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Investigation of respiratory and heart rate variability in hypertensive patients

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Abstract: In this paper, in order to examine the effect of respiration on heart rate variability (HRV), signal processing analyses were performed between the signal received from the periodic movement of the chest of respiration and the pulse plethysmograph (PPS) signal, providing the calculation of both the time and frequency behavior of HRV and also including pulse rate information at the same time. Respiration is used as the comparison parameter in both healthy subjects and in hypertensive patients, not only with the time and frequency components of the HRV, but also with the galvanic skin resistance simultaneously taken with body temperature and by calculating these signal changes. In our study, we aim to not only investigate the relationship between hypertension and HRV, but also to investigate the effect of respiration. Hence, in this study, 19 hypertensive patients and 19 healthy controls, who are all women, are used as subjects. As a result of the data received and analyzed from the subjects, HRV both in hypertensive and healthy subjects, the mean value of the high-frequency component and respiratory signal (RSP), and the mean value of the low-frequency/high-frequency ratio accepted as a sympathovagal balance index of the heart rate and RSP are statistically associated.

Key words: Heart rate variability, respiratory, hypertensive patients

1. Introduction

In recent years, many experimental studies have been performed about the effects of respiration on heart rate variability (HRV). In these studies, the effects of respiratory parameters such as the respiratory rate, tidal volume, end-tidal carbon dioxide partial pressure, ratio of the duration of inhalation and exhalation, and end-tidal volume on the formation of HRV were investigated and it was seen that the change in these parameters could affect both low-frequency (LF) and high-frequency (HF) formation [1,2].

In another study about obtaining the transfer function of the autonomic regulation, HRV changes corresponding to lung volume changes recorded using inductance plethysmography were examined in subjects, including a wide-frequency band, in supine and standing positions. It was revealed that at a normal breathing frequency ($>$0.15 Hz), the HRV increased with the initiation of breathing, while under a normal breathing frequency ($<$0.15 Hz) there was a slightly different phase relationship between respiration and the HRV, and, as a result of that, the HRV showed larger increases according to normal breathing conditions [1].

A different study examining the R wave-to-R wave (RR) intervals of the respiratory rate and their effects on systolic blood pressure changes included the respiratory rates of 14 healthy subjects at 6, 10, and 16 times per minute, and the respiration measurements were performed using impedance pneumography. Electrocardiography (ECG) measurements using patient monitors and blood pressure measurements using the

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plethysmographic method were performed. The coherence and phase relationship were calculated using a reciprocal spectral analysis between the respiration and RR interval and between the RR interval and blood pressure. It was deduced that a change in the HRV and systolic blood pressure with the respiratory rate was a frequency-dependent phenomenon and independent from sympathetic effects [3].

In a study performed with 9 healthy subjects, it was determined that respiration modulated the autonomic system by creating changes in the respiratory volume and frequency [4].

In another study including 22 healthy volunteers and 25 mechanically ventilated patients, it was reported that the respiratory rate, respiratory volume, and end-expiratory carbon dioxide pressure affected the HRV [5].

In [6], how HRV is affected by spontaneous and controlled breathing conditions was investigated in an experiment performed as a part of studies that examined the effects of mental activity and stress on HRV.

As a result of another study examining the effect of changes in the inhalation-exhalation intervals on the formation of respiratory sinus arrhythmia, it was seen that, in the case of a short duration of inhalation and long duration of exhalation, the HF and LF increased significantly; whereas in the opposite situation, the HF increased but the LF was not significantly affected [7].

In a study investigating the relation between hypertension and HRV, autonomic dysfunction was investigated in patients with high-normal blood pressure, and the baroreflex sensitivity and temporal QT variability index were evaluated. In the comparison of these patients with normotensive patients, in the patients with high-normal blood pressure, increased QT variability and decreased baroreceptor sensitivity index was determined as an indicator of sympathetic dominance [1].

In a study investigating white coat hypertension, upon which autonomic dysfunction and sympathetic predominance have been thought to be effective, patients were classified with hypertension or only with white coat hypertension and were compared with normotensive individuals. In that study, frequency domain HRV analyses were used. Lower HF and LF values reflecting low parasympathetic activation were determined in the groups with white coat hypertension and with normal hypertension than in the normotensive group. The LF/HF ratio, showing sympathetic predominance, was higher in these 2 patient groups than in the normotensive group [8].

