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Research Article

Experimental Evaluation of Cardiovascular Fitness Using Cardiopulmonary Exercise Testing

[1*]Dimpal Khambhati, [2]Dr. Chirag Patel, [3] Dr. Khemraj Deshmukh
[1]Department of Biomedical Engineering, Parul University
[2]Department of Computer Engineering, Charotar University of Science and Technology
[3]Department of Biomedical Engineering, Parul University

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ABSTRACT

Assessing the effects of unhealthy lifestyles, especially those resulting from insufficient physical activity (Sedentary life style), is essential for comprehending their role in chronic disease development and the degradation of overall health. These evaluations facilitate the formulation of strategies aimed at enhancing physical activity levels and optimizing public health results. Cardiopulmonary exercise testing (CPET) was emerging analytical tool for evaluating exercise capacity and forecasting outcomes in patients with heart failure and various cardiac conditions. In the present study the physiological parameter, including heart rate (HR), blood pressure (BP), and rate pressure product (RPP), had been evaluated to observe the R peak wave of the human body. All this parameter had been measured from the 10-subject (4 Male, 6 Female) having an age of in between 20 to 30 and it were analyzed by the signal processing tool in LabVIEW. The entire study was performed for five weeks and above parameters were observed every one-week interval at three different conditions: pre-exercise, immediate after exercise (12-minute running) and after 5 min recovery of exercise. The result indicated that all the measured parameters of all 10 subjects (at rest condition) was gradually decreases after they are involved in the regular exercise. The measurement of R peak indicate that the overall improvement occurred in all subject after five weeks. Cardiopulmonary exercise enhances cardiovascular fitness by improving myocardial oxygen supply and efficiency causes improved R-wave amplitude on the ECG waveform. The 12-minute exercise routine illustrates an enhancement in cardiac function, leading to an amplification of the sinus venosus and a reduction in heart rate, thereby improving the overall functionality of the heart..

Keywords: ECG, Cardiopulmonary exercise testing (CPET), Physiological parameter, Sedentary life style.

INTRODUCTION

A sedentary lifestyle, that includes extended durations of physical inactivity, presents significant risks to cardiovascular health. In Indian prospective, it had been reported (**Rastogi et al. 2024**) that the cardiovascular disease represents more than 25% of fatalities associated with non-communicable diseases, exhibiting mortality rates between 248.6 and 350.9 per 100,000 individuals. Sedentary behaviours, along with inadequate dietary practices and insufficient physical activity, play a crucial role in exacerbating this issue. In the context of worldwide, more than 17.9 million fatalities each year are associated with cardiovascular disease, with inactive lifestyles correlated to heightened risks of obesity, hypertension, and diabetes—fundamental contributors to heart disease (**Luo et al. 2024**). A report from the World Economic Forum and Harvard School of Public Health in 2014 estimates that the economic losses India could incur due to cardiovascular disease between 2012 and 2030 will be around $2.17 trillion (**Kalra et al. 2024**). The global economic burden of cardiovascular disease surpasses billions each year, including healthcare costs and diminished productivity in the workforce. Insufficient physical activity reduces the strength of the cardiac muscle, impairs the efficiency of blood circulation (**Park et al. 2020**), and enhance the risk of conditions such as hypertension (**Valenzuela et al. 2021**) and heart disease (**Benalikhoudja et al. 2023**). From the literature it had been observed that sedentary lifestyle facilitates weight accumulation, enhances insulin resistance, and triggers inflammation, all of which adversely affect cardiac function. It had been observed that (**Verdú, E., Homs et al. 2021**) physical exercise has the potential to reverse certain obesity-related pathologies by influencing the interactions between adipose tissue and various body systems. The author (**Andersen et al. 20211**) demonstrate that the advantages of enhancing physical activity and refining diet on cardiometabolic risk predominantly operate through their influence on alterations in body weight. Over time, these effects may result in significant cardiovascular complications, such as heart failure. Promoting consistent physical activity is crucial, as it enhances cardiovascular function, optimizes circulation, and mitigates the risk of various diseases.

