Exercise based evaluation of cardiac function improvement

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Abstract— Heart rate, Blood Pressure and Rate pressure product are important physiological parameters that can be utilized to analyze the physical condition of the human body. However, the step-by-step analysis on the changes of ECG waveforms and RPP before and after regular exercise has been presenting in this paper. This proposed work examines the Changes of ECG waveforms after regular exercise. Rate pressure product results can be calculated based on HR and SBP after 12-minute running exercise in three weeks with the 10 healthy subjects. In these study determines the regular three weeks of exercise changes the recovery of HR which is the main evolution parameter of the cardiovascular fitness. RPP is an important indicator of the ventricular function. HR, SBP and RPP increases with strenuous exercise which provide the adequate blood supply to the myocardium. Thus, according to Brody effect, amplitude of R-peak in ECG at rest increased, will most likely is caused by the LV volume increased with improvement of heart function. In this experiment measurement of amplitude features of ECG like RQ, SQ, and TQ which represent the difference of amplitude between R-, S-, T-, and Q- wave respectively. After the final results showed that the 100% of subject's HR at rest condition has continuously decreased and 100% of R peak amplitude at rest increased during the three weeks of experiment. Moreover, RQ/SQ/HR and TQ/RQ/HR at rest 80% and 90% decreased during the experiment duration respectively; while, 70% of RQ/SQ/HR decreased, 50% of TQ/RQ/HR increased immediately after exercise and also 100% of RPP at rest decreased which indicating increased MVO_2 at rest. According to the Variation of these parameters, it indicated that cardiac function enhanced.

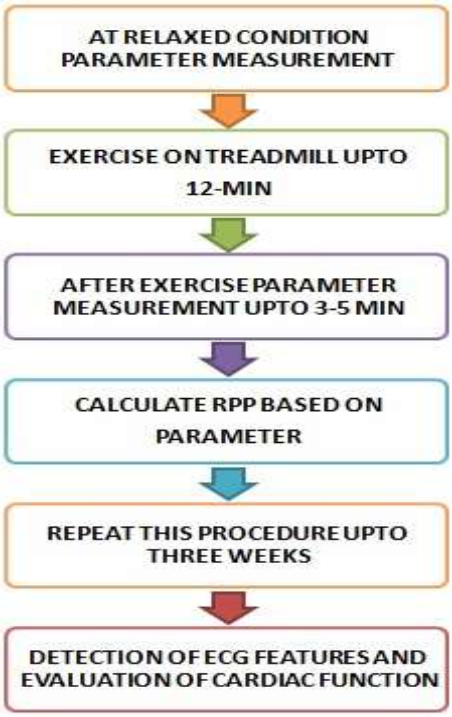
Keywords—ECG; SBP; RPP; Amplitude features; Brody effect; LV volume; 12-minute running; MVO_2

I. INTRODUCTION

ECG and systolic blood pressure results have been taken as guides to judge the physical condition of human body. The exercise is the best medicine in the world which is based on the number of medical conditions that can be improved as a result of exercise being a substantial part of the treatment. Exercise evaluation is a non-invasive; it evaluates the condition of subject's cardiovascular fitness state. Exercise can be defined as a subset of physical activity that is planned, structured, repetitive and purposeful in the sense that improvement of physical fitness is the main objective. Regular exercise yields a modest but beneficial effect on blood pressure [6]. There are basically three types of muscular contraction methods which can be applied in form of stress to cardiovascular system: static (isometric), dynamic (isotonic), and resistance (combination of static and dynamic). In dynamic exercise, which defined as a muscular contraction resulting in movement and it provides a volume load to the LV whereas, static exercise defined as a muscular contraction without movement and imposes to greater pressure than volume load on LV [7]. Oxygen uptake quickly increases when dynamic exercise is begun or increased. Thus, MVO_2 is the best measure of cardiovascular fitness and exercise capacity. MVO_2 can be easily calculated by indirect methods like Fick's Principle, stroke work, tension time index and Rate Pressure Product (RPP) [9]. The proposed system is based on treadmill exercise stress testing. Physiological parameter measurement before and after the exercise and based on that parameters calculating Rate Pressure Product (RPP), analysis on heart rate recovery, R peak improvement in ECG signal and also the measurement of feature extraction of ECG signal upto three weeks. 12-minute running time is chosen for the experimental exercise with the healthy subjects who had no history of cardiovascular disease, non-smoking, no chest pain and not participated in regular sports training[1].