In another study, the conclusion was the opposite. In this study, similarly, the patients with white coat hypertension were compared with persistent hypertensive and normotensive patients and the LF/HF ratio was examined. The patients with persistent hypertension were compared with normotensive patients; the LF/HF ratio was higher in the persistent hypertensive group, but there was no significant difference between the white coat hypertension and normotensive groups [2,6].

The main objective of the present study is to determine the effects of the amplitude and time components of the periodic respiration process on HRV. In addition, how irregular HRV affects patients with possible hypertension is investigated.

2. Materials and methods

The signals of pulse plethysmograph (PPS), galvanic skin resistance (GSR), body temperature (TEMP), and respiratory signal (RSP) used in this study were simultaneously obtained using the BIOPAC MP36 data acquisition system. The obtained signals of 19 hypertensive patients (mean age, 58.36; standard deviation, 13.28) and 19 healthy control subjects (mean age, 56.26; standard deviation, 11.48), who were all women, were analyzed at Giresun State Hospital. The signals were recorded by sampling at 1000 Hz for 3 min. For recording the RSPs, a respiratory effort transducer (SS5LB) was used in which the output resistance was 50–150 K, the humidity range was between 0% and 95%, operating temperature range was between –20 °C and 80 °C. A PPS transducer (SS4LA), with the converter of the same system working at 860 ± 60 nm wavelengths and an 800-nm low-pass filter wavelength, was optically used for recording PPS signals. Electrodermal activity transducer (SS3LA EDA) Ag-AgCl gel electrodes were used for recording GSR signals. The surface area was 6 mm and the surface area with gel was 1.66 mm. In order to record TEMP signals, a temperature transducer (SS6L) with a response time of 0.6 s, a nominal resistance of 2252 Ω, and a maximum operating temperature of 100 °C was used.

3. Preprocessing

In many studies performed to determine the relationship between heart rate and respiratory functions, only comparisons of the respiratory parameters with the parameters obtained from ECG recordings were used [9,10]. In this study, the PPS signal, which is more sensitive on the noise point and has more practical use than ECG, and the respiration GSR and TEMP signals recorded simultaneously are used.

Factors such as the position of the patient, ambient temperature, frequency of breathing, current hormone levels, and age cause changes in PPS signals [11]. To reveal the effect of respiratory functions on heart rate more clearly, the effects of the abovementioned factors should be kept under control. In this study, records were taken when the hypertensive patients and healthy controls were all in a sitting position. The mean age of the 19 female hypertensive patients and 19 female healthy controls was 57.31 and the standard deviation was 12.38. Thus, during the recording, the effects of position and age criteria were minimized. In this study, for the evaluation of the statistical significance, the average value of the PPS signal as well as the HF component, LF component, very-LF (VLF) component, (LF/HF) ratio accepted as a sympathovagal balance index, and total power of the signal were used.

The attributes obtained from the GSR signal vary depending on the surprising property of the stimulus more so than the duration of the stimulus. To avoid this situation, the interval between the stimuli should be kept longer. There were no outside influences that could have affected the GSR signal used in the study. Therefore, factors such as habitat did not affect GSR signals. Because the GSR signal is related directly to the condition of the skin on which the electrodes are placed, we placed the electrodes in the same position on the subjects' left hands, which they usually do not dominantly use. The average value of the GSR signal was used for the evaluation of statistical significance in the study.

TEMP signals are not a sensitive measurement parameter for the change in pulmonary function and heart rate. Changes in the differences in the TEMP signals are too small and cannot been observed. The TEMP signals were taken from both the hypertensive patients and the healthy controls in the same position and the same time. In this study, the average value of the TEMP signal was used for the assessment of statistical significance.

3.1. Signal processing

In this study, the RSP, PPS, GSR, and TEMP signals were recorded simultaneously. The features derived from these signals were statistically evaluated as follows:

1. $\mathbf{R_{max}}$, $\mathbf{R_{mean}}$, **and** $\mathbf{R_{min}}$**:** Maximum, mean, and minimum amplitude values of the RSP in the time domain, respectively.
2. The feature parameters were calculated from the frequency analysis of the PPS signal:

(a) $\mathbf{P_{hf}}$**:** The mean power density value of the HF component of the PPS signal.

