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Response of nasal airway and heart rate variability to controlled nasal breathing

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Abstract To investigate the responses of nasal airway and autonomic nervous system (ANS) under controlled nasal breathings. Ten healthy volunteers, aged between 21 and 37 years, were enrolled. The participants breathed either through bilateral nostrils (BNB) or unilaterally through the left nostril (UNB) at 0.25 Hz for 5 min. The electrocardiography was simultaneously recorded and the ANS activities were evaluated using heart rate variability analysis. Nasal airway resistance and related factors were measured by rhinomanometry. The results showed that the mean heartbeat interval during UNB was significantly greater than during BNB. The sympathetic modulation decreased significantly during UNB. The correlations between nasal airway resistance and mean heartbeat interval were significant for both UNB and BNB. The increase of heartbeat intervals during UNB was associated with the decrease of cardiac sympathetic activities. The changes of ANS activities and nasal airway resistance during UNB are similar to the changes caused by a prolonged lying.

Keywords Nasal airway resistance · Autonomic nervous system · Heart rate variability · Controlled nasal breathing · Unilateral nostril breathing · Rhinomanometry · Sympathetic activity

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Introduction

Clinically, bilateral nasal obstruction can cause significant hypoxia and is associated with an increased risk of cardiac arrhythmias and mortality which has been observed in patients with bilateral nasal packing [1]. There have been extensive investigations of the cardiopulmonary changes that appear after bilateral nasal obstruction. The increased bronchomotor tone and the decrease of pulmonary compliance mediated by nasopulmonary reflex were proposed as a mechanism of the hypoxia and its consequences secondary to nasal obstruction [2–5]. Stimulation of the chemoreceptors by hypoxemia leads to increased pulmonary ventilation and increased systemic blood pressure as a result of peripheral vasoconstriction. These changes are associated with changes in the activity of the autonomic nervous system.

However, in addition to bilateral obstruction, the presence of various other obstructive conditions in the nasal cavity, such as deviation of nasal septum, edema of nasal mucosa, hypertrophy of inferior turbinates, stenosis of the

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nasal valve and nasal polyposis, may cause significant fixed unilateral nasal obstruction. Less attention has been given to such fixed nasal obstructions. In this study, the immediate effects of unilateral nasal breathing on heart rate, blood pressure, oxygenation, ANS activity and nasal airway resistance were evaluated by analysis of heart rate variability (HRV) and anterior rhinomanometry (RMM) using healthy volunteers with the aim of exploring the possible effects of unilateral nasal obstruction.

Materials and methods

Subjects

Ten healthy volunteers, three males and seven females, aged between 21 and 37 years, were enrolled in this study. All participants had no history of sneezing, nasal blockage, rhinorrhea, or the use of any oral or topical nasal medications during the previous month; furthermore, any volunteer with a history of nasal surgery was excluded. None of the participants were smokers and volunteers with any abnormalities in the nasal cavities, such as deviated nasal septum, nasal polyps, and a nasal tumor, were also excluded by anterior rhinoscopy. Informed consent was obtained from all participants after a thorough explanation of the study protocols.

Nasal breathing

The experimental room was maintained at 25°C using air conditioning to prevent the possible vascular reflexes in the nasal mucosa [6]. Taking into account the possible influences of the nasal cycle, the tests were all performed in less than 30 min.

Two sessions were conducted on separate days. For each session, the participants used bilateral breathing (BNB) through both nostrils and controlled unilateral breathing (UNB) through the left nostril while lying in a supine position for 5 min per session. It is known that HRV and autonomic activities are significantly affected by respiration such as the well-known respiratory sinus arrhythmia (RSA) [7, 8] and, therefore, the breathings were controlled diaphragmatically; the cycle was slow, one every 4 s and was controlled using the beep of a timer with no sense of exertion. Session A: participants used BNB first then UNB. Session B: participants used UNB first then BNB. Before each session, the participants were instructed to lie quietly on beds for 2 min to allow adaptation to the environment. The responses to each breathing type were assessed using a visual analog scale (VAS) to access the sensation of nasal obstruction In addition, information on blood pressure (BP), arterial blood oxygen saturation (SaO_2), anterior RMM, and ECG was collected. All participants had to complete both sessions. The two sessions were completed on two separate days and the order was randomized for each participant.

