Influence of paced respiration on parameters of the cardiorespiratory system

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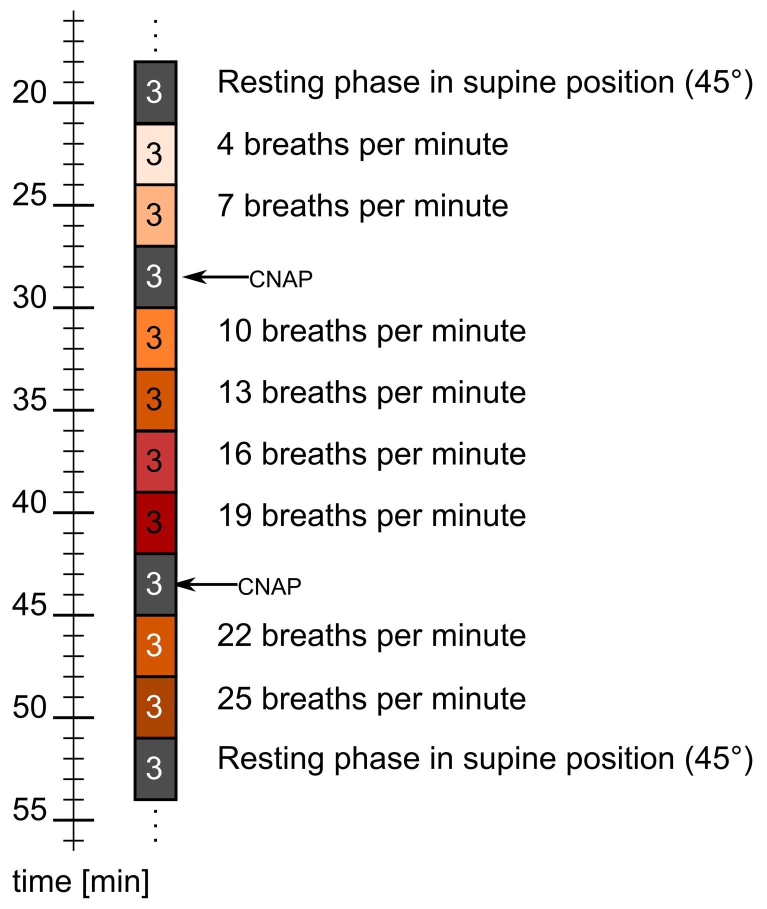
Data acquisition

Test Record during paced respiration



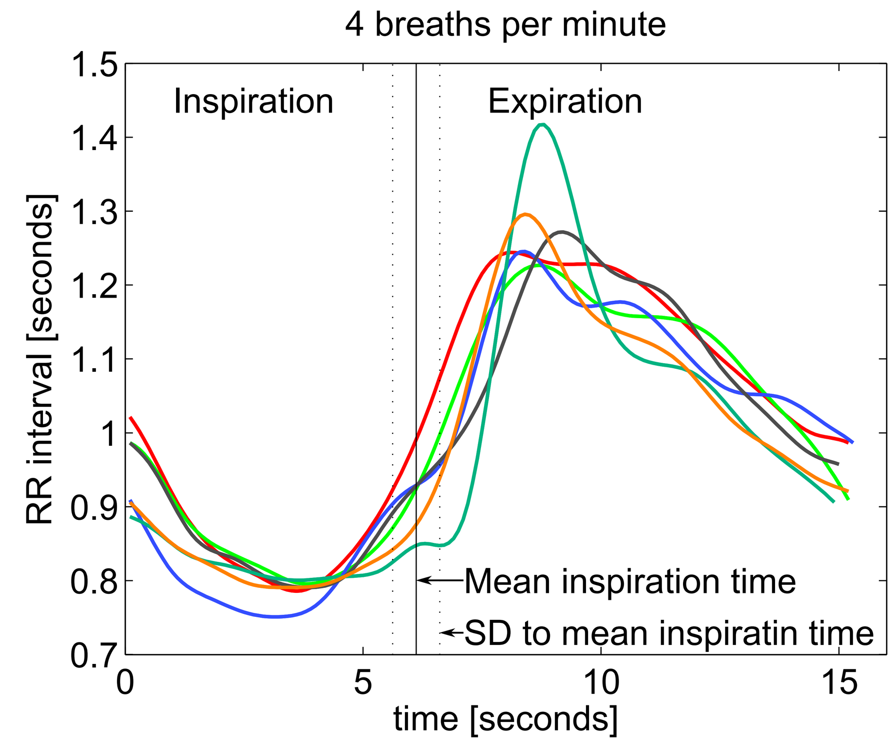
10 healthy male volunteers (age: 26.5 ± 2.3 yrs, BMI: 23.7 ± 3.7, mean ± SD) were studied during paced respiration.

