# Synchronization of Heart Rate and Blood Pressure with Respiration

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## Abstract

*Time offsets between changes in heart rate, blood pressure and breathing are important to understand when developing cardiovascular models.*

*This study recorded six subjects breathing at 6 and 12 breaths per minute, with and without breathing resistance. RR intervals and systolic pressure (SP) levels were extracted from ECG and Finapres signals; breathing was measured using magnetometers. Time offsets were calculated from the position of peaks in the cross-correlated signals.*

*ANOVAs showed significant effects with breathing resistance for the time offsets relative to the breathing signal. ANOVAs showed significant effects with breathing frequency for time offsets relative to changes in SP levels.*

## 1. Introduction

Knowledge of the interaction of heart rate and blood pressure with respiration is important for the development of cardiovascular models. The interaction between heart rate and blood pressure has been modelled on numerous occasions, although in many cases different time offsets have been used [1]. Fewer studies have considered modelling the interaction with breathing, and how this interaction is affected by breathing frequency and breathing resistance. Resistance was particularly relevant, since we had already shown that subjects appear to breathe more consistently through a resistance [2].

This study investigated the interrelationships of the time offsets between the breathing signal and RR intervals, breathing signal and systolic pressure (SP) levels, and RR-intervals and SP levels, and how they were affected by breathing frequency and resistance.

## 2. Methods

### 2.1. Subjects

This study recruited six subjects (2 females, 4 males) aged 32 ± 12 years. All subjects were unaware of any cardiovascular or respiratory problem. Subjects gave their written informed consent before taking part in the study.

### 2.2. Study protocol

Subjects in a semi supine position were asked to breathe at 6 and 12 breaths per minute (0.1 and 0.2 Hz respectively) each for 3 minutes. This was then repeated but the subject breathed through a constant resistance, a tube of internal diameter 2 mm and 10 cm in length.

### 2.3. Physiological data

Throughout the protocols subjects had their ECG recorded from a single lead ECG, their non-invasive blood pressure recorded by a Finapres device [3] and their breathing (inspiration positive gradient) recorded by magnetometers [4]. All data were sampled at 500 Hz and recorded to computer.

### 2.4. Data processing

The stages of offline processing are shown in figure 1. RR-intervals and SP levels were automatically extracted from the ECG signal and Finapres signal respectively. These were visually checked. Interpolation was applied when the Finapres device performed a short 'servo self-adjustment', this usually occurred for 2 beats out of 70. The Berger algorithm [5] was applied so that the data were regularly sampled at 4 Hz. The breathing signal was decimated to 4 Hz.

The time offsets between changes in the RR interval and SP level signals were calculated from the positions of the minima and maxima in the cross correlation signal (bottom graph in figure 1c). Related time offsets between breathing and RR intervals, and between breathing and SP levels, were similarly calculated from the cross correlation signals (top two graphs in figure 1c).

A previous publication [1] considered three time offsets between changes in the RR interval and SP level signals, a, b and c as shown in figure 2. These represent the time between the RR interval peak and previous SP level peak, the time between the RR interval peak and subsequent SP level trough, and the time between the RR interval peak and subsequent SP level peak respectively. These time offsets can be derived from the difference in positions of the minima and maxima of the breathing