II. SYSTEM CONFIGURATION

In this proposed system configuration, the flow of Parameter Measurement procedure is as follows:

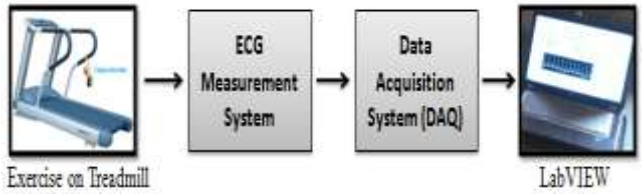


[Figure 1: Flow diagram of Proposed System]

The proposed system consists of mainly two steps for the parameter measurement: ECG measurement system and Blood pressure measurement system.

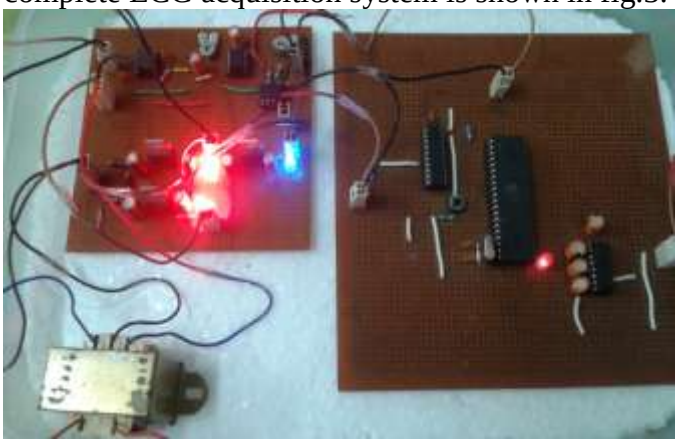
A. ECG measurement system

In constructing the experimental setup, a treadmill is used for the strenuous exercise. Fig.2 shows a schematic diagram of experimental setup.



[Figure 2: Experimental Setup]

Exercise stress test was performed on treadmill, which is the most commonly used device for the dynamic exercise test. The subject was subjected to graded exercise according to the Bruce protocol. This protocol dictates the slope and precise speed of the treadmill. The subject was run on treadmill till exhaustion [10]. In the ECG measurement system block consist of clamp electrodes, Instrumentation amplifier, Signal conditioning circuit, and summing amplifier. In that the electrodes work as a transducer which picks up the ECG signal from the body. INA126 instrumentation amplifier is used for the low level of amplification. The gain of amplifier is 13. After the low level of amplification, the signal conditioning circuit is used for the removal of noise and getting the better signal of ECG. The frequency range of signal conditioning circuit is 0.5-30 Hz. After that summing amplifier is used for the signal has been summed in the range of 0-5v. Thus, the ECG signal is getting at the stage of summing amplifier from the range of 0-5v. The data acquisition system block comprises the ADC0804, AT89c51 microcontroller, MAX232 and RS232 to USB connector. Output of the summing amplifier is fed to the data acquisition system and with the use of RS232 to USB connector, data logging with PC using National Instrumentation LabVIEW software for the real time acquisition of ECG signal. The complete ECG acquisition system is shown in fig.3.