CPET provides a crucial diagnostic and prognostic instrument for evaluating cardiac function by measuring the intricate interactions among the cardiovascular, pulmonary, and muscular systems during exertion. This analysis includes essential metrics such as peak oxygen uptake (VO_2 peak), anaerobic threshold, and oxygen pulse, which indicate cardiac

output, myocardial efficiency, and circulatory reserve. These parameters assist in the identification of cardiac limitations, risk stratification, and the assessment of the severity of conditions like heart failure or ischemic heart disease. CPET's precision is essential for customizing interventions and progressing research in cardiac physiology. Author had (**Glaab et al. 2022**) provide the complete protocol for conducting the cardiovascular experiment via a CPET. The observation found by the **Weber et al. 1985** that respiratory gases during physical activity called CAR-PET (cardiopulmonary exercise testing) to evaluate cardiac and pulmonary function in individuals with cardiovascular or pulmonary conditions, or both. The author (**Boutou et al 2020**) reported that the CPET can be used to determine the main factors that limit exercise in COPD patients with multiple comorbidities, assess the severity of dynamic hyperinflation, provide prognostic information, and evaluate the response to several therapeutic interventions.
CPET examines exercise capacity through the analysis of combined cardiovascular, respiratory, and muscular responses. This approach distinguishes between cardiac and non-cardiac limitations by analyzing parameters such as blood pressure, Herat rate, oxygen uptake (VO_2), heart rate kinetics, and ventilatory efficiency (VE/VCO_2 slope). Cardiac limitations typically manifest as decreased peak VO_2 and oxygen pulse, whereas non-cardiac factors, including pulmonary or muscular dysfunction, exhibit irregular ventilatory patterns or premature fatigue without notable cardiovascular compromise. It had been reported (**Mattavelli et al. 2023**) that the conventional CPET lacks the ability to differentiate among these various impairments, necessitating the development of advanced CPET technologies. In the realm of non-invasive techniques for assessing cardiac output during CPET, inert gas rebreathing and thoracic impedance cardiography stand out as the predominant methods. Both have been validated in healthy individuals as well as in patients with heart failure, applicable at rest and during physical exertion. The non-invasive evaluation of peripheral muscle perfusion can be achieved through the use of near-infrared spectroscopy, which measures tissue oxygenation effectively. The author (**Chwiedź et al. 2023, Juarez et al. 2024**) had been summarized the application of IGR for a non-invasive evaluation of cardiac output during cardiopulmonary exercise testing. Based on the extracted data, a proposed CPET report is identified that incorporates an assessment of cardiac output utilizing the IGR method.

Cardiopulmonary exercise testing (CPET) determines the synchronized reactions of the cardiovascular, pulmonary, and musculoskeletal systems in the context of physical exertion. Essential physiological outcomes utilized as indicators encompass oxygen uptake (VO_2), which signifies aerobic capacity and is vital for evaluating functional fitness and cardiorespiratory health. Author (**Agostoni et al. 2019, Sietsema et al. 2023**) reported that the CPET is performed in individuals without diagnosed conditions as a component of the diagnostic assessment for unexplained symptoms. The production of carbon dioxide (VCO_2) offers valuable information regarding metabolic processes and the equilibrium between aerobic and anaerobic metabolism. The author (**Dorelli et a. 2021**) concluded that the exercise minute ventilation (VE) in relation to carbon dioxide output (VCO_2) (VE/VCO_2) provides additional insights into ventilatory limitations and control mechanisms. The normal range for the VE/VCO_2 slope is reported to be between approximately 21 and 31. Elevated values of VE/VCO_2 slope indicate a lack of efficiency in ventilatory response during exercise (EVin). Minute ventilation (VE) quantifies the air volume inhaled and exhaled in one minute, serving as an indicator of pulmonary capacity and ventilatory efficiency (**Petek et al. 2023**). Metrics like the ventilatory threshold (VT) and the respiratory exchange ratio (RER) constitute the shift between aerobic and anaerobic energy systems as well as substrate utilization (**Zignoli et al. 2022**). Heart rate (HR) and oxygen pulse (VO_2/HR) are useful data for evaluating cardiovascular response and stroke volume during physical activity. The findings of this study conducted by **Krejčí et al. 2018** indicated that the reduction in ΔSpO_2 reached statistical significance ($P<0{\cdot}001$) within the first minute of hypoxia, while the decline in ΔLn RMSSD became significant ($P = 0{\cdot}002$) during the second minute, and the decrease in ΔLn SDNN was significant ($P = 0{\cdot}001$) by the third minute. The Author (**Claessen et al. 2019**) Early reductions in ventricular filling and stroke volume lead to a plateau in cardiac output, beyond which any further increases in heart rate would not be physiologically feasible. Furthermore, end-tidal partial pressures of oxygen ($PETO_2$) and carbon dioxide ($PETCO_2$) provide insights into the efficiency of gas exchange. The combination of these metrics is essential for diagnosing exercise intolerance, directing rehabilitation efforts, and assessing the physiological effects of disease. It had been observed (**Kojima et al. 2021**) that reduction of O_2Hb just prior to peak exercise in incremental exercise could be associated with an increase in cerebral oxygen metabolism due to heightened neural activity, rather than a decrease in cerebral blood flow influenced by $PETCO_2$ levels.

