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The Gender Effects of Heart Rate Variability Response during Short-Term Exercise using Stair Stepper from Statistical Analysis

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Abstract

This study is aimed to explore the heart rate variability (HRV) response during short-term exercise by stair stepper and to compare the finding between young healthy male and female subjects. The responses were statistically analyzed by applying independent-samples t-test statistical method. The calculation of coefficient of variation (CoV (%)) and the slope of the linear regression are used to assess the steadiness of the HRV. Furthermore, the results also demonstrated that female subjects had greater significant p-value of RMSSD feature, and significance p-value of an LF feature is greater in males. Thus, the ongoing results demonstrated that males have the sympathetic drive and females have predominant parasympatheticdrive during a short-term exercise on stair stepper. Thus, the experiment results indicate the suitability of developing rehabilitation devices in the field of Autonomic Nervous System (ANS) research, control system and rehabilitation engineering, which may help to isolate males and females.

Keywords: *signal processing, heart rate variability (HRV), ECG, during exercise, stepper*

1. Introduction

Many researchers in various fields trying to use HRV techniques as the view of gaining a non-invasive representation of ANS activity during exercise is appealing and expanding [1-4]. HRV is supremely declined during exercise when computed in either the frequency domain such as low frequency (LF) or in the time domain such as RMSSD [5].

Basically, one of the most dominant stimulators of sympathetic activity is exercise. During medium-level exercise, HR is controlled by the ANS at first with increased sympathetic adjustment and withdrawal of the parasympathetic movement [6, 7]. The frequency domain components of HRV have been notified to diminish, reflecting a dynamic diminishing in vagal modulation [8]. Sympathetic have been reported to increase during exercise in healthy humans [8]. These HRV changes have been mostly seen during leg cycling exercise [2], [9] with less study carried out on treadmill training [10] and even less on other modes of exercise. Both time and frequency domain values of HRV were claimed to be lower for dynamic i.e., cycling exercise compared to static leg exercise i.e., arm crank exercise at the same relative intensity [11].

Gender is known to affect HRV. Several studies have analyzed gender differences in autonomic adjustments in autonomic control following during exercise [7], [12]. Kuo *et al* studied HRV in normal populations of women and men to clarify the influence of gender in sympathetic and parasympathetic control of heart rate in middle-aged subjects and on the subsequent aging process. In their study, males express sympathetic predominance while females illustrate vagal predominance parasympathetic as implied by the middle-aged men in which the value of LF power is higher while the value of HF power is lower compared to middle-aged women [13]. Huang *et al* identified the relationship of personality traits and autonomic functions to show gender differences. Their results claimed that personality features are associated with

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autonomic functioning and that gender is a moderator in these relationships. Such distinctions clarify the fact that there is a higher chance of heart disorder among men and recommend that the ANS balance might be influenced by sex hormones [12]. Other than that, Haruki*et al.*, aimed to clarify the heart rate and blood pressure response during the ramp exercise test and mentioned that some of the parameters such as AT, peak Vo_2 and Vo_2 were influenced by weight, gender and age, as well as mode of exercise and the protocol used [14]. Yashoda studied the HRV response to exercise using Harvard step test and compare the findings between male among medical students. Their results suggested that males have higher sympathetic drive and females have predominant parasympathetic drive [15].

Other than that, women rather exhibit significantly larges values of the HF spectral power of RRi than men as shown from various researches of gender differences in autonomic regulation [16-20]. Higher parasympathetic stimulation to cardiac regulation is also protective during cardiac stress [21]. Some HRV tests have shown that the parasympathetic control of heart rate is increased and sympathetic control is decreased in females [16], [22]. Moreover, there are also researches on gender significant differences among patients. For example, Hasan *et al* had evaluated the gender differences with regard to time-domain HRV parameters in patients with vasovagal syncope. Their studies found that female patients with VVS have increased sympathetic activity demonstrated with time-domain HRV analysis [23]. Then, Raul *et al.*, examined the gender-specific effects of trait anxiety on the cardiac defensive response and claimed that gender moderates the association of trait anxiety with defensive reactivity [24].

Different exercises are utilized as part of the study of cardiovascular functions, for example, cycling, running and even high effort interval training. Harvard step test and stepper machine are also one of these methods. The stair stepper provides a comprehensive leg workout, offers a complete leg workout together with a cardiovascular workout. All of the major muscles of the legs, including quadriceps, hamstrings, and lower abs are all targeted by a stair stepper. No previous study has assessed the gender differences in the effect of HRV during exercise using stepper machine by statistical analysis.

