Impact of breathing mechanics, body posture and physique on heart rate variability

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Abstract. The aim of this work was to assess the impact of breathing mechanics, body posture and subject's physique on heart rate variability (*HRV*). 13 healthy students performed series of breathing with different rates and depths, while supine, sitting and standing. Impedance pneumography (*IP*) and electrocardiography signals were registered. Repeated ANOVA was used to estimate the factor effect on 4 parameters proposed. For standard deviation one (**SD**), ratio of **SD** and mean heart rate (**SDM**), and for maximum value of cross-correlation (**COR**, which describing the correspondence between *IP* and *HRV* signals in term of shapes), depth and rate of breathing and body posture had statistically significant impact. Slow, deep breathing caused increase of *HRV*.

Keywords: heart rate variability, impedance pneumography, breathing

1 Introduction

It is known that variability of heart rate is observed in stable physiological conditions and is considered as a predictor of cardiovascular morbidity and mortality [1]. Heart rate variability (*HRV*) is one of the key parameters in the cardiac and autonomic nervous systems activity analyses [2]. The natural aging is associated with a loss of complex variability in RR intervals, however if the cardiac cycle equalizes over time, there might be a disorder in regulation between the action of the sympathetic and parasympathetic systems [3]. In this way *HRV* shows off the degree of coupling between these systems.

HRV could be influenced by a number of diseases, e.g. cancer, chronic fatigue syndrome, sleep apnea or septic shock. Circadian effect seems to be other natural factor. *HRV* indexes are larger in patients with higher functional capacity. No correlation was noted between *HRV* and *BMI* [4].

It seems that current body posture should be also considered. The force of gravity and the mutual arrangement of organs would change the heart activity in natural way. The nonlinear study of *HRV* time series showed highly significant differences between supine and standing postures [5].

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In our previous research, we have verified that impedance pneumography method allows the registration of the rate of breathing, as well as its depth. Joint together they could reflect the dynamics of breathing, interesting factor varying *HRV*, which was overlooked in the analyses or was regarded as the effect, but without its diversity [6]. For example, deep breathing is taken into account in the maneuvers that make up the "Ewing battery", but it is standardized [7]. Several studies have shown, that slow, controlled breathing resulted in a decrease of systolic, diastolic and mean arterial blood pressure, and also in the increase of *HRV* [8].

The aim of this study was to check the impact of the current body posture, rate and depth of breathing, sex and subject's physique (understood as *BMI* index) on heart rate variability. The work is a pilot one, which was to examine the possibility of conducting association studies of heart rate variability with impedance pneumography as a non-invasive method of quantitative determination of the parameters characterizing the activity of the respiratory system.

2 Method

13 healthy students (9 males, aged 20-24, *BMI*: 21.5 ± 1.6, and 4 females, aged 21-26, *BMI*: 22.5 ± 2.3, without any reported respiratory and cardiac diseases) were participated in this study. We informed all subjects about the aims and they gave the written informed consent to take part in it.

The *ECG* signal was measured by the cardiomonitor FX2000P, manufactured by Emtel, Poland, in single-lead configuration. Electrodes were mounted on the chest and in the upper abdomen in the standard Einthoven's positions. Impedance signal was registered using our own pneumograph prototype - Pneumonitor [9]. *IP* measurements were performed using the tetrapolar method. Electrode placement configuration was chosen as proposed by *Seppa et al.* [10]. The receiving electrodes were positioned on the midaxillary line at about 5th rib level. The application electrodes were mounted on the proximal side of the arm on the level of receiving ones. In both cases, standard spot *ECG* electrodes were used. The outputs were connected to the WinAcq ADC converter, which sampled the signals at 200Hz and stored to data files.

Every subject was asked to perform 8-10 normal and deep breaths with 6, 10 and 15 breaths/minute rates in three body postures - supine, sitting and standing. Between every series we proposed short breaks in order to establish heart rate. In that way we carried out 18 series of measurements for each subject. As the *IP* signal relates to the volume changes in terms of shape [11], it was used without any pre-calculations, only drift was removed.