[Figure 3: Complete ECG acquisition system]

B. Blood pressure measurement system

Blood pressure is considered a good indicator of the status of the cardiovascular system. Blood pressure can be measured by the two methods: direct method and indirect method. The direct method provides the continuous and more reliable information about the vascular pressure from transducers inserted directly into the blood stream. But the complexity is more and cost for this procedure is high to the patient. On the other hand, the indirect methods consist of simple equipment and cause a little discomfort to the subject. They are based on the adjustment of a known external pressure to the vascular pressure so that the vessels are collapses. The subject's blood pressure is expressed in terms of SBP over DBP and its unit is mmHg. Blood pressure may vary depending on situation, activity and disease state. It may be depends on cardiac output (CO), peripheral

resistance (PR) and Blood volume. Thus, after any physical activity the blood volume will change that time blood pressure will change and recovery of BP after some time. Recovery period of BP will vary from subject to subject and it depends on subject's fitness.

C. Measurement parameter:

After the regular three weeks of exercise, the parameter measurement based on HR from ECG and Blood pressure results.

1) Rate Pressure Product (RPP):

RPP is the product of heart rate and systolic blood pressure which is used in the exercise physiology and cardiology to indirectly determine the MVO_2 and also determination of cardiovascular risk to the subjects. It is also known as double product or cardiovascular product. It is an easily measurable index, and it defines the response of the coronary circulation to myocardial metabolic demands. It correlates to the myocardial oxygen consumption, and hence it is used to measure the workload or oxygen demand of the heart [9].

RPP increases with the workload increases on the heart. So, it is to provide the adequate blood supply to the myocardium during the exercise. In healthy people, rate pressure product changes according to the increased blood flow in myocardium and oxygen consumption during exercise. The internal myocardial work performed is represented by RPP and external myocardial work performed is generally expressed as stages of exercise [10]. The low value of RPP indicates the sufficient oxygen consumption by myocardium and decreased left ventricular function.

2) ECG analysis in LabVIEW:

After three weeks of regular exercise, the signal acquired in PC has some noise, hence to eliminate these noises or baseline wandering two steps are performed for the better signal analysis: 1) ECG signal Pre-processing and 2) ECG feature extraction.

A. ECG signal pre-processing:

The recorded ECG signal is contaminated by various noise and artefacts. We need to extract the useful information from the noisy signal, thus we have to processes the ECG signal by using the wavelet transform.

Baseline wandering usually comes from the respiration frequency. So, it can be removed by a wavelet transform. Wavelet transform is used to remove the baseline wandering by eliminating the trend of the ECG signal. Advanced signal processing toolkit in LabVIEW provides the WA Detrend which removes the Low frequency of trend in the signal.

$$\text{Trend Level} = \left[\frac{\log_2 2t}{\log_2 N}\right]$$

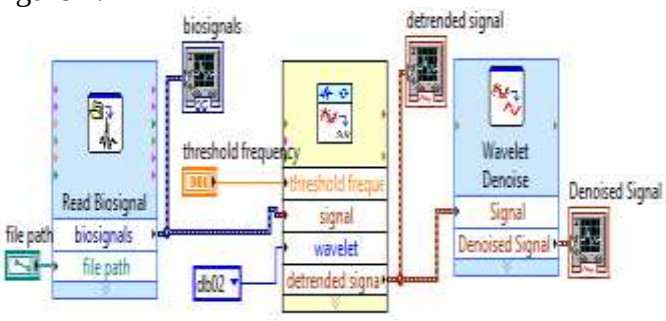
Where, t = Sampling Duration

N = the Number of Sampling Points

The data used here has a sampling duration of 6 sec and 5000 sampling points in total; therefore the trend level is 0.29 according to the above equation. Trend level specifies the number of levels of the wavelet decomposition, which is approximately,