The aim of this study is to explore and analyze the HRV response during short-term dynamic exercise using stepper machine. Therefore, an attempt was made to answer the question whether there exist gender significant differences in HRV response during this activity. The authors tried to find out which physiological parameters, reflecting the activities of the HRV are the best indicators of body response to potential gender significant differences and explore the significant gender differences. Then, the ongoing work can be used to implement the fusion of HRV with other biosignal such as EMG [25] in order to support the interface system of the controllable current-induced stepper in rehab application. This paper is part of an effort to utilize information extracted from different physiological signals including EMG to quantitatively characterize the knee injury, and design a robust and reliable automatic system to assess knee injury and develop less monitoring lower limb rehabilitation system [26], which may help to isolate male and female subjects.

This paper is organized as follows. Section 2 describes the steps involved in the process to explore the Heart Rate Variability (HRV) response during short-term exercise by stair stepper and compare the finding between young healthy male and female subjects. The steps included the process of obtaining HRV from the ECG, extracting time and frequency domain features from the HRV and statistically analyzed the HRV data using the independent-samples t-test to compare the pair of HRV components in males and females during exercise by the stepper. The preliminary results and performance of gender effects on HRV response during short-term exercise are evaluated and discussed in Section 3.

2. Materials and Method

2.1. Subjects

The study was done in the Faculty of Biomedical and Health Science Engineering, UniversitiTeknologi Malaysia, Johor Bahru on 10 healthy, untrained young volunteers (mean 26.4 years, range 20 to 30). Of ten subjects, five were male and five were female. All subjects were free from any disease and had been explained about the procedure and their informed consent was taken.

2.2. Instruments

The TMSi DAW was used to record the ECG and EMG signals synchronously for stress assessment during exercise. Two pairs of active surface electrodes and a single reference surface electrode were used with the TMSi DAQ to measure the electrical signals from the cardio and the muscle. These surface electrodes are circular in shape with 11.4 mm in diameter and are composed of silver/silver chloride (Ag/AgCl) materials. The mini stair stepper was used to perform stepping exercise to generate the electrical activity of the heart and muscle (see Figure 1). Metronome at 45 beat per minute was used to fix the stepping rate.

2.3. Procedures and Preprocessing

For electrode placement on the heart, the skin of the chest was readied using a skin cleaning gel and alcohol swab. The surface electrodes were then placed on the skin based on the Einthoven Triangle [27] to generate the electrical activity of the heart called ECG. Then, the subjects were asked to step right up on the stair stepper and keep the body upright with the hips centered over the legs. Then hands are straight side of the body along the recording so that there are no much interference exists. Next, the subjects were asked to press the entire heel down the step and focused on the metronome rhythm for 180 s (prolonged experiment). Figure 1 shows the experimental setup during stair stepper workout. One channel ECG was recorded simultaneously along with one channel of EMG. EMG with active or inactive signals was identified. Both the raw ECG and EMG were sampled at 2048 Hz.

Figure 1. Experimental setup during ECG and surface EMG data recording

Essentially, QRS complex detection is the most elementary issue associated with ECG process. A QRS detection algorithm is utilized to extract the R points. A reliable QRS detection technique explained in [28] was used to localize and extract the R points from the ECG signal. Other than that, ECG's R peak can also be detected using Hilbert Transform [29]. Plus, the analysis of the QRS detection algorithm for noisy ECG in [30] can also be utilized for better features extraction.The signals from each test were segmented into 180 s period length to have a standard length of all signals. The QRS wave was then detected usingPan and Tompkin algorithm [28]. This algorithm was chosen because it has been proved to detect 99.3% of adult QRS using the MITBIH database [28].

The algorithm started by allowing the signal through a digital band-pass filter to reduce the noises. The bandpass filter is composed of both highpass and lowpass filters with 5 and 11 Hz cutoff frequencies [27]. The process continued with differentiation, followed by squaring and moving window average at 50 ms. Next, the adaptive thresholds are utilized to classify the location of the R points. The output of each preprocessing step and the resultant of HRV are shown in Figure 2.

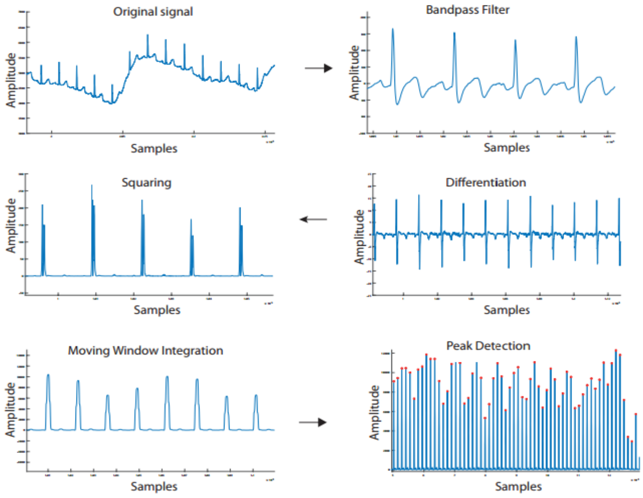

Figure 2. The output of ECG preprocessing

2.4. HRV Quantification

The HRV is the inverse of the RRi. The RRi was then computed and passed through the outliers removal process. Next, the RRi with outliers' removal is resampled at 4 Hz and detrended.