The VAS used to access nasal obstruction was 100 mm in length and 2 mm in width, with 0 mm representing no sensation of nasal obstruction and 100 mm representing total nasal obstruction. BP was recorded using a mercury sphygmomanometer. The SaO_2 was obtained using a pulse oxymeter (General Electric Company, Ltd) mounted on the right index finger. The nasal airway was accessed using an anterior rhinomanometer (model NR6Rhino, version 4.3, GM Instruments Ltd., Kilwinning, UK). The analytical parameters included nasal airflow and nasal airway resistance at pressures of 75, 150, and 300 Pa. In addition, each individual's ECG was recorded synchronously during each 5-min breathing session.

Analysis of heart rate variability

Detailed procedures for HRV analysis have been reported in the literature [9]. In brief, the ECG signals were recorded for 5 min in digital format using an ECG amplifier and an 8-bit analog-to-digital converter with a sampling rate of 256 Hz. The ECG signals were then processed using a computer algorithm that identifies each QRS complex, but rejects ventricular premature complexes or noise according to their likelihood of fitting a standard QRS template. Each R-R interval was retrieved, re-sampled, and interpolated at a rate of 7.11 Hz in order to construct an evenly sampled smooth contour of heartbeats in the time domain.

The power spectrogram of the heartbeats was acquired using fast Fourier transformation (FFT) of the heartbeat contour. The power spectrum was subsequently quantified into standard frequency-domain measurements as described in the literature [10], including very-low-frequency power (VLF, <0.04 Hz), low-frequency power (LF, 0.04–0.15 Hz), high-frequency power (HF, 0.15–0.40 Hz), and the ratio of LF to HF (LF/HF). The LF, HF, and LF/HF were logarithmically transformed to correct the skewness of their distributions. In general, HF represents the parasympathetic activity of the ANS, whereas LF/HF represents the sympathetic modulation of heart rate [10].

Statistics

The values obtained from rhinomanometry are expressed as medians and ranges. Comparisons between the groups were made using paired sample *t* test. Correlations between the R-R intervals and the rhinomanometric nasal airway measurements were made using Pearson's correlation analysis. The differences were considered statistically significant if $P < 0.05$.

Results

Mean artery pressure and arterial blood saturation

The age, sex, mean artery pressure, SaO_2, and VAS of nasal obstruction are shown in Table 1. There were no significant differences observed in mean BP ($P = 0.91$, paired sample t test), VAS ($P = 0.14$, paired sample t test), or SaO_2 ($P = 0.99$, paired sample t test) between BNB and UNB. However, there was a significant decrease in systolic BP as a result of adaptation to the supine state during BNB ($P < 0.05$, paired sample t-test). There was a trend of lower systolic BP during UNB than during the adaptation state, although the statistics were not significant ($P = 0.09$, paired sample t test).

Bilateral nostril breathing versus unilateral left nostril breathing

The HRV analysis (Fig. 1a, b) and rhinomanometric recordings (Fig. 1c, d) of one study participant for both types of nasal breathing are shown in Fig. 1. Both power spectra of the HRV (Fig. 1a, b) showed a very large peak at the controlled respiratory frequency (0.25 Hz). In addition, UNB (Fig. 1b) showed an increased R-R interval, a decrease in total power, and a decrease in LF/HF as compared to BNB (Fig. 1a). Although there was only left nasal passage for breathing during UNB, the nasal airflow measured by RMM after each session did not show a significant change between these two types of nasal breathing (Fig. 1c, d). These measures tended to be consistent both within and across sessions for this individual and most other participants.

The mean R-R intervals of the two types of nasal breathings are illustrated in Fig. 2a, and the mean R-R intervals of UNB were significantly greater than during BNB ($P < 0.05$, paired sample t test). This indicated a significant decrease in heart rate during unilateral nasal breathing. In addition, during UNB, the decrease of heart rate would seem to be a result of a decrease in sympathetic activity, which is indicated by the significant decrease in LF/HF (Fig. 2b; $P < 0.01$, paired sample t test). The VLF (Fig. 2c), for which the physiological basis is unclear in the present study, is also decreased significantly ($P < 0.01$, paired sample t test). Nevertheless, the HF, an indicator of parasympathetic activity [11], did not reveal a significant difference between BNB and UNB. The nasal airway resistance for UNB and BNB are plotted in Fig. 4. During

