Evaluation Of Heart Rate Variability Indices During Postural Changes

Jae Mok Ahn, Jeom Keun Kim

Abstract: Hear rate variability (HRV) is an interesting and noninvasive way to identify autonomic nervous system (ANS) imbalances as well as to assess the effects of stress on the body in various environments. At present, there is no accepted standard for ANS activity measurements when one's posture changes from a sitting to a standing position. The aim of the present study was to evaluate the effects of postural changes on ANS activity by evaluating HRV indices. HRV indices in the time and frequency domains derived from fast Fourier transform (FFT) analysis and a nonlinear analysis were investigated. We evaluated the ANS activity before and after postural changes throughout the entire measurement session. A total of 271 HRV segments were analyzed by shifting the 1-minute data window forward by 2 s for the entire 10-minute HRV dataset. The HRV indices that were affected most by postural changes were SDNN, TINN, CVAA%, SD2, ApEn, and Ln LF. Among the indices, the nonlinear parameters such as CVAA%, SD2, TINN, and ApEn reflected ANS activity better than frequency parameters did. The results demonstrate that a simple change in posture such as moving from sitting to standing increases sympathetic activity and fluctuations in Ln LF magnitude and that the parasympathetic activity recovers one minute after standing up. Therefore, postural changes may be an effective approach for investigating parasympathetic activity through evaluations of nonlinear HRV parameters.

Index Terms: Autonomic nervous system, heart rate variability, fast Fourier transform, parasympathetic nervous branch, sympathetic nervous branch, frequency domain.

1 INTRODUCTION

Heart rate variability (HRV) is a good indicator for the assessment of autonomic nervous system (ANS) imbalances, which lead to psychological and cardiovascular diseases [1, 2, 3]. HRV is simply a measure of the variation in time between two consecutive heartbeats. This variation is controlled by the ANS, which consists of parasympathetic and sympathetic nerve branches, known as the relaxation and fight-or-flight responses, respectively. Fight-or-flight responses are responses to an acute threat that manifests in physical or mental changes triggered by the sympathetic nervous system. The body's sympathetic nervous system plays a critical role in preparing the body for external stressors. The sympathetic nervous system stimulates the adrenal glands, which in turn trigger the release of adrenaline and noradrenaline, resulting in an increase in heart rate, blood pressure and breathing rate [4, 5]. The relaxation response is a way of activating the parasympathetic nervous system which can have a positive influence on health because the immune system works better when it is relaxed [6]. A deep abdominal belly breath was reported to stimulate the vagus nerve, which is the main stimulator of this relaxation response [7]. HRV represents the capacity of the heart to respond to a variety of physiological environmental stimuli by ANS activity [8]. A monotonously regular heart rate creates low HRV, which is associated with impaired regulatory and homeostatic ANS functions, resulting in a reduction in the body's ability to overcome any stressors [9]. HRV has been used as an interesting and noninvasive way to detect ANS activity causing relaxation and fight-or-flight responses due to external stimuli, such as simple physical activity [10].

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However, few studies have reported the characteristics of the HRV indices derived from the time and frequency domains, including nonlinear parameters referred to as descriptors in the geometrical domain. It is important that specific HRV indices that are dependent on physical activity are investigated to develop physical therapy strategies or to improve ANS functions by monitoring the corresponding indices that are good indicators. In this study, we evaluated the effects of a simple physical activity, such as a change in posture, on ANS activity. The measurement was performed while the participant was standing at the time of 5 minutes and sitting at the time of 6 minutes for an entire 10-minute HRV data collection session. The participant's heart rate increased when the sit-to-stand transition occurred, but it decreased within 1 minute after the participant remained in the standing position. This postural change test was found to affect most nonlinear HRV parameters, and it especially caused larger fluctuations in Ln LF magnitude in the frequency domain.