(b) $\mathbf{P_{lf}}$**:** The mean power density value of the LF component of the PPS signal.

(c) $\mathbf{P_{vlf}}$**:** The mean power density value of the VLF component of the PPS signal.

(d) $\mathbf{P_{tp}}$**:** The total power value of the PPS signal.

(e) $\mathbf{P_{lf}/P_{hf}}$**:** Sympathovagal parameter from the ratio of the low-to-high frequency components.

3. The mean amplitude value of the GSR in the time domain.
4. The mean amplitude value of the TEMP in the time domain.

Basically, frequency components of the HRV signal are discussed within 2 bands. The first of the best-known periodic components of the HRV is the component in the HF domain (HF: 0.15–0.4 Hz), which is controlled only by the parasympathetic nervous system. The other well-known component of the HRV is the LF component, which is located at 0.04 to 0.15 Hz in the frequency domain, and the effect of sympathetic modulation in this frequency domain has been reported previously [12,13]. For short-term HRV signals outside of this frequency domain, the VLF domain (VLF: 0–0.04 Hz) is also calculated in studies performed with HRV; however, no results could be obtained, which shows that this component is associated with subbranches of the autonomic nervous system. The power component of this frequency part can be calculated as an absolute power by power spectral density (PSD) graphics, such as in Figure 1.

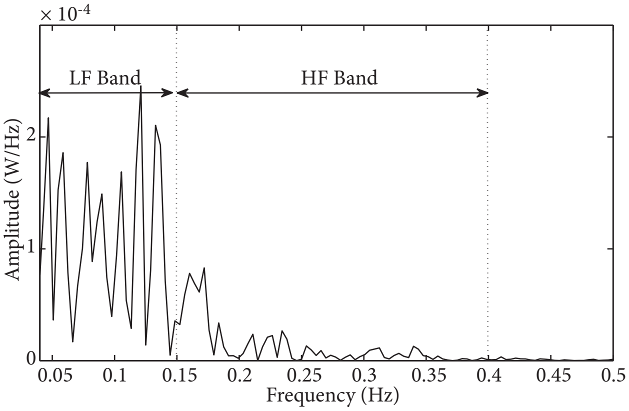

Figure 1. Hypertensive patients with HRV signals obtained from the PSD graph.

The LF and HF power values can be given in a normalized form as a result of the proportion of each power component value and the value obtained by subtracting the power value belonging to the VLF band from the total power [14]. It has been verified by other studies that the power value of the HF component varies according to the parasympathetic effects completely [13–15]. There are some studies showing that the LF component varies according to both the sympathetic and parasympathetic agents [16,17], and there are some studies showing that it is influenced only by sympathetic agents [13–18]. To avoid confusion in this case, a new parameter (LF/HF) is obtained by proportioning both power components. If this rate, also called the sympathovagal balance, shows an increase compared to the previous state, it is interpreted as an increase in the sympathetic activity. However, if this rate shows a decrease, it is interpreted as an increase in the parasympathetic activity. Therefore, the HRV analysis is performed first.

To determine the R-waves, a previously proposed algorithm is used [19,20]. The obtained RR interval series do not occur from equidistant data points. Therefore, before proceeding to analyze in the frequency axis, it is necessary to obtain a signal consisting of an equal number of samples in every moment of time using the interpolation process.

Interpolation, also known as the estimation intermediate value, is a mathematical method for finding values of the experiment or measurement at unknown points using the numerical values obtained from the experiments or measurements. Linear and cubic interpolation methods are the most well-known methods often used to fit the data collected to a function curve. The linear interpolation method uses the nearest points to their values known to find the value of the unknown point. For example, an $f(x)$ function forming from n numbers of values is defined. According to this,

$$f(x) = \begin{cases} a, x = x_0 \\ b, x = x_1 \end{cases} , \tag{1}$$

and the solution for x point, which has an unknown value and is located in the range of $(x_0,\ x_1)$, is y in Eq. (2).

$$y = a + (b - a). \left(\frac{x - x_o}{x_1 - x_o} \right) \tag{2}$$

Linear interpolation is required even less and is an easy procedure, which is an advantage, and the curve obtained by this type of interpolation contains an error proportional to the square of the distance between $(x_0,\ x_1)$ data points.