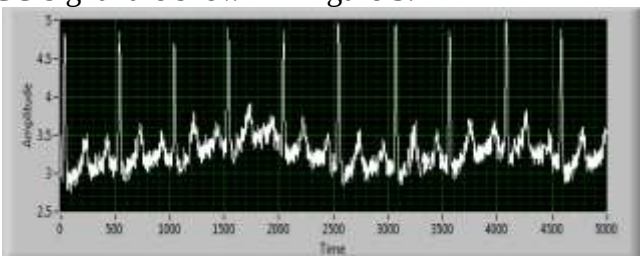
Number of decomposition level= $(1 - \text{trend level}) * \log_2 N$

Here, Daubechies (db02) wavelet is used because this wavelet is similar to the real ECG signal. After removing the baseline wandering the resulting ECG signal is more stationary and explicit than the original signal. However, some other types of noise might still affect feature extraction of ECG signal. Thus, to remove such type of wideband noise by using the wavelet denoise express block in LabVIEW. The VI Block diagram is shown in figure 4.

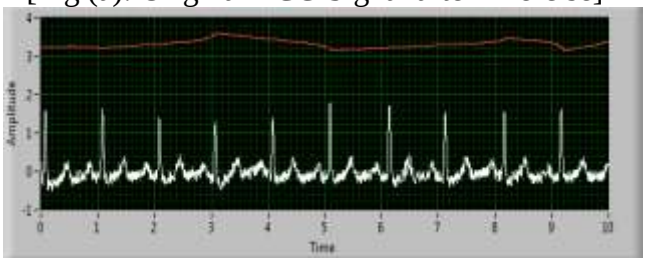


[Figure 4: VI diagram to remove the baseline wandering and Noise]

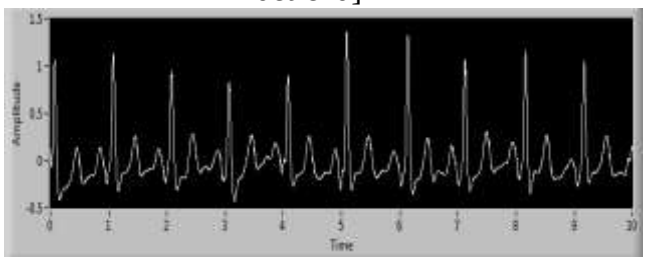
The results of baseline wandering and denoising ECG signal are shown in Figure 5.



[Fig (a): Original ECG Signal after Exercise]



[Fig (b): Baseline wander Removed using WA detrend]

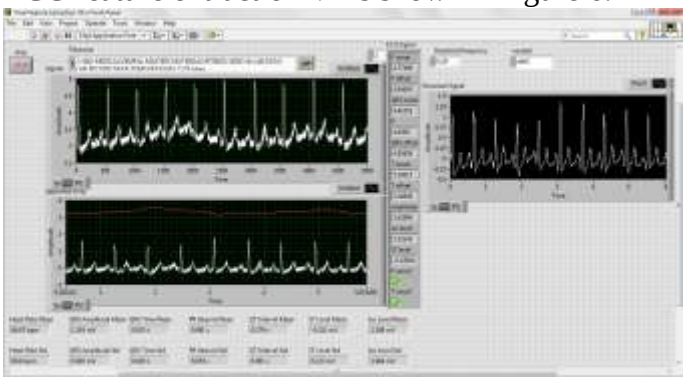


[Fig (c): Denoise Signal using WA Denoise]

[Figure 5: WA of ECG Signal using WA detrend and WA denoise (subject 7)]