Recorded biosignals:

- ECG (electrocardiogram)
- SpO_2 (saturation of peripheral oxygen)
- $etCO_2$ (end tidal CO_2)
- respiratory mechanics
- CNAP (continuous non-invasive blood pressure)

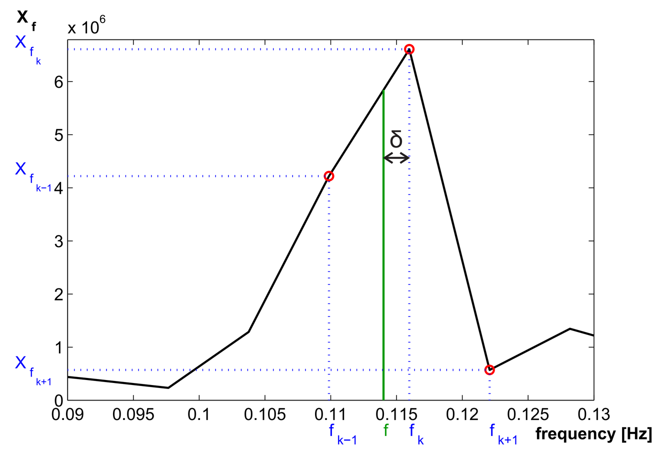
Variation of RR intervals within one breath

- Start of inspiration and expiration were extracted from respiratory data
  - Calculation of mean inspiration time
- Plot of RR intervals over each breath
- Duration of RR intervals decrease during inspiration and increase during expiration



Methods

- RR intervals were extracted from ECG recordings
- Frequency of respiration was estimated using Fourier transform with weighted mean



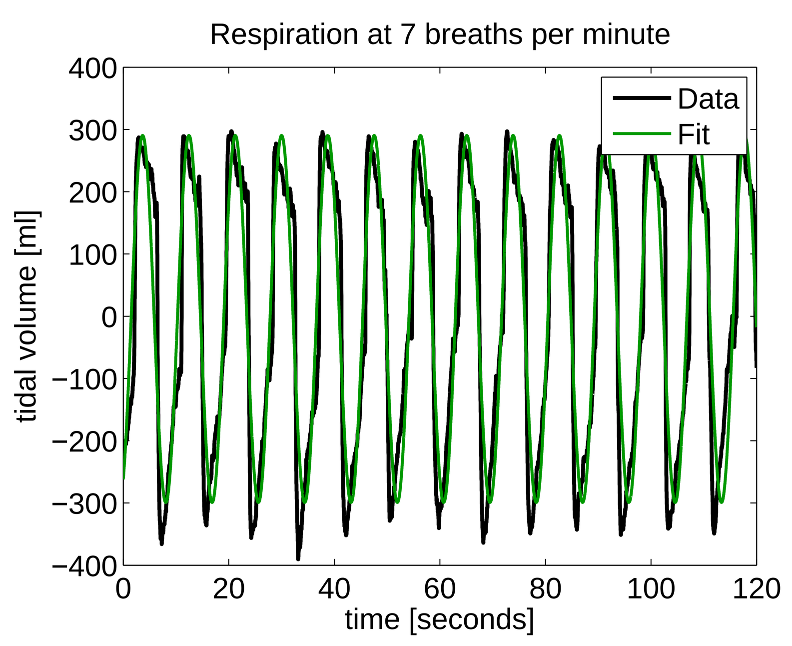
$$f = \frac{\sum_{i=-1}^{1} X_{f_{k+i}} \cdot f_{k+i}}{\sum_{i=-1}^{1} X_{f_{k+i}}}$$