The polynomial, which as a second-degree derivative is 0, is used for the curve passing into the x point, which has an unknown value and is located in the $(x_0,\ x_1)$ interval with cubic, spline, or other bond interpolation at a small-degree x_1 point.

Cubic interpolation is applied at a value of 4 Hz [5,21,22]. After the interpolation process, the PSD of each signal is calculated using the Welch method. When the Welch method is applied, 256 Hanning windows are used, and for each calculation, 128 samples are performed by shifting. Hence, a frequency resolution value of 0.0156 Hz is obtained:

$$\tilde{P}(w) = \frac{1}{MUL} \sum_{i=1}^{L} \left| \sum_{n=0}^{M-1} x^i N(n) W(n) e^{-jwn} \right|^2 , \tag{3}$$

where

$$x_N^i(n) = x_N \left[n + (i-1)M \right], 0 \leq n \leq M-1, 1 \leq i \leq L. \tag{4}$$

After performing the $xN^{(n)}$ interpolation process, the N length of the signal obtained is the HRV signal. This signal is divided into segments of M length and L number. $x_N^i\ (n)$ is a segment of $x_N(n)$. $W(n)$ also shows the Hanning window, which has a length of M.

3.2. Calculation of attributes from the PPS signal

The increase in the PPS signal amplitude points toward the decrease in the stimulation of the sympathetic nervous system, therefore providing more blood flow to the finger tips by expanding the walls of the blood vessels. In order to calculate the amplitude value of the PPS signals belonging to the each patient, first local maximum and minimum points in the signal are found. The series of Bk forming amplitude values of the waves in the PPS signal, such as the ak_{max} and $ak_{\min}$ of the PPS signal, and the local maximum and minimum points of the k wave are described in Eq. (5).

$$Bk = ak_{\max} - ak_{\min}. \tag{5}$$

However, the local maximum and minimum points that are obtained first also contain the values belonging to stigmas forming due to interferences in the signal without an amplitude value.

In order to eliminate the effect of the maximum points that do not represent the amplitude value belonging to the signal, histograms are obtained belonging to these signals, where 10% of the value of these values is removed and the series of Bk is recalculated. The recalculated mean value of this series of Bk is used as an attribute in the study.

Data received from the hypertensive patients are recorded on a time axis; therefore, meaningful information for hypertensive patients from graphs with a time axis is not possible. The signal in Figures 2a and 2b obtained on the time axis also includes noise at the same time. Only amplitude information can be obtained from the signal on the time axis as in Figure 2.

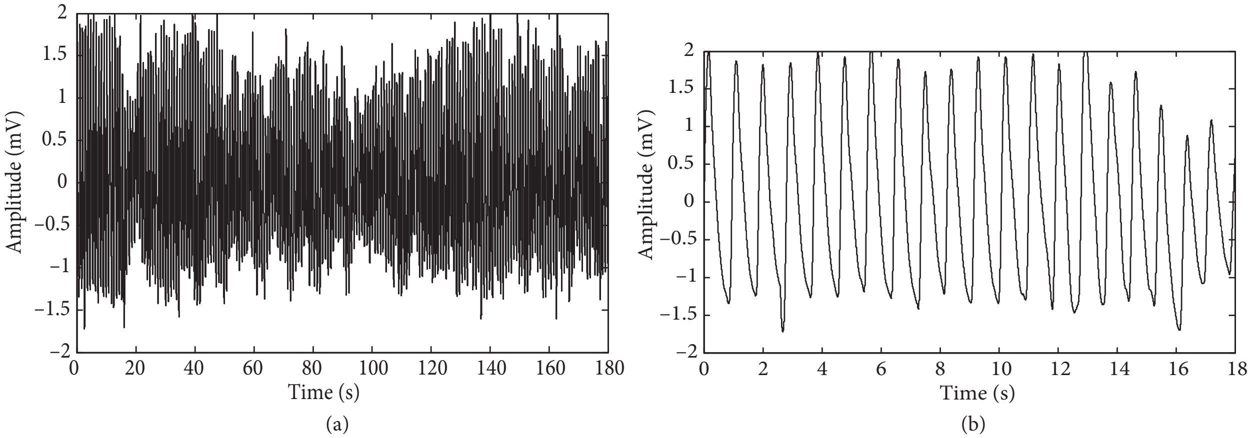

Figure 2. PPS graph of a hypertensive patient in the time domain: a) for a 3-min period, b) for an 18-s part of a 3-min period.