B. ECG feature extraction:

The aim of ECG signal analysis is to extract all the primary ECG parameters [8]. The parameter extraction starts with the detection of QRS complex. The main extract are QRS complex, P wave, and T wave amplitude and duration. Multiresolution express in LabVIEW is used for the peak detection. And WA multiscale peak detection is used in peak detecting mode to detect P, R, and T points by specifying proper width and threshold [5]. The QRS detection is achieved by first find out the maximum spatial velocity of an ECG and after that setting a threshold at 40% of the maximum value. If spatial velocity value is greater than threshold value then the R peak detected. Based on R peak finding the RR intervals and calculate the HR in Beats per minute. We have used LabVIEW feature extractor VI of Biomedical toolkit for extracting various parameters. Amplitude features are calculated relative to the amplitude of R peak. Thus, finding out the RQ, SQ, and TQ represent the amplitude difference between R-Q, S-Q and T-Q waves of ECG. Finally, the normalization is an important issue to obtain the consistent features with change in HR [11]. The HR varies cause of change in pressure inside the heart and also the ventricular volume. Change in HR consequently changes the amplitude of Q, S and T wave and also the Intervals of ECG wave. Thus, the amplitude features are normalized by dividing them to the Heart Rate. Therefore, two characteristic parameters RQ/SQ/HR and TQ/RQ/HR were calculated in this paper for the comparison of ECG wave after the three week of experimental period. Front panel of ECG feature extraction VI is shown in figure 6.

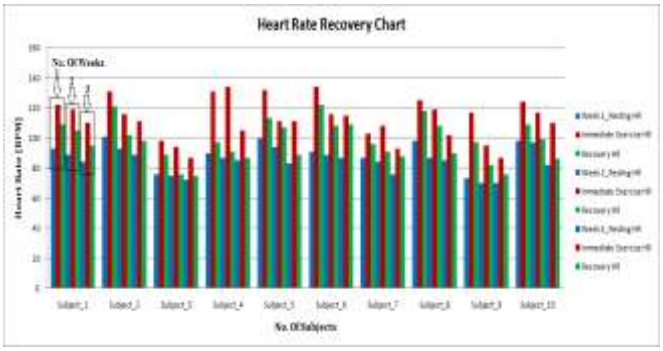


[Figure 6: Front panel of ECG feature extraction (subject 7 in resting state of 1st week result)]

III. RESULTS

A. Heart rate of ECG and RPP

In this paper, heart rate is calculated by the average RR interval, while rate pressure product (RPP) is calculated by the product of HR and SBP. 10 healthy subjects resting condition heart rate is shown in fig 7. It indicates obviously that the HR at rest has become lower after three weeks of regular exercise.



[Figure 7: Changes of HR at rest after three weeks with 10 healthy subjects.]

TABLE 1: Changes of Heart Rate (HR) in Three weeks

No. of Subjects	1st Week			2nd Week			3rd Week		
	Pre Exercise HR	Immediate after Exercise HR	HR after 5min of Recovery	Pre Exercise HR	Immediate after Exercise HR	HR after 5min of Recovery	Pre Exercise HR	Immediate after Exercise HR	HR after 5min of Recovery
Subject 1	93	122	109	89	119	105	84	110	95
Subject 2	101	131	121	93	116	102	89	111	98
Subject 3	76	98	89	75	94	76	72	87	75
Subject 4	90	131	97	87	134	91	85	105	87
Subject 5	100	132	113	94	111	107	83	111	89
Subject 6	91	134	122	89	116	108	87	115	109
Subject 7	87	103	96	84	108	91	76	93	88
Subject 8	98	125	118	87	119	108	85	102	90
Subject 9	73	117	97	70	95	82	70	87	76
Subject 10	98	124	109	97	117	99	82	110	86

TABLE 2: Rate Pressure Product (RPP) changes in three weeks

Subject No.	1st Week			2nd Week			3rd Week		
	Pre	Immediate	Post	Pre	Immediate	Post	Pre	Immediate	Post
Subject 1	11811	16470	12535	10858	15351	11655	9828	13310	10640
Subject 2	12625	18078	14641	11346	16124	11220	11481	14985	10290
Subject 3	10944	14798	11214	8700	14476	9576	8496	12963	9525
Subject 4	11340	18078	12028	10614	17554	10465	10965	13230	10701
Subject 5	12200	18084	13221	11186	13986	12412	9960	13542	10769
Subject 6	11739	19162	16226	11214	15312	13824	11049	14835	13298
Subject 7	10266	12875	10752	9996	13932	10920	8892	11439	10472
Subject 8	11662	16250	14396	10527	15232	12852	9945	12546	10530
Subject 9	8541	14859	11640	8540	12160	10250	8470	10875	9272
Subject 10	12348	16988	14061	12028	15210	12474	9840	13860	10492