Table 1 Age, sex, blood pressure, blood oxygen saturation, and sensation of nasal obstruction for all participants

Age (years)	Sex	Session[a]	MAP (mmHg)			SaO_2 (%)			VAS (mm)		
			Adap	BNB	UNB	Adap	BNB	UNB	Adap	BNB	UNB
32	F	A	81	75	81	98	98	98	0	0	0
		B	85	77	89	97	97	98	0	0	0
21	F	A	81	75	81	98	98	98	10	11	13
		B	87	75	85	99	99	99	14	3	5
33	M	A	107	91	95	98	98	97	2	4	7
		B	86	97	99	96	94	96	9	14	14
29	M	A	96	93	89	96	98	99	11	18	22
		B	98	97	100	97	98	98	13	7	7
30	M	A	100	98	98	97	97	97	15	8	11
		B	108	108	108	97	98	98	12	15	16
29	F	A	83	95	84	98	96	98	7	17	22
		B	85	88	88	99	99	99	2	5	10
28	F	A	87	83	75	99	100	99	0	4	0
		B	85	79	89	98	99	99	1	1	1
26	F	A	77	91	83	98	98	97	16	16	29
		B	78	87	82	98	97	98	26	15	16
27	F	A	85	81	77	98	100	100	0	0	0
		B	90	84	86	97	98	97	0	0	0
21	F	A	85	83	74	99	99	97	1	0	2
		B	82	77	82	98	99	98	2	12	3

MAP mean arterial pressure, *SaO2* arterial blood oxygen, *VAS* visual analog scale, *Adap* adaptation, *BNB* bilateral nostrils breathing, *UNB* unilateral left nostril breathing

[a] Session A: session BNB followed by session UNB; Session B: session UNB followed by session BNB