We also subtracted the baseline drift from *ECG* signal (low-pass filtered with $f_{pass} = 0.5\ Hz$ and $f_{stop} = 5\ Hz$) and we automatically detected R waves and their locations in time. Heart rate was calculated as the interpolated first differentiate (using second order finite difference) of R wave locations.

We proposed the parameters estimated from (*HRV*) to show the diverse impact of the body posture, breathing rate and depth on the *HRV*:

- standard deviation of the *HRV* signal (abbreviation - **SD**)
- the ratio of **SD** and the mean *HR* value (**SDM**)
- the maximum value of cross-correlation for shifts in range $\pm 5s$ (**COR**)
- the shift value for which the cross-correlation maximum was gained (**DEL**), what was indirectly understood as a value describing whether *HRV* signal was leading or lagging the breathing one.

In order to estimate the impact of body posture, breathing rate and breathing depth, we firstly calculated basic summary of parameters for specific series and presented them in the box-plot figures. Secondly we performed repeated ANOVA analysis, with body posture, breathing rate and breathing depth as within-subject effects. Sex and *BMI* was considered as between-subject effects. For those factors, for which ANOVA states statistical significance, we performed post-hoc Tukey HSD tests.

We also performed correlation test for all pairs of parameters in order to estimate the correlation/dependance between parameters and statistical significance. All signal processing was carried out with MATLAB and statistical analysis using R.

3 Results

Sample *IP* and *ECG* signals, with corresponding *HRV* curve was presented in the Fig. 1. This example was taken from the measurements of third subject, in supine body posture, during deep breathing at 10 breaths per minute rate.

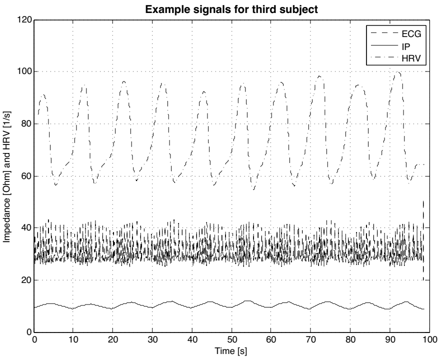

Fig. 1. The example of the impedance pneumography, electrocardiography and corresponding heart rate variability signals for third subject, supine body posture, deep breathing at 10 breaths per minute rate.

We also performed exploratory data analysis on the four described parameters, before ANOVA. The box-plot figures, presenting the impact of sex, body posture, breathing rate and depth for all parameters (**SD**, **SDM**, **COR** and **DEL**, respectively) was showed in the Fig. 3.

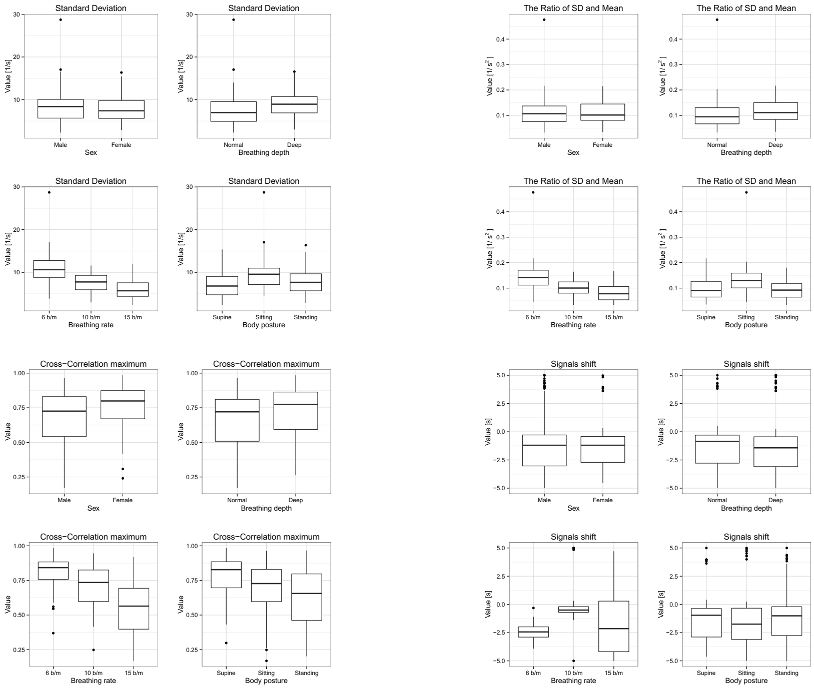

Fig. 2. The comparison of the impact of the sex, body posture, breathing rate and depth for all considered parameter: Standard Deviation in the upper left, Ratio of Standard Deviation and Mean in the upper right, Maximum Cross-Correlation Value in the lower left and Signal Shift for Maximum Correlation in the lower right.