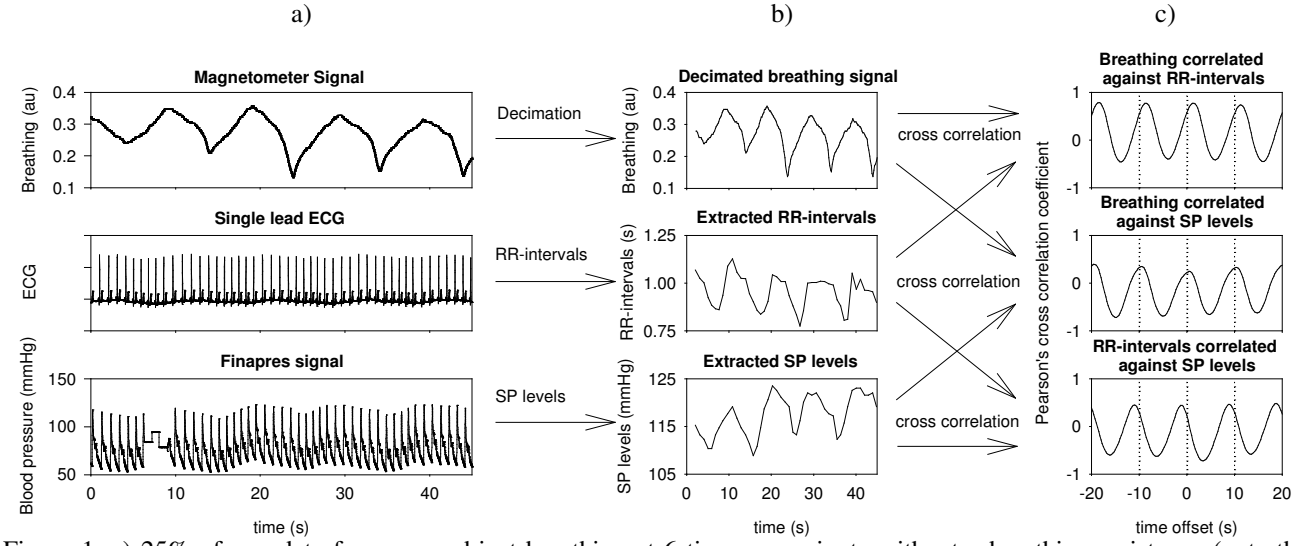


Figure 1. a) 25% of raw data from one subject breathing at 6 times per minute without a breathing resistance (note the 'servo self-adjustment' that has occurred in the Finapres signal). b) 25% of the extracted data (decimated breathing signal, RR-intervals and SP levels). c) The correlated signals (calculated from 100% of the extracted data).