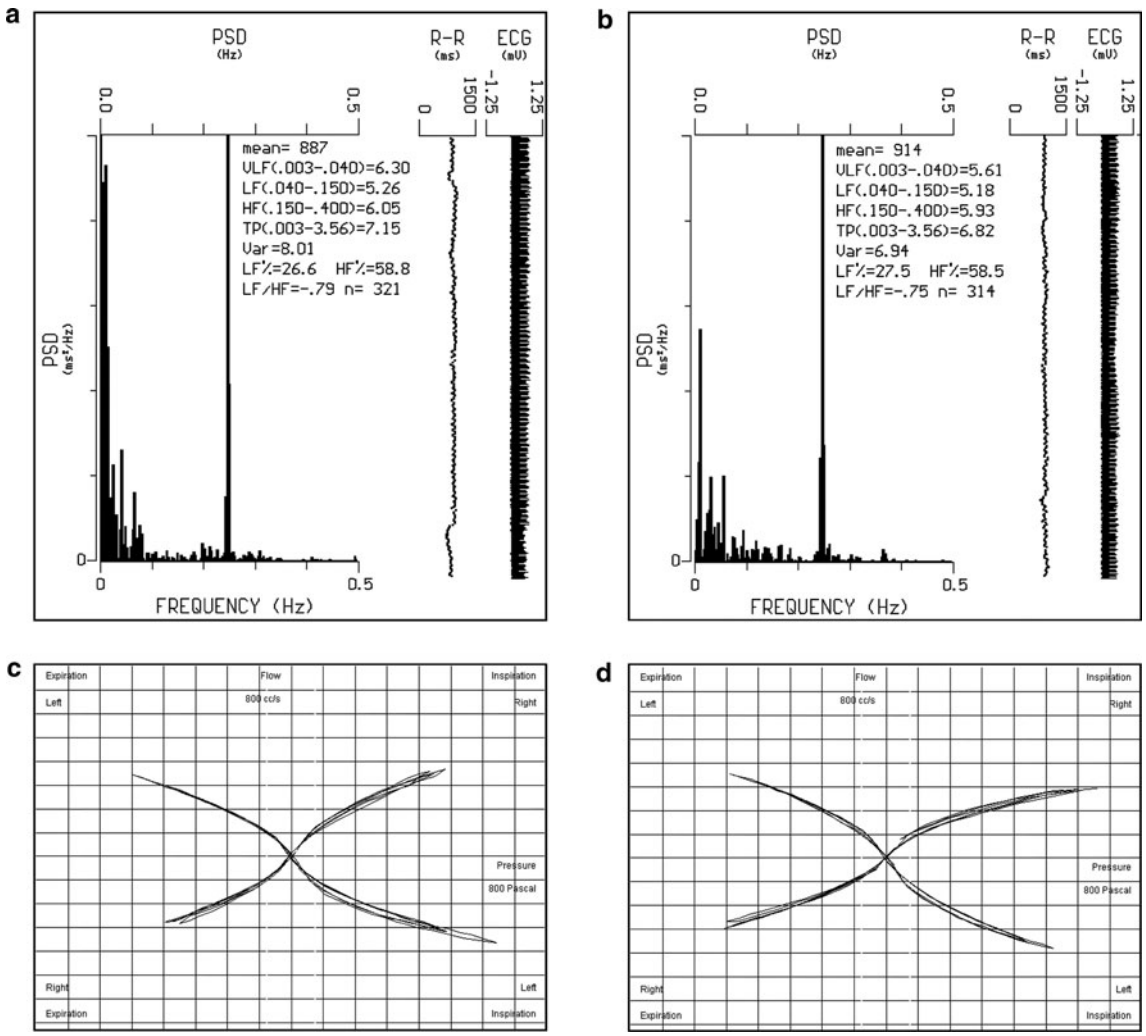

Fig. 1 The ECG tracings, R-R contours, power spectra of heart rate variability and rhinomanometric measures of a study participant during bilateral nasal breathing (**a**, **c**) and unilateral nasal left nostril breathing (**b**, **d**)

UNB, the nasal airway resistance showed a significant increase comparing with BNB because the left nasal passage was the only nasal airway for breathing.

In summary, during UNB, the nasal resistance increased significantly and the heart rate decreased significantly. These changes seemed to be related mainly to the withdrawal of sympathetic activity rather than any change in the parasympathetic activity.

Nasal airway resistance

While the participants were lying in supine position during adaptation and controlled nasal breathings, the total nasal airflow at 75 Pa (Fig. 3a) was lower for BNB ($P < 0.05$, paired sample t test) and UNB ($P = 0.055$, paired sample t test) than at the adaptation stage. In addition, the total nasal airway resistance (Fig. 3b) was higher for BNB ($P < 0.05$, paired sample t test) and UNB ($P = 0.062$, paired sample t test) than during the adaptation stage.

Correlation between nasal airway resistance and R-R interval

The correlation between R-R intervals and nasal airway resistance at 75 Pa during BNB and UNB is shown in Fig. 4. The correlation was positive and significant using Pearson's correlation ($R = 0.44$, $P < 0.01$).

Discussion

In this study, controlled UNB for 5 min resulted in a significant increase in nasal airway resistance and a significant decrease in heart rate, which was associated with a decrease in sympathetic activity, although there were no