The recommendation of the task force was followed [31] in estimating the HRV indices. The time and frequency domain analysis of HRV were conducted in this study and the major HRV parameters used as per observation were the mean RRi (ms), RMSSD (ms) and LF (ms^2). Furthermore, the RMSSD is said to be connected with predominant parasympathetic drive and LF is connected with sympathetic drive [31] in which will be utilized for further analysis.

2.5. Performance Analysis

The collected data were statistically analyzed. The independent-samples t-test was used to compare the pair of HRV components in males and females during exercise. The descriptive statistics, including mean, SD, and CoV (%), were calculated for each of 5-male and 5-female subjects for each 180 s exercise period. Regression analysis was performed to analyze the relationship between the significant HRV components and time (s) variables. The null hypothesis corresponding to the linearity of each regression was tested using an F-test. Finally, each individual dataset from the trial was fitted with linear regression in the logarithmic space to obtain a function I the form of $y = mx + c$. Linear regression was used to test whether there is an association between the signals and the time lag. Additionally, the slope of the regression relationship was used to test whether the relationships are consistent for the subject's HRV at different time slots during exercise.

3. Results and Discussion

The data were expressed as mean±standard deviation (SD). Overall, the mean age of all subjects was 26.4±2.8 years.

Table 1 summarizes the mean ± SDof the HRV parameters in male and female subjects during exercise using stair stepper calculated in this study. As shown, there are significant gender differences ($p < 0.05$) in the mean of RRi, RMSSD and LF that were significantly high in males.

After that, the significant features from previous analysis are tested for each 60 s time slots. Table 2 summarizes the mean and SD of the significant HRV features (mean RRi, RMSSD and LF) in both male and female subjects. As shown, there is no association between the mean RRi and the time slots in both male ($p = 0.213$) and female ($p = 0.351$) subjects. Thus, this study is focused on the gender association between both the RMSSD and LF features with the time slots.

Table 1. HRV parameters in male and female subjects during exercise using stair stepper

Variable	Mean±SD		*t* value	p value
	Male	Female		
	Time Domain			
Mean RRi (ms)	656.5±19.1	569.7±26.4	2.667	0.03*
SDNN (ms)	23.9±2.3	21.1±1.6	1.011	0.34
RMSSD (ms)	18.4±2.0	10.4±1.8	2.980	0.02*
NN50 (count)	1.8±0.9	0.4±0.4	1.400	0.20
pNN50 (%)	0.7±0.4	0.1±0.1	1.548	0.16
HRV Triangular Index	6.6±0.6	5.1±0.5	1.859	0.10
TINN (ms)	127.0±18.6	105.00±5.0	1.145	0.2
	Frequency Domain			
VLF (ms^2)	287.4±102.1	268.2±85.8	0.144	0.89
LF (ms^2)	204.20±36.5	77.6±8.1	3.383	0.01*
HF (ms^2)	62.8±19.6	26.80±4.7	1.788	0.11
VLF (%)	47.3±9.2	66.2±6.7	-1.667	0.13
LF (%)	40.0±7.1	26.1±6.8	1.418	0.19
HF (%)	12.7±4.0	7.5±1.0	1.241	0.25
LF (nu)	76.8±6.5	74.0±4.5	0.355	0.73
HF (nu)	23.1±6.5	25.6±4.4	-0.328	0.75
Ratio LF/HF (ms^2)	4.7±1.3	3.8±1.3	0.449	0.67
Total Power (ms^2)	554.6±118.4	373.2±86.6	1.236	0.25

* $p < 0.05$: Statistically significant

Table 2 also presents the CoV values, which were used to assess the steadiness of the HRV. The findings indicate that the HRV is more steady in male subjects compared to female subjects as the CoV values for all the significant features in male is lower than the female subjects. Thus, it indicates that male subjects are more active than the female subjects. It is also indicates positive slope in the graphs of male's RMSSD and LF as shown in Figure 3.