2 HRV PARAMETERS

2.1 Frequency domain analysis

The HRV analysis is used to identify the autonomic influences of physical activity on heart rate. Fast Fourier transform (FFT) is a useful method for determining three spectral frequency bands that reflect ANS activity in the HRV dataset, which are shown in Table 1: very low frequency (VLF), low frequency (LF), and high frequency (HF). In general, the VLF band increases at a steady rate throughout the night, peaking shortly before an individual waking [11]. The VLF band is less clearly defined than the LF and HF bands, but the VLF power has been reported to be related to thermoregulation, the renin-angiotensin system, and other hormonal factors [12]. The low frequency spectrum is the LF power that reflects both sympathetic and parasympathetic activities. In particular, the LF power represents, in most cases, a fair approximation of sympathetic activity. Enhancement of the LF power has been reported to be stronger during the fight-or-flight response than during the relaxation response. The high frequency spectrum is the HF power to which vagal or parasympathetic activity is the major contributor. The HF band tends to increase throughout the nighttime, reflecting the fast changes in the beat-to-beat variability, which are due to parasympathetic or vagal stimulation. However, the VLF is thought to reflect mostly sympathetic stimulation. Reduced parasympathetic activity has been found under stress or aging [13]. The normalized power represents the value of each power component relative to the total power minus the VLF component. The LF and HF normalized powers stress the controlled and balanced behavior of the two branches of the ANS, resulting in a minimal effect on the values of the LF and HF components and changes in the TP power. The frequency domain parameters of Ln HF, Ln LF and Ln VLF were calculated in real time by using the following equations:

$$\text{Ln HF}=ln\int_a^b |X(f)^2| df \quad (1)$$

$$\text{Ln LF}=ln\int_c^d |X(f)^2| df \quad (2)$$

$$\text{Ln VLF}=ln\int_e^f |X(f)^2| df \quad (3)$$

where the LF band is the activity between a=0.04 and b=0.15 Hz, the HF band is the activity between c=0.15 and d=0.1 Hz, and the VLF band is the activity between e=0.0033 and f=0.04 Hz. The power spectrum, X(f) was calculated as the squared magnitude of the fast FT of the HRV dataset that was reported in our previous study [14].

***Table 1**. Heart rate variability measurement: frequency domain parameters*

TP	*ms^2*	*Area under the entire power spectral curve, VLF+LF+HF*
Ln VLF	*ms^2*	*Natural logarithmic value of very low frequency power, bands of 0.0033-0.04 Hz*
Ln LF	*ms^2*	*Natural logarithmic value of low frequency power, bands of 0.04-0.15 Hz*
Ln HF	*ms^2*	*Natural logarithmic value of high frequency power, bands of 0.15-0.40 Hz*
LF norm	*nu*	*Normalized low frequency power*
HF norm	*nu*	*Normalized high frequency power*
Ln LF/Ln HF		*Ratio of the low to high frequency power*

2.2 Time domain analysis

The time domain parameters used in this study are displayed in Table 2. The normal-to-normal (NN) intervals between successive normal peaks based on photoplethysmogram (PPG) measurements were collected to calculate the time domain HRV indices. The SDNN reflects all the frequency components responsible for variability in the HRV dataset. Specifically, the SDNN includes the high frequency band, as it estimates short cycle lengths, but it is inappropriate to directly compare the HF power with the SDNN because of its dependence on the length of the HRV dataset. However, for a 5-minute HRV dataset, a reduction in the SDNN has been correlated with left ventricular dysfunction, resulting in an increased risk for sudden cardiac death [15]. The RMSSD provides an estimate of the parasympathetic regulation of the heart, as it estimates the fast NN interval variations in the HRV. The SDSD represents short-term variability that is known to be equivalent to HF power as well. The mathematical equations for SDNN, RMSSD, and SDSD are as follows:

$$\text{SDNN}=\sqrt{\frac{\sum_{n=1}^{N-1}\left(NN_n-\overline{NN}\right)^2}{N-1}} \quad (4)$$

$$\text{RMSSD}=\sqrt{\frac{1}{N-1}\sum_1^{N-1}[NN_n-NN_{n-1}]^2} \quad (5)$$

$$\text{SDSD}=\sqrt{\frac{\sum\left(NN_{diff}-\overline{NN}_{diff}\right)^2}{N-1}} \quad (6)$$

where $NN_{diff}=NN_n-NN_{n-1}$.

***Table 2**. Heart rate variability measurement: time-domain parameters*

SDNN	*ms*	*The standard deviation of all NN intervals*
RMSSD	*ms*	*The square root of the mean of the sum of the squares of differences between adjacent NN intervals*
SDSD	*ms*	*The standard deviation of the differences between adjacent NN intervals*

2.3 Nonlinear analysis

Table 3 shows five nonlinear parameters for the HRV analysis. Poincare plots can be evaluated qualitatively using the shape of the plot and the computation of the SD1 and SD2 parameters. Using Poincare plot analysis of the HRV dataset is reported to be a better way of monitoring the dynamic changes in autonomic function during physical activity. The ApEn is a statistic that can quantifies the regularity and complexity of a stationary signal for a number of data points [16]. The TINN is highly associated with diabetes mellitus, and the CVAA% decreases with age, and an increase in a healthy subject in his 20 s has been reported [17]. All parameters were calculated with the following equations.

