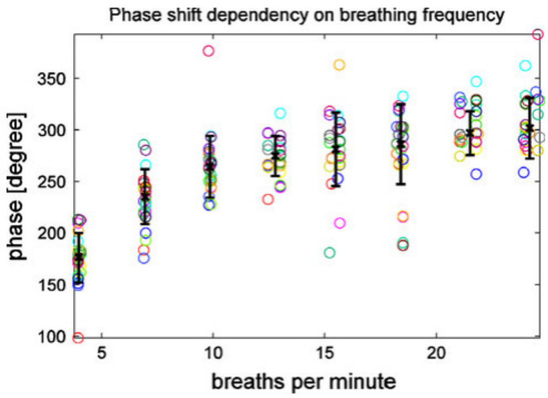

Fig. 1 Phase shift dependency on breathing frequency

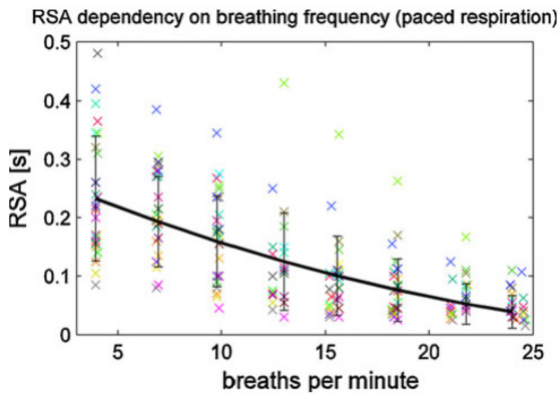

Fig. 2 RSA dependency on breathing frequency

polynomial of second order was applied. This polynomial is illustrated in the solid line together with the standard deviation as error bars.

IV Conclusion

The frequency of respiration influences the phase shift between the respiratory and cardiovascular system. The phase shift rises and reaches a plateau at about 22 breaths per minute. This can be ascribed to a physiological state. Further investigation is needed to determine the causes of this behavior.

V References

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