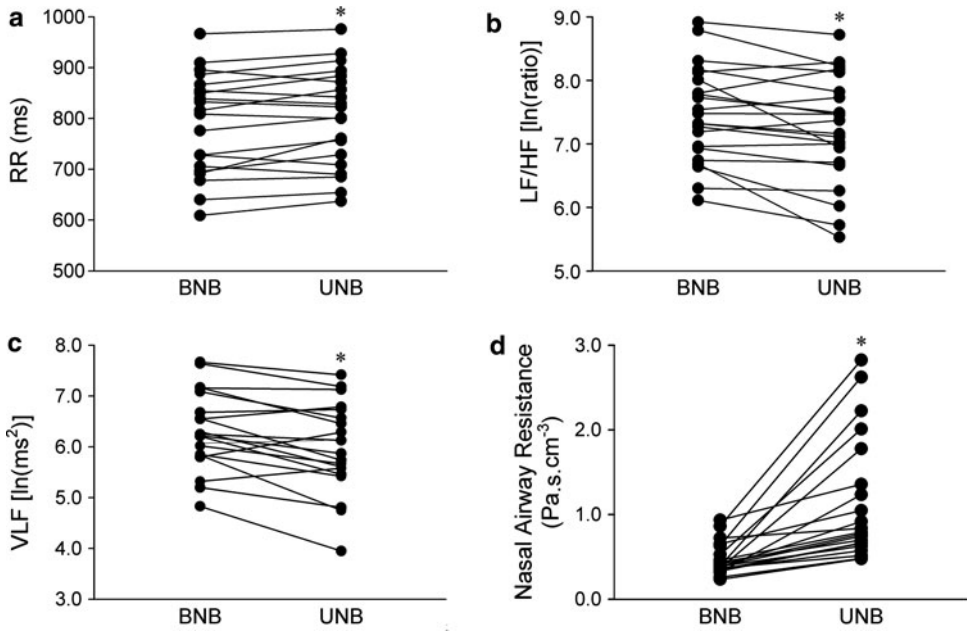

Fig. 2 The R-R interval (**a**), LHR (**b**), VLF (**c**) and total nasal resistance (**d**) during bilateral nostril breathing (BNB) and unilateral left nostril breathing (UNB) for 5 min in a supine position. R-R interval is expressed in ms. LF/HF, ratio of low-frequency power to high-frequency power expressed using a logarithm scale. Total nasal airway resistance is expressed in Pa s cm^{-3}. *$P < 0.05$, comparison between two groups using paired sample *t* test

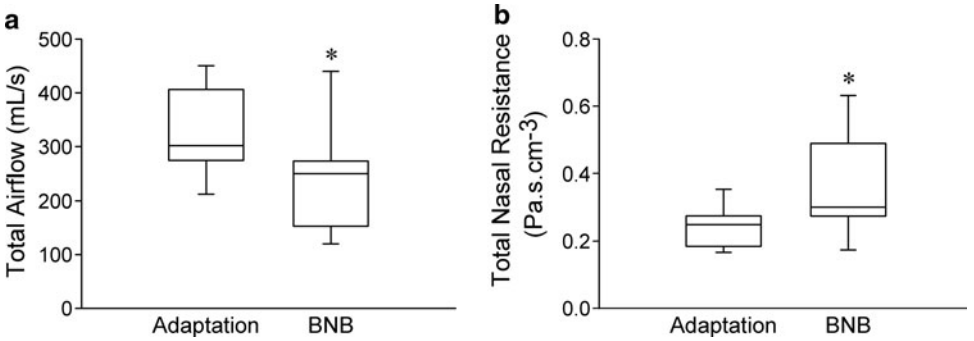

Fig. 3 Total nasal airflow (**a**) and total nasal airway resistance (**b**) at 75 Pa between adaptation for 2 min and bilateral nostrils breathing (BNB) for 5 min in a supine position. The total airflow is the summation of inspiration and expiration nasal airflows expressed in mL s^{-1}. The total nasal resistance is expressed in Pa s cm^{-3}. *$P < 0.05$, comparison between two groups using paired sample *t* test. Values are expressed as median and 5th/95th percentile range

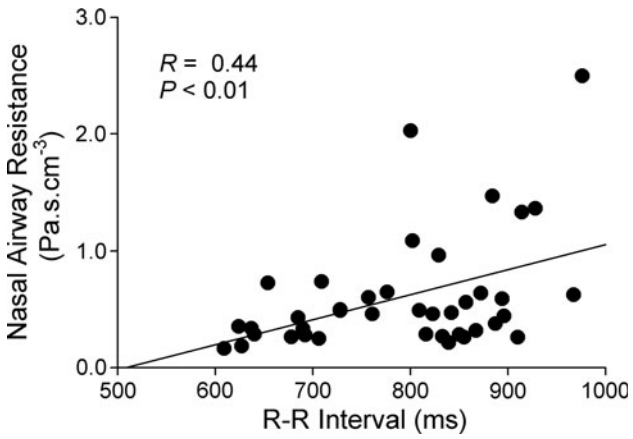

Fig. 4 The correlation between nasal airway resistance at 75 Pa and R-R intervals during UNB and BNB. The correlation was significant using Pearson's correlation analysis ($R = 0.44$, $P < 0.01$)

significant changes in SaO_2 or BP during this period. In addition, nasal airway resistance using both BNB and UNB also increased after the participants had been lying down for 5 min in quiet wakefulness. The significant and positive correlation between nasal airway resistance and R-R intervals implies that there is sympathetic withdrawal after prolonged lying in supine and UNB might cause an increase in nasal airway resistance. These findings support the hypothesis that changes in nasal airway resistance during UNB and lying may be caused by the changes in central sympathetic activity. In addition, the changes in cardiac ANS activities and nasal airway can be detected using non-invasive analysis of the HRV and RMM.