$$\text{SD1} = \sqrt{var(x1)}\ ,\ \text{x1} = \frac{NN(n+1)-NN(n)}{\sqrt{2}} \quad (7)$$

$$\text{SD2} = \sqrt{var(x2)}\ ,\ \text{x2} = \frac{NN(n+1)+NN(n)}{\sqrt{2}} \quad (8)$$

$$\text{ApEn}(\text{m},\text{r}) = \pi^m(r) - \pi^{m+1}(r) \quad (9)$$

$$\pi^m(r) = \frac{1}{N-m+1}\sum_{i=1}^{N-m+1}\text{lo g}[C_i^m(r)] \quad (10)$$

$$C_i^m = \frac{B_i(r)}{(N-m+1)} \quad (11)$$

$$B_i(r) = d[x(i),x(j)] \leq r \quad (12)$$

$$\text{d}[\text{x(i)},\text{x(j)}] = \max_{k=1,2,\dots,m}(|u(i+k-1)-u(j+k-1)|) \quad (13)$$

CVAA% = SDNN/mean NN intervals *100 (14)

***Table 3**. Heart rate variability measurements: nonlinear parameters*

CVAA	%	Coefficient of variation of the a-a intervals
TINN	ms	Baseline width of the minimum square difference triangular interpolation of the highest peak on the NN interval histogram
ApEn		Approximate Entropy
SD1	ms	One standard deviation of the length of the transverse line on the Poincare plot
SD2	ms	Two standard deviation of the length of the longitudinal line on the Poincare plot

3 MEASUREMENT

The entire 10-minute HRV recording using a commercial pulse analyzer with a finger-type sensor of a photoplethysmogram (PPG), TAS9VIEW (CANOPY9 RSA, IEMBIO Co. Ltd., Chuncheon-si, South Korea) was obtained. While measuring the NN intervals, sit-to-stand postural changes occurred at 5 minutes and stand-to-sit postural changes occurred at 6 minutes. It was not important in this study to check the participant's health status because the purpose of the study was to investigate the HRV indices that can affect postural changes the most.

4 RESULTS

The HRV tachogram for the entire 10-minute session with a postural change is displayed in Fig. 1. The tachogram shows a variation range of 10-20% when moving from a sitting position to a standing position. The HRV parameters that are affected by a postural change were assessed based on statistical operations (time domain), spectral analysis (frequency domain), and geometrical method (nonlinear domain). All HRV indices were calculated from 271 1-minute segments from the entire 10-minute recording. Fig. 2 shows profiles of six HRV parameters, which were affected by the postural change. The five parameters, except for SD1, were significantly higher in the standing position than in the sitting position, and the standing period is marked as a red dot. The SDNN, TINN, ApEn, SD2, and CVAA% with the SDs were 25.351±7.8345, 108.579±29.7188, 0.502±0.1026, 32.368±11.9182, and 3.338 ±1.1056, respectively. The SD1 dropped sharply when the stand-to-sit change occurred at 6 minutes. Fig. 3 shows significantly more fluctuations in the Ln LF in the frequency domain analysis for a whole recording than in the Ln HF. Specifically, the Ln HF decreased during the standing posture, causing stimulation of the sympathetic nervous branch. Thus, a decrease in fluctuations in the Ln HF occurred due to a decrease in the high frequency HRV measures in response to the standing posture. Fig. 3 shows the relationship between the Ln HF and Ln LF for 271 1-minute HRV segments, which can reflect the ANS balance. All trajectories of the Ln HF and Ln LF demonstrated how the ANS activity changes during a change in position. To quantify the ANS activity, the slope of an asymptotic curve between the Ln HF and Ln LF trajectories was used. The slope value was 0.303. The low slope represents a higher amount of fluctuation in Ln LF than in Ln HF, resulting in more attenuation of parasympathetic nervous branch. A slope higher than 1 represents an enhancement of the parasympathetic nerve.

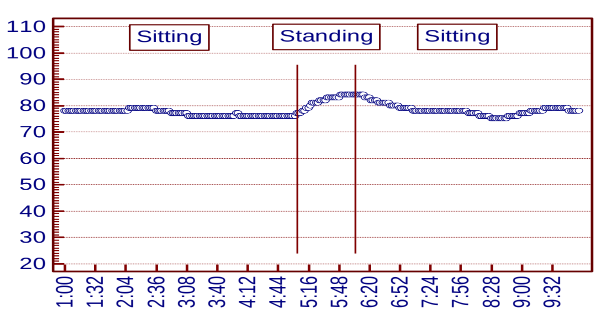

Fig. 1. A tachogram measured for 10-minute HRV dataset. The duration between 5 minutes and 6 minutes corresponds to the standing position, and the remaining duration corresponds to the sitting position.