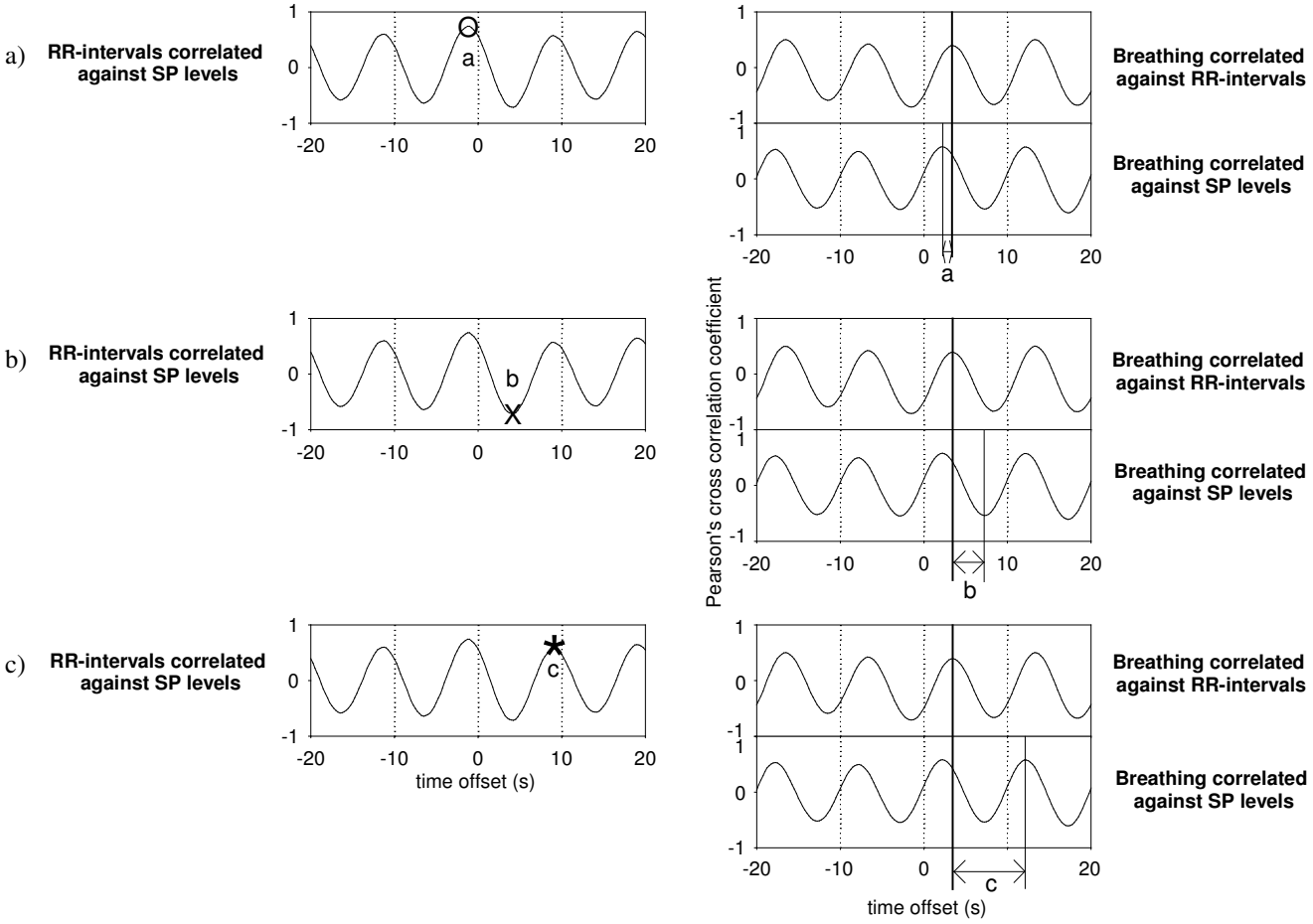


Figure 2. Correlation signals from one subject breathing at 6 times per minute without a breathing resistance to illustrate the interrelationship between the time offsets when using the first maxima after the 0 offset point in the breathing to RR interval correlation signal as the reference.