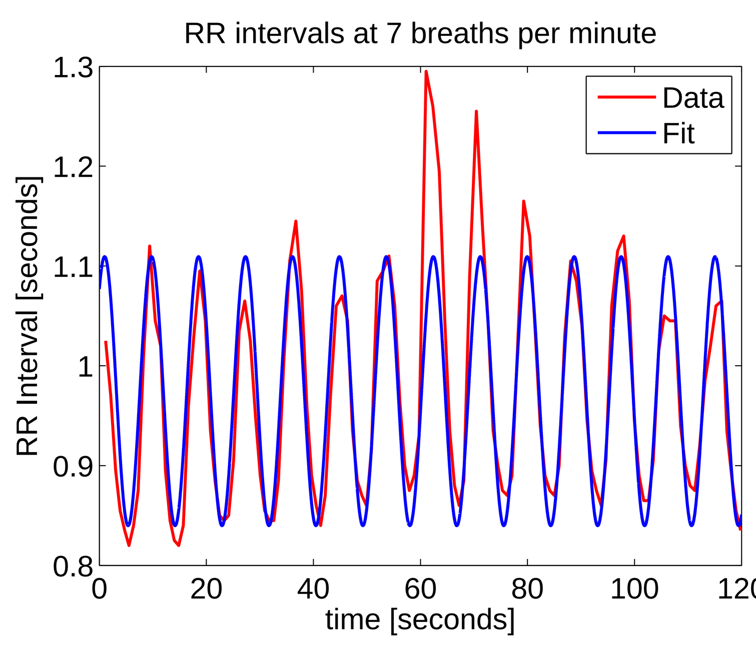
$$f = f_k + \underbrace{\frac{X_{f_{k+1}} - X_{f_{k-1}}}{\sum_{i=-1}^{1} X_{f_{k+i}}}}_{\delta}$$

- Sinusoidal fit to respiration and RR intervals to calculate the phase shift between the time series
  - Assumption: frequency f of respiration equals the frequency of RR intervals
  - Fit function is composed of a sine wave with frequency f and the phase shift φ:

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

(calculated using least squares approximation)

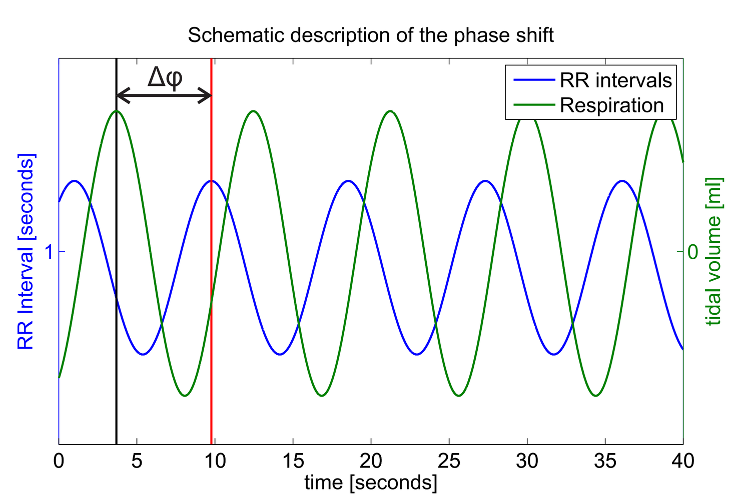




$$x_{resp}(t) = A_{resp} \cdot \sin(2\pi f t + \varphi_{resp}) + c_{resp} \qquad x_{rr}(t) = A_{rr} \cdot \sin(2\pi f t + \varphi_{rr}) + c_{rr}$$

- Fit to respiration and RR intervals differ in the phase shift $\Delta\varphi$

$$\Delta\varphi = \varphi_{resp} - \varphi_{rr}$$



- Goodness of fit statistics:

$$\text{Adjusted R-Square}: R^2_{ad} = 1 - \frac{s_e \cdot (n-1)}{s_m \cdot v}$$

Sum of squares due to error : $s_e = \sum_{i=1}^{n} (x_i - \hat{x}_i)^2$

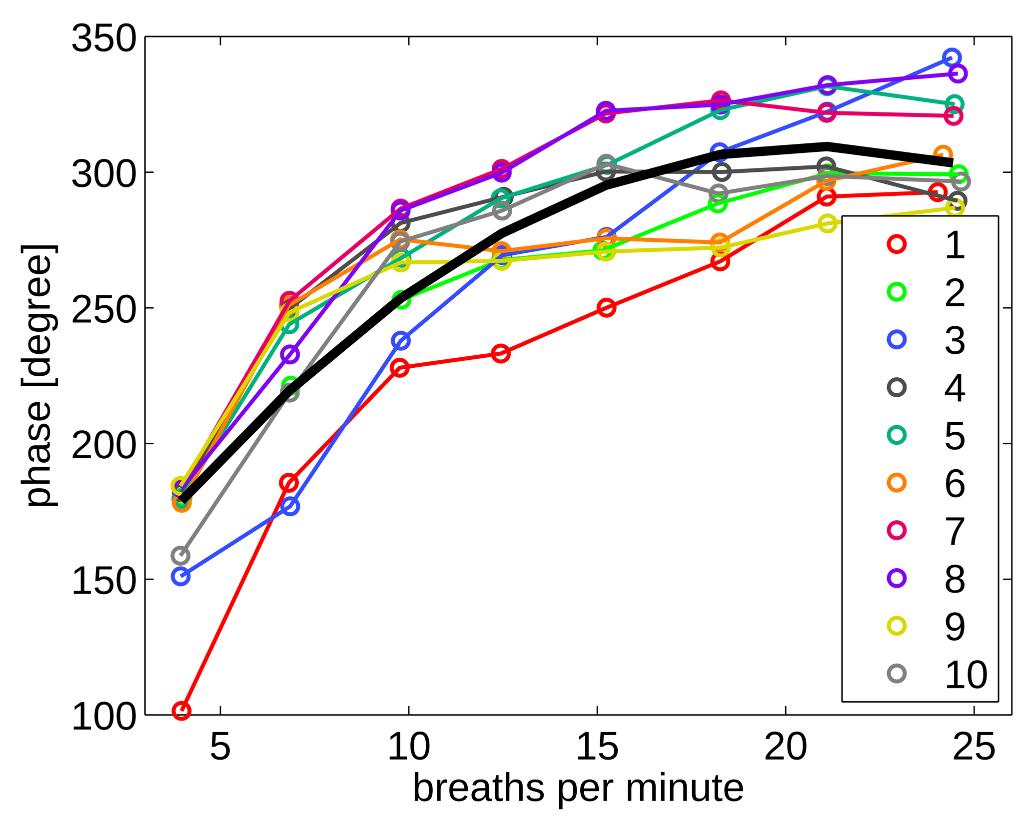
Sum of squares about the mean : $s_m = \sum_{i=1}^{n} (x_i - \bar{x})^2$

n : number of data points
v : number of degrees of freedom
x_i : data point
$\hat{x}_i$: fitted point
$\bar{x}$: mean of data

- Adjusted R-square R^2_{ad} closer to 1 indicates a better fit

Phase shift dependency on breathing frequency

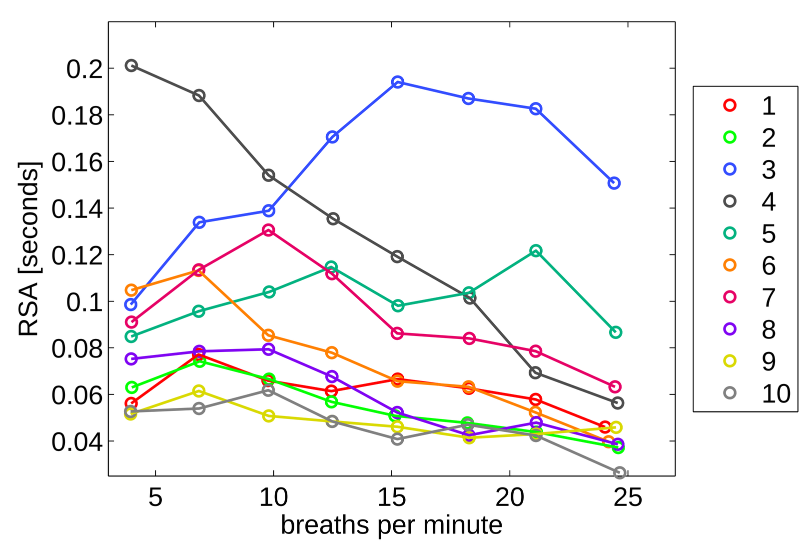
- Adjusted R-Square for respiration time series and RR intervals was 0.81 and 0.34, respectively
- Phase shift rose continuously with increasing breathing frequency in all 10 volunteers



$$\Delta\varphi = \varphi_{resp} - \varphi_{rr}$$

RSA dependency on breathing frequency

- Respiratory Sinus Arrhythmia (RSA) is defined as the difference between the maximum RR interval and the minimum RR interval within one breath
- Overall RSA was calculated by averaging RSA values for each breath
- Values of RSA differ for each volunteer
- RSA trends to decline with rising breathing frequency



Conclusion

- **Obviously, the frequency of respiration influences the phase shift between the respiratory and cardiovascular system, since we observed a coupling between RR intervals and frequency of respiration.**
- **Further investigation is needed to determine the causes of this behaviour.**

[1] John W. Denver, Shawn F. Reed, and Stephen W. Porges. Methodological issues in the quantification of respiratory sinus arrhythmia. *Biological Psychology*, 74(2):286 – 294, 2007.

[2] Dwain L Eckberg. The human respiratory gate. *J Physiol*, pages 339–352, 2003.

[3] Eric Jacobsen and Peter Kootsookos. Fast, accurate frequency estimators. *IEEE Signal Processing Magazine*, pages 123–125, 2007.