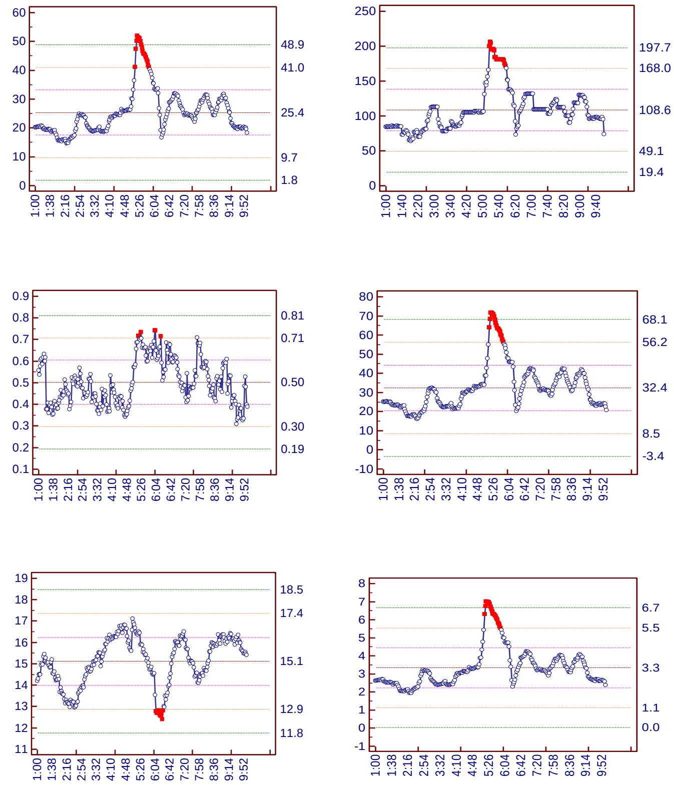

Fig. 2. Data plots of 271 1-minute segments of the SDNN, TINN, ApEn, SD1, SD2, and CVAA%.

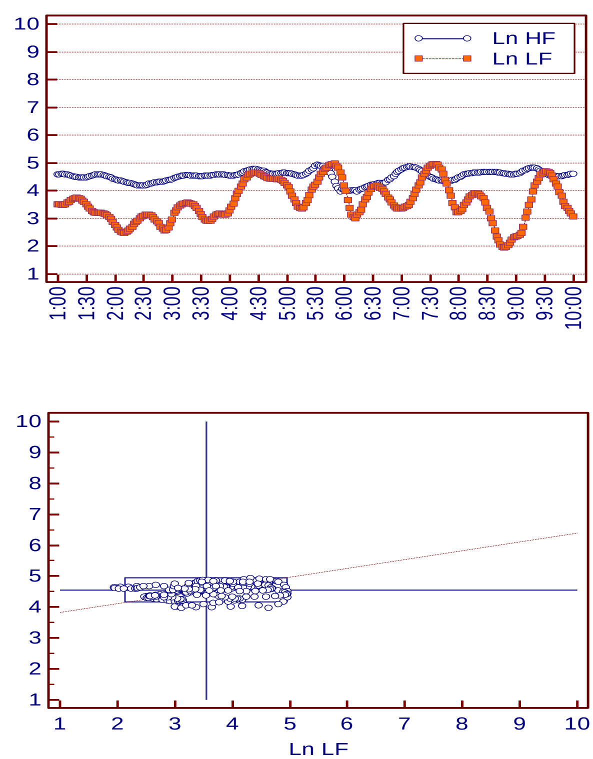

Fig. 3. Plots of the Ln LF and Ln HF indices: (top) data analyzed from 271 1-minute segments, and (bottom) fluctuations of the ANS activity.

5 CONCLUSION

This study attempted to explore the ANS activity as an individual changed posture from a sitting position to a standing position and then from a standing position to a sitting position. The study showed significant increases in SD2, SDNN, ApEn, TINN, and CVAA% during standing compared with those during sitting. A significant increase in these indices from a sitting position to a standing position was observed within one minute. One of the meaningful results was that the vagal activity was lowest, and sympathetic activity was highest during the change from standing to sitting. The results demonstrate that the influence of simple physical activity on the ANS activity can be evaluated by investigating the nonlinear parameters rather than those in frequency and time domain analyses. In the future, the standing respiratory rate will be considered in evaluating the effect of HRV parameters on physical activity.

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