Much of the signal information on the time axis is embedded. To understand the patient's information, the signal should be transported to the frequency axis. Therefore, the recorded data on the time axis, as in Figure 2a, are moved to the frequency axis, as in Figure 3.

The signals transported to the frequency axis have information with much less noise component than the signals on the time axis. Both the amplitude information and how powerful the signal is at which frequency point can be understood from the frequency axis. At the same time, the frequency can divide into (HF – LF – VLF) components, as in Figure 4, and the information of where these components begin and end can be understood from the frequency axis. The data obtained as a result of the analysis in the frequency axis shed light on the patient's condition.

The PSD graph of a healthy person is shown in Figure 5. Comparing Figures 5 and 3, the HF band of the PSD is shifted to left for the hypertensive patients compared to that of the healthy controls.

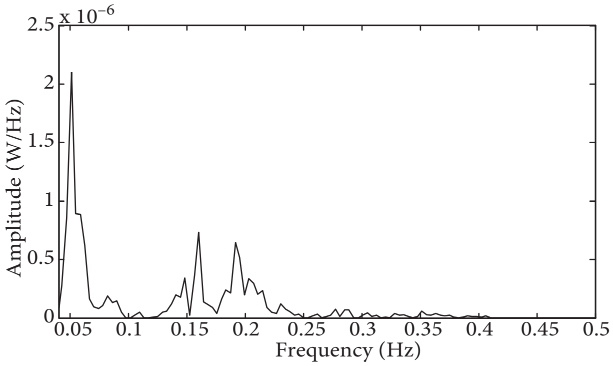

Figure 3. PSD graph obtained for a hypertensive patient.

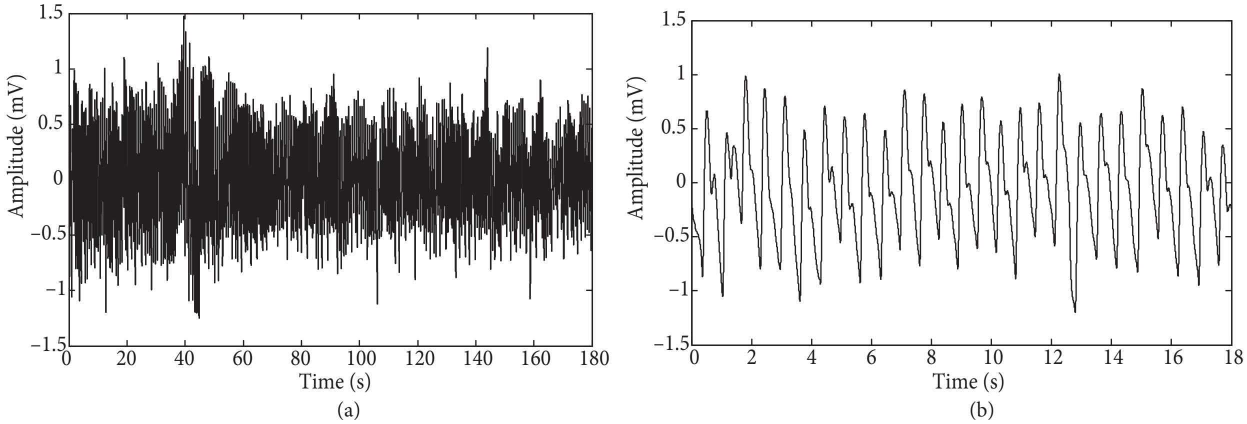

Figure 4. a) PPS graph of a healthy person in the time domain for a 3-min period, b) for an 18-s part of a 3-min period.

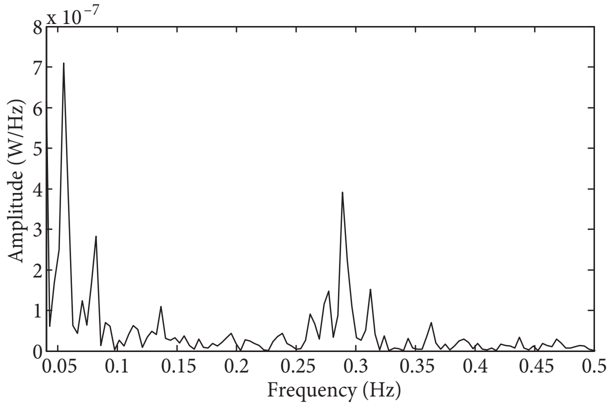

Figure 5. PSD graph of a healthy person in the frequency domain.