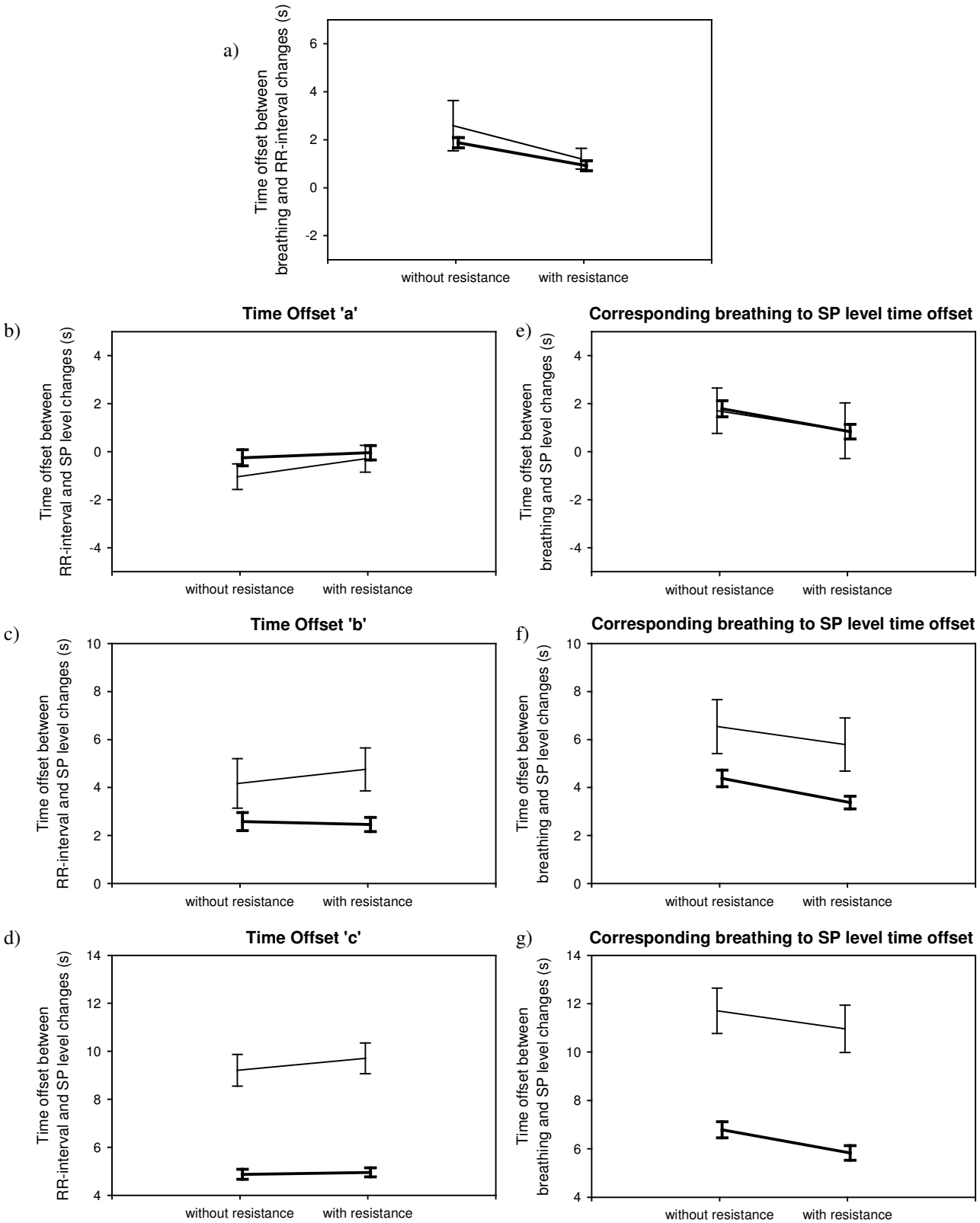


Figure 3. The effect of breathing resistance on a) the time offset between breathing and RR-interval changes b),c),d) the time offsets between RR-interval and SP level changes e),f),g) the time offsets between breathing and SP level changes (thin line = 6 breaths per minute, thick line = 12 breaths per minute); mean ± standard deviation shown.

correlation signals as shown in figure 2. To make the interrelationships clearer the first maxima after the 0 offset point in the breathing to RR-interval correlation signal was used as the reference.

## 2.5. Statistics

Results are presented as mean ± standard deviation. Two way analysis of variances (ANOVAs) were performed by breathing frequency and resistance.

# 3. Results

## 3.1. Breathing to RR-interval

The position of the maxima in the correlation signal between breathing and RR-intervals, as described in figure 2, are shown in figure 3a. This was equivalent to the mean time offset between peaks of the breathing signal and the subsequent peaks of the RR-interval signal. The ANOVA showed breathing resistance had a significant affect on the time offset ($p<0.01$), but not the breathing frequency ($p=0.053$).

## 3.2. RR-interval to SP level

The position of the maxima and minima of the correlation signal between RR-intervals and SP levels which represent time offsets 'a', 'b' and 'c' as described in figure 2 are shown in figure 3b, 3c, and 3d. The position of these maxima and minima were equivalent to the mean time offset between peaks of the RR-interval signal and the previous peaks, subsequent troughs and subsequent peaks of the SP level signal. The ANOVAs showed breathing frequency had a significant affect on all the time offsets ('a', 'b' & 'c') ($p<0.01$). Only the ANOVA for time offset 'a' showed breathing resistance had a significant affect ($p<0.01$).

## 3.3. Breathing to SP level

The position of the maxima and minima of the correlation signal between breathing and SP levels which represent corresponding time offsets to 'a', 'b' and 'c' as described in figure 2 are shown in figure 3e, 3f, and 3g. The position of these maxima and minima were equivalent to the mean time offset between peaks of the breathing signal and the previous peaks, subsequent troughs and subsequent peaks of the SP level signal. The ANOVAs showed breathing resistance had a significant affect on all the corresponding time offsets to 'a', 'b' and 'c' ($p<0.01$). The ANOVAs for the corresponding time offsets to 'b' and 'c' showed breathing frequency had a significant affect ($p<0.01$).

# 4. Discussion and conclusions

This study shows the breathing peaks are approximately a quarter of a breathing cycle ahead of the RR-interval signal. This is in keeping with our understanding of respiratory sinus arrhythmia.

Three time offsets are presented in this study to provide a complete analysis. Therefore, there is an incremental offset which is a constant fraction of the breathing cycle length between each of the time offsets.

This study has shown that it is important to clearly state which time offset has been used since each time offset has different results for changes in breathing frequency and breathing resistance.

These data provide a useful starting point to develop a simple model that represents the interaction between breathing, beat-by-beat heart rate and systolic blood pressure.


# Acknowledgements

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