All subjects before exercise HR, Immediately after exercise HR and after five minutes of recovery HR were recorded in table 1 in three weeks of experimental period. Recording data shows that the three kinds of HR in 3rd week are smaller than in the 1st week of HR. 100% of subjects HR at rest decreased during the experiment period, while one subject HR stable at resting condition after third week of exercise. The decrement of heart rate between first week and second week is larger than it between second week and third week, which means that the heart rate decreased more sharply in the first half period than in second [1]. Table 2 shows the changes of RPP at resting condition, immediate after exercise and after five minute of recovery condition. The peak RPP is an accurate reflection of the myocardial oxygen demand and workload. The rate pressure product increase during the immediate after exercise which indicates that the very large stress on heart with its regard to oxygen delivery needs. The results of table 2 indicate that the RPP at rest significantly decreased. In after immediate exercise results shows that the RPP has increased greater than 10000 which not indicate the higher risk of cardiac disease but it mainly due to increase in SBP which indicates the increase in myocardial activity.

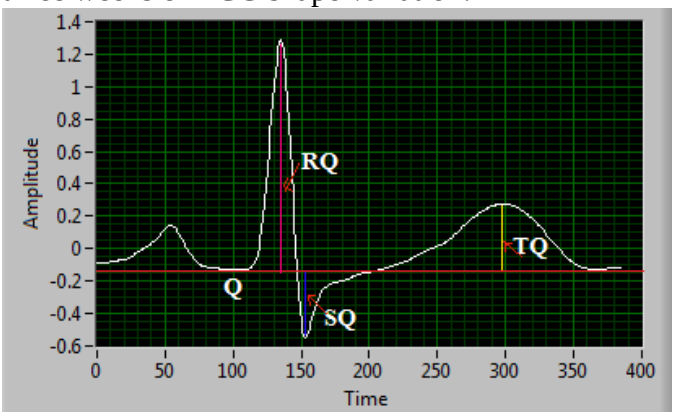
B. ECG Characteristic parameter measurement

In this paper, two characteristic parameters were calculated which denotes the amplitude changes after the regular exercise based on changes of HR shown in table 3.