4. Results and discussion

The features used in this study are the maximum, minimum, and average values obtained using the RSP; the average amplitude value of the series forming at the amplitude value of each wave obtained from the time axis of the PPS signal; the HF, LF, and VLF values obtained from the frequency axis of the signal; the ratio of the low and high frequencies of the PPS signal (LF/HF), which is accepted as the sympathovagal balance index; the mean amplitude value obtained from the GSR signal; and the mean amplitude value obtained from the TEMP signal.

In this study, a statistical comparison is made for the relationship of the respiratory and heart-rate variability between hypertensive patients and healthy controls and the compliance of the rest of the parameters. The group of patients with hypertension and the statistical data are shown in Table 1.

Table 1. The statistical average table of the hypertensive patients.

	R_{max}	R_{min}	R_{mean}	P_{mean}	P_{hf}	P_{lf}	P_{vlf}	P_{tp}	$P_{lf/hf}$	GSR_{mean}	$TEMP_{mean}$
Averages	1.19	–1.75	0.01	0.65	1.18	0.51	0.34	1.00	2.25	2.20	35.28
Standard deviation	1.10	2.28	0.03	2.21	2.27	1.17	0.64	1.93	2.88	1.37	1.40

According to the comparison results of the analysis of the data received from hypertensive patients at $P < 0.05$, which is a statistical significance criterion, the values of ($R_{mean} - P_{hf} = 0.030$, $P < 0.05$), ($R_{mean} - P_{vlf} = 0.028$, $P < 0.05$), ($R_{mean} - P_{tp} = 0.032$, $P < 0.05$), ($R_{mean} - P_{lf/hf} = 0.002$, $P < 0.05$), ($R_{mean} - GSR_{mean} = 0.001$, $P < 0.05$), and ($R_{mean} - TEMP_{mean} = 0.000$, $P < 0.05$) are statistically significant. According of the results of this analysis, which was performed in MATLAB, there is a statistical relationship between the mean RSP and the HF component of the PPS signal and between the mean RSP and the ratio of the PPS signal, named the sympathovagal balance index (LF/HF).

The values of ($R_{mean} - P_{hf} = 0.030$, $P < 0.05$) and ($R_{mean} - P_{lf/hf} = 0.002$, $P < 0.05$) are statistically significant; other values are otherwise significant but have very small standard deviations. These values are shown in Table 2 in bold font.

Table 2. Paired t-test2 table of respiratory mean values (R_{mean}) in the hypertensive patients.

Statistical comparison	Significance, P
R_{mean}-P_{mean}	0.216
R_{mean}-P_{hf}	**0.030**
R_{mean}-P_{lf}	0.073
R_{mean}-P_{vlf}	**0.028**
R_{mean}-P_{tp}	**0.032**
R_{mean}-$P_{lf/hf}$	**0.002**
R_{mean}-GSR_{mean}	**0.001**
R_{mean}-$TEMP_{mean}$	**0.000**

The maximum RSP value of the hypertensive patients and the results of the PPS signal are compared and a significant result is not obtained at $P < 0.05$. This shows that there is not a statistically significant relationship between the Rmax value and the signal components of the PPS, as shown in Table 3.

There is not a statistically significant difference between the respiration minimum value obtained from the data and the values of the PPS signal. The standard deviations of these values are very small; therefore, they do not make sense statistically. The values are shown in Table 4.

Moreover, the average statistical values of all of the parameters of the healthy controls are shown in Table 5.

Table 3. Paired t-test2 table of respiratory maximum values (R_{max}) in the hypertensive patients.

Statistical comparison	Significance, P
R_{max}-P_{mean}	0.348
R_{max}-P_{hf}	0.996
R_{max}-P_{lf}	0.073
R_{max}-P_{vlf}	0.011
R_{max}-P_{tp}	0.721
R_{max}-$P_{lf/hf}$	0.140
R_{max}-GSR_{mean}	0.007
R_{max}-$TEMP_{mean}$	0.002

Table 4. Paired t-test2 table of respiratory minimum values (R_{min}) in the hypertensive patients.