During controlled nasal breathing, the nasal airway resistance and systolic BP showed significant differences from the adaptation state. Lying in supine for 5 min might cause a congestion of nasal mucosa due to the increased

hydrostatic pressure in the sinusoid vessels [12] and/or from venous stasis combined with atony of the minor vessels and ANS changes [13]. In a previous study, central ANS activity showed a significant correlation with nasal airflow during postural change [14]. In this study, UNB was associated with a significant increase in nasal airway resistance and a decrease in sympathetic activity. Any changes in the vascular beds of nasal mucosa during UNB might be similar to those that occur while lying from the viewpoint of ANS activity and nasal airway resistance.

The nasopulmonary reflex has been suggested as the cause of the hypoxemia during bilateral nasal packing [3–5]. Acute hypoxia leads to stimulation of the peripheral chemoreceptors, which in turn directly increases sympathetic outflow. It is believed that the increase in sympathetic outflow is directly responsible, at least in part, for any acute blood pressure changes [11]. Although blood oxygen levels and BP were not significantly affected by UNB in this study, the heart rate and sympathetic activity did reveal significant decreases. The change in cardiac ANS activity might result from the differences in the inspiratory and expiratory phases, but not in the respiratory rate for the two types of nasal breathing. The results also support the idea that the ANS responds to the changes in nasal airway resistance even though no hypoxia develops.

There have been many investigations of cardiopulmonary changes after acute total nasal obstruction, and bilateral nasal obstruction is generally accepted to induce hypoxia, hypercapnia and the following cascade of effects. In some studies performed using bilateral nasal packing after nasal operations, the nasal obstruction caused a significant decrease in blood O_2 saturation [15]. However, mechanical stimulation of the nasal mucosa may have introduced a bias in these studies. In our study, a gel pad was used to seal the nostril opening and any mechanical stimulation was limited. The experimental conditions in this study are closer to the pathophysiological status found in disorders, such as acute rhinitis, allergic rhinitis, deviated nasal septum, etc.

The HF in the frequency-domain analysis of the HRV is considered to represent cardiac vagal activity and is thought to be related to RSA [16]. In this study, although the HF during UNB (5.87 ± 1.17, mean $\pm$ SD) was not significantly different from that during BNB (6.08 ± 1.33, mean $\pm$ SD), the HF of both types of controlled nasal breathing is significantly higher than for a healthy population aged 40 and 79 years as described in the literature [9], whose HF was measured to be 4.06 ± 0.04 (mean $\pm$ SD). The greater HF during UNB and BNB relative to a healthy population may result from the nasal breathing at a cycle of 4 s (0.25 Hz). The intensity peak at a frequency of 0.25 Hz in the power spectra of HRV (Fig. 1) showed that there were effects of controlled breathing on the HRV. Consequently, it would seem that the HF might have been maintained at a constant level by the controlled rate of breathing and dose not show a significant change between UNB and BNB. The efficiency of pulmonary gas exchange is improved by RSA, suggesting that RSA may play an active physiological role. The matched timing of alveolar ventilation and its perfusion with RSA within each respiratory cycle could reduce energy expenditure by suppressing unnecessary heartbeats during expiration and ineffective ventilation [16].

Reductions in the very-low-frequency oscillations of the R-R interval (with periods between 30 and 330 s or 0.03–0.003 Hz) are associated with the increased risk of cardiac and dysrhythmic death and possibly syncope [17]. Three mechanisms for these very slow heart period oscillations have been proposed, namely thermoregulation [18], the renin-angiotensin-aldosterone system [19], and functioning of the peripheral chemoreceptors [20]. However, the actual cascade of physiological events that generates the very-low-frequency variability of heart rate has not been defined. In this study, there was a significant reduction in the VLF during UNB. The reduction might be produced by the differences in the inspiratory and expiratory phases because the breathing was controlled at the same rate for the two types of nasal breathing.

Conclusions

The heart rate significantly decreased during UNB and the decrease was associated with a decrease in cardiac sympathetic activities that could be evaluated by frequency-domain analysis of heart rate variability. In addition, cardiac ANS activities were also affected by the inspiratory and expiratory phases of the two types of nasal breathing. The positive correlation between nasal airway resistance and R-R interval implies central control of the nasal airway by ANS activities. Unilateral nasal breathing, which can also be regarded as unilateral nasal obstruction, caused a similar change to a prolonged lying in supine from the view of ANS activity and nasal airway resistance.

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