The ANOVA analysis results (*p-values*) was collected in the Table 1.

Post-hoc tests performed for those situations, for which *p-value* was under the significance level, showed that all pairs were statistically significant, except the supine-standing for **SDM** parameter and sitting-standing for **COR** one.

As an additive information, only first and second parameter are correlated each other ($r = 0.948$, $p\text{-}value < 10^{-5}$) and the average tidal volume during normal breathing was 1036 ml, and during deep breathing was 2374 ml.

4 Discussion

In our study we only analyzed time-related parameters and did not consider frequency-related ones, due to the observation, that during controlled breathing its component of the *HRV* spectrum was covering the other parts and strongly influencing the analysis.

In the natural way, slow, deep breathing influenced on the larger **SD** values. It seems that during such breathing, respiration affects the control and regulation of heart activity in the greatest way. Relatively interesting and intriguing remark is

Table 1. The *p-values* of the ANOVA analysis for all considered parameters and factors effecting the values of parameters

	SD	**SDM**	**COR**	**DEL**
Sex	0.60	0.94	0.06	0.85
BMI	0.36	0.63	0.36	0.92
Breathing Rate	<10-5 ***	<10-5 ***	<10-5 ***	<10-5 ***
Breathing Depth	0.001 **	0.026 *	<10-3 ***	0.76
Body Posture	<10-4 ***	<10-4 ***	<10-5 ***	0.86

that sitting posture caused the largest **SD** parameters, besides every considered body postures were ”static”.

As the correlation between **SD** and **SDM** was strong, it seems that division by mean value does not change the relation with **SD**. It drew the finding, that standard deviation of *HRV* is not related with HR mean value. Instead of using MANOVA, we decided to use simple ANOVA two times to treat these two parameters separately and show off their impact and make the inference as simple in terms of physiological conclusions as possible.

The average values of maximum of cross-correlation coefficient, approximately 0.75, suggest breathing affecting on *HRV* in terms of signals shape. The results for **COR** parameter seems to match the preliminary expectations, that the slower inspiration and expiration allows the reaction of the sympathetic and parasympathetic systems, respectively. Depth of breathing improves the effect by changing the geometry of the thorax more.

The $\pm 5s$ distraction to **DEL** calculations was added in order to exclude these shifts, which did not correspond to the possible physiological effect. Due to the laboratory conditions signals was recurrent, quasi-sinusoidal. However, still the locations of the cross-correlation maximum differed. The average value indicated that the *HRV* slightly overtakes the breathing signal, because the largest value of heart rate occurred in the beginning of inspiration and the rate was decreasing at the end of inspiration. This suggests, that breathing might be considered as the cause for the *HRV* signal, however the sequence of the signals in terms of shapes was reverse. In our opinion, the influence of other parameter is compensated, because the maximums of cross-correlation were sometimes obtained for positive shifts and sometimes, for negative ones. It seems necessary to estimate causality of the breathing signal on heart activity using other nonlinear techniques.

5 Conclusion

It was spotted, that both breathing mechanics and body posture had statistically significant impact on the heart rate variability. Either subject's sex and *BMI* index did not. The greatest changes of *HRV* existed for deep and slow breathing.

Due to the fact that both respiration and body posture seem to be an important factors, they should be taken into account in the physiological studies considering heart activity.

It appears that the impedance pneumography method is the interesting non-invasive and portable-ready solution for performing respiration signal registration for that purpose.

Breathing seems to be the cause for heart rate changes, however simple, linear method do not assess it in the proper way. Some more research on that topic is needed.

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