TABLE 3: Characteristic parameter of all subjects in three weeks

Subject No.	Parameter	1st Week			2nd Week			3rd Week		
		Pre Exercise	Immediate after Exercise	After 5 min of Recovery	Pre Exercise	Immediate after Exercise	After 5 min of Recovery	Pre Exercise	Immediate after Exercise	After 5 min of Recovery
1	RQ/SQ/HR	0.1071	0.0477	0.0630	0.0991	0.0455	0.0704	0.0956	0.0426	0.0928
	TQ/RQ/HR	0.00418	0.00299	0.00344	0.00367	0.00333	0.00340	0.00329	0.00351	0.00385
2	RQ/SQ/HR	0.1126	0.0978	0.1034	0.1091	0.0750	0.0945	0.1075	0.0642	0.0869
	TQ/RQ/HR	0.00732	0.00530	0.00590	0.00633	0.00547	0.00567	0.00596	0.00560	0.00566
3	RQ/SQ/HR	0.2621	0.2286	0.2142	0.2417	0.1999	0.2006	0.2286	0.1973	0.1755
	TQ/RQ/HR	0.00561	0.00431	0.00473	0.00502	0.00408	0.00476	0.00446	0.00309	0.00383
4	RQ/SQ/HR	0.1201	0.4236	0.1422	0.1174	0.3117	0.2855	0.1058	0.2688	0.3806
	TQ/RQ/HR	0.00735	0.00520	0.00701	0.00627	0.00493	0.00642	0.00551	0.00483	0.00560
5	RQ/SQ/HR	0.1447	0.1076	0.1124	0.1435	0.1042	0.1318	0.1425	0.1041	0.1601
	TQ/RQ/HR	0.00516	0.00375	0.00459	0.00487	0.00449	0.00451	0.00545	0.00471	0.00490
6	RQ/SQ/HR	0.1389	0.0699	0.1168	0.1353	0.0714	0.0937	0.1059	0.0736	0.0898
	TQ/RQ/HR	0.00345	0.00241	0.00235	0.00286	0.00172	0.00220	0.00165	0.00119	0.00123
7	RQ/SQ/HR	0.0345	0.0244	0.0271	0.0406	0.0266	0.0287	0.0574	0.0340	0.0387
	TQ/RQ/HR	0.00371	0.00299	0.00378	0.00347	0.00313	0.00374	0.00316	0.00340	0.00342
8	RQ/SQ/HR	0.0676	0.0509	0.0524	0.0861	0.0682	0.0689	0.0903	0.0854	0.0868
	TQ/RQ/HR	0.00454	0.00445	0.00402	0.00442	0.00330	0.00351	0.00428	0.00351	0.00392
9	RQ/SQ/HR	0.1027	0.0645	0.0837	0.0876	0.0639	0.0815	0.0760	0.0634	0.0757
	TQ/RQ/HR	0.00647	0.00329	0.00441	0.00563	0.00374	0.00464	0.00506	0.00391	0.00418
10	RQ/SQ/HR	0.0643	0.0485	0.0686	0.0577	0.0478	0.0507	0.0508	0.0362	0.0431
	TQ/RQ/HR	0.00503	0.00381	0.00472	0.00411	0.00343	0.00409	0.00378	0.00280	0.00361

Feature extraction is concerned to the detection of differences in voltages in the myocardial cells that occur during depolarization and repolarization [11]. RQ, SQ, and TQ are the amplitude difference between R and Q wave, S and Q wave and T and Q wave respectively shown in fig 8. These all are the raw features of ECG. Changes of heart rate during the three weeks of exercise, so normalization is required. Thus, we have to calculate the RQ/SQ/HR and TQ/RQ/HR features for the measurement of three weeks of ECG shape variation.



[Figure 8: RQ, SQ and TQ of ECG wave]

After three weeks of exercise, not only the ECG shape variation but it also the interval and amplitude of ECG also reduced. Table 3 shows the variance of RQ/SQ/HR and TQ/RQ/HR of a subject in three weeks, it indicates 100% of variance have downward trend in three weeks. Thus, the results showed that the variability of ECG waves has significant reduced during the exercise period.

Table 3 shows that the 80% of RQ/SQ/HR and 90% of TQ/RQ/HR before exercise decreased during the experiment period. It means that in most of subjects, S-wave increased relative amplitude to R-wave, and T-wave decreased relative amplitude to R-wave at the same time [1]. On the other hand, 70% of RQ/SQ/HR decreased and 50% of TQ/RQ/HR increased immediately after exercise. It indicates that in post-exercise S-wave increased relative amplitude to R-wave, and T-wave also increased relative amplitude to R-wave at the same time [1]. Thus, the changes of ECG waveforms in recovery period became smaller during the experiment period. As well as amplitude of R wave increased at resting state shown in table 4.