Table 2. Results of the HRV with mean RR, mean HR, RMSSD and LF (ms^2) from every 60 s workout period of total 180 s workout duration for male and female subjects

Variable	Time slots	Mean±SD	Total	p value	F- ration	CoV (%)	Total CoV (%)
			Male				
Mean RRi (ms)	1ST 60s	661.2±16.8	656.5±10.5	0.213	1.55	5.8	6.21
	2nd 60s	658.1±20.6				7.0	
	3rd 60s	650.2±21.0				7.2	
RMSSD (ms)	1ST 60s	17.4±1.2	18.1±1.4	4.98E-11*	84.11	15.7	30.6
	2nd 60s	18.2±2.3				27.7	
	3rd 60s	18.7±3.8				45.8	
LF (ms^2)	1ST 60s	215.0±60.2	216.1±61.9	3.64E-7*	0.05	62.6	110.8
	2nd 60s	187.0±27.3				32.7	
	3rd 60s	246.4±188.0				170.6	
			Female				
Mean RRi (ms)	1ST 60s	585.2±25.8	79.4±32.1	0.351	0.81	9.9	9.9
	2nd 60s	565.6±27.3				10.8	
	3rd 60s	558.7±26.7				10.7	
RMSSD (ms)	1ST 60s	12.0±2.2	10.3±1.1	1.11E-12*	146.20	41.7	40.8
	2nd 60s	9.7±1.7				38.9	
	3rd 60s	9.1±1.8				44.2	
LF (ms^2)	1ST 60s	158±80.5	109.6±29.3	0.002*	0.20	113.9	103.5
	2nd 60s	91.4±24.8				60.6	
	3rd 60s	79.4±32.1				90.3	

* $p < 0.05$: Statistically significant

Moreover, the straight lines indicate the linear regression relationship between the significant HRV components (RMSSD and LF) and the phase during the three time slots for both the male and female subjects. The main issue addressed in the current study is the quantification of the relationship between the HRV and the time course (180 s) male and female subjects through linear regression analysis. As shown in Figure 3, the slope of the RMSSD – time and LF-time relationship are positive in male subjects and negative in female subjects. It also indicates that male subjects are more active than female subjects. Additionally, the highest significance level (p = 1.11E-12) was found for the RMSSD as a function of time in HRV of female subjects while the highest significance level (p = 3.64E-7) was found for the LF as a function of time in the HRV of male subjects.

(a) Male's RMSSD (b) Female's RMSSD

(a) Male's LF (b) Female's LF

Figure 3. Relationship between HRV and endurance in the RMSSD ((a) male and (b) female) and LF ((c) male and (d) female)

The studies of HRV with the combination of various pharmacological and physiological manipulations showed that HF components of the HRV power spectrum are associated with cardiac parasympathetic activity, LF components of power spectrum might be associated with both cardiac sympathetic and parasympathetic activity also with resistant reactivity [4], [32]. Besides, RMSSD component of HRV is also reflected with cardiac parasympathetic activity [31]. The ongoing findings demonstrate that males have higher sympathetic drive and females have predominant parasympathetic drive during stepping exercise by stepper machine. In support of this discovery, a research had shown that physiological levels of estrogen enhance vagal tone and stifle sympathetic modulation of heart rate in females [33].

Similar to the results obtained in a study done by [15], their study results demonstrated that males have a higher sympathetic drive at rest and females have a predominant parasympathetic drive at rest and after exercise using Harvard step test. However, they did not find any significance difference in males and females group during exercise as preliminary done in this paper. Other than that, similar to the study done by [4] and [34], showed that there was marked reduction in HRV spectral power at all frequencies as the exercise progressed. But, they did not find any significant difference between male and female. This study also similarly shows in a study done by [12] that implies LF a high positive correlation with exploratory excitability in males.

Data from studies of autonomic function shows that heart regulation during exercise is dominated by SNS activity [35] which is dominant in male subjects. The higher sympathetic autonomic regulation modulation in male may be caused by their physical constitution contained a greater muscle SNS activity and higher number of sympathetic ganglionic neurons [36].

The gender difference in HRV activity in terms of time slots during exercise using stepper machine has not yet been assessed. So, the preliminary experimental results indicate the suitability of developing rehabilitation devices in the field of autonomic nervous system research, control system and rehabilitation engineering, which may help to isolate male and female subjects.

4. Conclusion

The purpose of the present study is to analyze gender-related changes in the HRV through ECG signal analysis during short-term exercise by stair stepper machine using independent-samples t-test statistical analysis. Then, the descriptive statistics including mean, SD and CoV were calculated to test the steadiness of the HRV signal. It is also determined and supported through regression curve fitting from the positive slope of the linear regression curve in male and the gender difference in HRV activity during exercise. The ongoing works support the hypothesis that a meaningful correlation exists between HRV features, gender and time period of exercise intensity.

Furthermore, this ongoing study demonstrates that males have higher sympathetic drive and females have predominant parasympathetic drive during exercise using stair stepper machine. Similar to the results obtained in a study done by [15] which using Harvard step test in their study. The preliminary findings can beused to implement the fusion of HRV with other biosignal such as EMGto support the interface system of the development of the controllable current-induced of the stepper with less monitoring, which may help to separate male and female subjects. Finally, the outcome enhances our comprehension of the ANS control belonging to different genders and open new windows for further research. For further research, the duration for data collections could be made for long enough to get much better analysis.

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