Statistical comparison	Significance, P
R_{min}-P_{mean}	**0.007**
R_{min}-P_{hf}	**0.001**
R_{min}-P_{lf}	**0.003**
R_{min}-P_{vlf}	**0.008**
R_{min}-P_{tp}	**0.003**
R_{min}-$P_{lf/hf}$	1.290
R_{min}-GSR_{mean}	**0.000**
R_{min}-$TEMP_{mean}$	**0.000**

Table 5. The statistical average values of all of the parameters of the healthy controls.

	R_{max}	R_{min}	R_{mean}	P_{mean}	P_{hf}	P_{lf}	P_{vlf}	P_{tp}	$P_{lf/hf}$	GSR_{mean}	$TEMP_{mean}$
Averages	1.05	–1.56	–0.24	0.37	1.66	0.74	0.58	0.93	2.25	2.20	35.28
Standard deviation	2.04	2.61	1.38	2.21	2.27	1.17	0.72	1.93	2.88	1.37	1.40

When the mean respiration value and the values of the PPS (mean, HF, LF, VLF, TP, LF/HF) obtained from the analysis of the healthy controls are compared, significance is found for the values of ($R_{mean} - P_{hf} = 0.20$, $P < 0.05$) and ($R_{mean} - P_{lf/hf} = 0.001$, $P < 0.05$). According to the results of this analysis, a relationship between the mean respiration value and the HF component of the PPS, and the mean respiration value and the ratio of the PPS, named the sympathovagal balance index (LF/HF), is found. A relation between the respiration mean value and the (mean – HF) and (mean – LF/HF) data of the PPS signal is demonstrated, and the results shown in Table 6 in bold font are statistically significant. Other values are not statistically significant due to the standard deviation being very small.

Table 6. Paired t-test2 table of respiratory mean values (R_{mean}) in the healthy controls.

Statistical comparison	Significance, P
R_{mean}-P_{mean}	0.802
R_{mean}-P_{hf}	**0.019**
R_{mean}-P_{lf}	0.106
R_{mean}-P_{vlf}	0.062
R_{mean}-P_{tp}	0.092
R_{mean}-$P_{lf/hf}$	**0.037**
R_{maean}-GSR_{mean}	0.089
R_{mean}-$TEMP_{mean}$	**0.001**

According to the analysis results of the healthy controls, the maximum value of the RSP and the values of the PPS signal (mean, HF, LF, VLF, TP, LF/HF) are compared and there is not a significant result between them at a value of $P < 0.05$. There is no significant result between the maximum value of the RSP and the values of the PPS signal (mean, HF, LF, VLF, TP, LF/HF) for both the hypertensive patients and the healthy controls, as shown in Table 7. These results indicate that there is no statistically significant difference.

Table 7. Paired t-test2 table of respiratory maximum values (R_{max}) in the healthy controls.

Statistical comparison	Significance, P
R_{max}-P_{mean}	**0.027**
R_{max}-P_{hf}	0.477
R_{max}-P_{lf}	0.658
R_{max}-P_{vlf}	0.926
R_{max}-P_{tp}	0.515
R_{max}-$P_{lf/hf}$	**0.037**
R_{max}-GSR_{mean}	0.912
R_{max}-$TEMP_{mean}$	**0.003**

As a result of the analysis, a statistical relationship is not found between the minimum value of the respiratory function in the healthy controls and the function of the HRV. The effects of change could not be observed due to the Pvlf, which is a function of the HRV and was very small, as shown in Table 8.

Table 8. Paired t-test2 table of respiratory minimum values (R_{min}) in the healthy controls.

Statistical comparison	**Significance, P**
R_{min}-P_{mean}	0.109
R_{min}-P_{hf}	**0.001**
R_{min}-P_{lf}	**0.006**
R_{min}-P_{vlf}	**0.006**
R_{min}-P_{tp}	**0.008**
R_{min}-$P_{lf/hf}$	0.366
R_{min}-GSR_{mean}	**0.000**
R_{min}-$TEMP_{mean}$	**0.001**

Statistical comparison results of the hypertensive patients and healthy controls are shown in Table 9. According to the results obtained in the MATLAB environment, a significant relationship is revealed between the mean value of the respiration and the HF component of the PPS signal ($R_{mean} - P_{hf}$) and between the mean value of the respiration and sympathovagal balance index of the PPS signal ($R_{mean} - P_{lf/hf}$). The results of these analyses are consistent with the results in the literature, where it was observed that for the effects of respiration on the formation of the HRV, the changes of these parameters may affect the HF as well as LF formation [1,2]. In light of these studies, it is demonstrated that the LF/HF ratio cannot be considered as a net indicator of the change in autonomic balance in the case of not performing an analysis of the HRV with respiration simultaneously [2,5].