TABLE 4: Amplitude of R wave Increased at resting state after three weeks of experimental period

Subject No.	1st Week			2nd Week			3rd Week		
	Pre	Immediate	Post	Pre	Immediate	Post	Pre	Immediate	Post
Subject 1	0.859639	0.834038	0.849083	0.923465	0.860929	0.89571	0.995519	0.923465	0.993228
Subject 2	1.19817	1.09571	1.12159	1.344	1.22577	1.33443	1.37462	1.34062	1.35057
Subject 3	1.49768	1.37415	1.43738	1.52577	1.45402	1.5141	1.5628	1.5387	1.56003
Subject 4	0.850543	0.767231	0.824052	0.986284	0.844055	0.940168	1.07071	0.960929	1.07001
Subject 5	1.43819	1.19317	1.25625	1.56298	1.27092	1.37795	1.56678	1.54922	1.56386
Subject 6	1.45161	1.2661	1.39126	1.54668	1.38347	1.47516	1.87556	1.68029	1.860929
Subject 7	1.24541	0.93427	0.99095	1.28907	0.98425	1.00195	1.50141	1.05427	1.15387
Subject 8	1.38734	1.00724	1.24253	1.5278	1.38576	1.52004	1.57198	1.54851	1.571002
Subject 9	0.735962	0.698007	0.72731	0.748772	0.705826	0.730779	0.833379	0.82427	0.83285
Subject 10	0.892952	0.790648	0.86299	0.934274	0.855184	0.922089	1.0211	0.935313	0.993531

IV. DISCUSSIONS AND CONCLUSIONS

The results of this study confirm and extend the past observations of the changes of ECG behavior and RPP data before and after exercise in normal healthy subjects. Heart rate, Rate pressure product, RQ/SQ/HR, TQ/RQ/HR, and R peak amplitude noticeable changes which indicate that the ECG waveform changes after regular exercise.

Heart rate of each subject at rest has significant difference between 1st week and last week of exercise, which means that the heart rate decreased obviously. Heart rate is one of the most important physical signs in the cardiovascular disease prevention [1], it reflects the cardiac reserve, and HR at rest is a most important parameter related to the subject's health condition.

In the previous study, ECG waves (Q-, R-, S-, and T-) are most important indicator for exercise studies [4]. Thus, we have to calculate two characteristic parameters, RQ/SQ/HR and TQ/RQ/HR, to characterize the changes of ECG waves and in this heart rate are dividing for the normalization purpose. Systolic Blood pressure is also a common index to monitoring the vascular condition during the experiment period.

Heart rate and systolic blood pressure are the most important variables for determining the changes in myocardial oxygen consumption between the resting state and exercise period. HR, SBP and RPP increase with increases the workload on the heart which has to provide the adequate blood supply to the myocardium during exercise. The increased RPP during exercise shows that individual not only has an increased risk of heart disease but also has a very large stress on the heart with regard to the oxygen delivery needs [9]. In healthy people, RPP decreased at rest after the regular exercise which indicates that the sufficient oxygen provides to the myocardium. RPP changes according to the increased myocardial blood flow and oxygen consumption during exercise. Thus, the RPP changes to exercise which is an indirect measure and good indicator of MVO_2 could be used for the early detection of cardiac dysfunction [9].

Therefore, after running 12-minutes, the T- and S-wave increased and the R-wave decreased after the immediate exercise, which had proved that the T-wave shape changes with the Heart rate [1].

Thus, the final results showed that the 100% of subject's HR at rest condition has continuously decreased and 100% of R peak amplitude at rest increased during the three weeks of experiment. Moreover, 80% of RQ/SQ/HR and 90% of TQ/RQ/HR at rest decreased during the experiment duration; while, 70% of RQ/SQ/HR decreased, 50% of TQ/RQ/HR increased immediately after exercise and also 100% of RPP at rest decreased which indicating increased MVO_2 at rest. Thus, the HR, RPP, characteristic parameters and R-peak has noticeable changes at resting condition during the experimental period. According to the Brody effect, amount of blood is increased in the left ventricle which amplifies the transmural activation front and resulting from the high voltage QRS complex. Thus,

the amplitude of R-wave has positive correlation with the LV volume.

As results shows that the amplitude of R-wave at rest increased, will most likely is caused by the left ventricular volume increased with the heart function enhanced [1]. According to the variation of this parameter, the 12-minute running has improved the cardiac function.

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