Table 9. Statistical comparison between the PPS and HRV parameters of the hypertensive patients and healthy controls.

Comparison parameters	Hypertensive significance, P	Healthy significance, P
R$_{mean}$-P$_{mean}$	0.216	0.802
R$_{mean}$-P$_{hf}$	**0.030**	**0.019**
R$_{mean}$-P$_{lf}$	0.073	0.106
R$_{mean}$-P$_{vlf}$	**0.028**	0.062
R$_{mean}$-P$_{tp}$	**0.032**	0.092
R$_{mean}$-P$_{lf/hf}$	**0.002**	**0.037**
R$_{mean}$-GSR$_{mean}$	**0.001**	0.089
R$_{mean-}$TEMP$_{mean}$	**0.000**	**0.001**
R$_{max}$-P$_{mean}$	0.348	**0.027**
R$_{max}$-P$_{hf}$	0.996	0.477
R$_{max}$-P$_{lf}$	0.073	0.658
R$_{max}$-P$_{vlf}$	0.011	0.926
R$_{max}$-P$_{tp}$	0.721	0.515
R$_{max}$-P$_{lf/hf}$	0.140	0.037
R$_{max}$-GSR$_{mean}$	0.007	0.912
R$_{max}$-TEMP$_{mean}$	0.002	**0.003**
R$_{min}$-P$_{mean}$	0.007	0.109
R$_{min}$-P$_{hf}$	0.001	**0.001**
R$_{min}$-P$_{lf}$	0.003	**0.006**
R$_{min}$-P$_{vlf}$	0.008	**0.006**
R$_{min}$-P$_{tp}$	0.003	**0.008**
R$_{min}$-P$_{lf/hf}$	1.290	0.366
R$_{min}$-GSR$_{mean}$	0.000	**0.000**
R$_{min}$-TEMP$_{mean}$	0.000	**0.001**

Statistical comparison results for the same parameters of the hypertensive patients and healthy controls are shown in Table 10, where a statistical significance in the mean of the GSR (GSRmean) parameters (P = 0.039) is obtained.

Table 10. Statistical comparison for the same parameters of the hypertensive patients and healthy controls.

Hypertensive vs. healthy comparison parameters	Significance, P
R$_{max}$	0.806
R$_{min}$	0.842
R$_{mean}$	0.428
P$_{mean}$	0.123
P$_{hf}$	0.587
P$_{lf}$	0.679
P$_{vlf}$	0.291
P$_{tp}$	0.572
P$_{lf/hf}$	0.472
GSR$_{mean}$	**0.039**
TEMP$_{mean}$	0.302

5. Conclusion

Of all of the features calculated as a result of the analysis, the signals that changed the least are those of the GSR and TEMP in the groups representing the maximum, minimum, and average values of the RSP. There was no statistically significant difference between the time and frequency results of respiration and HRV in the hypertensive patients and healthy controls. In addition, the hypertensive patients and healthy controls were subjected to comparisons within their own groups, and the respiration and HRV were found to be related to each other. The mean respiration value and HF component of the HRV were statistically significant in both the hypertensive patients and healthy controls. When the hypertensive patients and healthy controls were compared within their own groups, a statistically significant difference was obtained between the parameter accepted as the sympathovagal balance index (PPS $_{LF/HF}$) and known as the ratio of high and low frequencies of the PPS signal, and the mean value of the RSP (R_{mean}). With this study, it is understood that meaningful results can be obtained in the case of performing an HRV analysis with respiration simultaneously. When the results of the analysis of the hypertensive patients and healthy controls were evaluated statistically, the only meaningful value obtained was for the skin resistances.

In future, for a better understanding of the relationship between respiration and HRV, a comparison can be made using different signal processing methods and different parameters. In particular, these operations can be implemented again on patients with respiratory disease.

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