Heart rate (HR), blood pressure (BP), and rate pressure product (RPP) are critical parameters to evaluate during CPET to analyze cardiac function and overall cardiovascular status. These indicators offer critical data regarding the heart's reaction to physical stressors. Heart rate functions as a key measurements for assessing cardiovascular response during

Cardiopulmonary Exercise Testing (CPET). The autonomic modulation of the heart is reflected, with primary influence from sympathetic and parasympathetic inputs. During graded exercise, heart rate escalates in direct correlation with the workload to satisfy increasing oxygen requirements. Monitoring HR utilizes electrocardiography (ECG), employing real-time R-wave detection to compute beats per minute. A failure to reach the expected maximum heart rate, known as chronotropic incompetence, or an irregular recovery heart rate may suggest underlying cardiac dysfunction or an imbalance in autonomic regulation. HR trends offer essential data regarding exercise tolerance and cardiac reserve (**Corra et al. 2018, Rissanen et al. 2022**). Evaluating blood pressure during cardiopulmonary exercise testing is crucial for analyzing vascular and myocardial responses under stress conditions. Systolic blood pressure (SBP) generally rises with the intensity of exercise as a result of increased cardiac output, whereas diastolic blood pressure (DBP) tends to remain constant or decline due to vasodilation occurring in the muscles that are engaged in activity. Automated sphygmomanometers and intra-exercise auscultation are employed as non-invasive methods for measuring blood pressure. Unusual blood pressure responses, including pronounced hypertensive or hypotensive patterns, could indicate left ventricular dysfunction, arterial stiffness, or coronary artery disease (**Costache et al. 2022, Li et al. 2022, Badagliacca et al. 2019**). The rate pressure product, determined by multiplying heart rate by systolic blood pressure, serves as an indirect indicator of myocardial oxygen demand and cardiac workload. During CPET, RPP indicates the equilibrium between oxygen supply and demand in the myocardium, with elevated values signifying heightened cardiac strain. RPP is assessed through indirect monitoring of heart rate (via ECG) and systolic blood pressure (via BP measurement). Abnormal elevations or reductions in RPP during physical activity could indicate ischemic heart disease or compromised coronary perfusion. This offers a comprehensive assessment of cardiac function, essential for analyzing ischemic thresholds and exercise capabilities (**Senefeld et al.2020, Murthy et al. 20218, Horton et al. 2019**).

The combination of heart rate (HR), blood pressure (BP), and rate-pressure product (RPP) metrics is crucial in developing personalized rehabilitation or treatment strategies for patients with cardiac issues. There is different literature were available which clinically proven that individual HR, BP and RPP are plays curial role to validate the result. Apart from this very limited experimental result was available that uses these three parameters in combinational form to Excess the risk assessment of cardiovascular diseases using CPET to validate the result.

In the present study the physiological parameter, including heart rate (HR), blood pressure (BP), and rate pressure product (RPP), had been evaluated to observe the R peak wave of the human body. All this parameter had been measured from the 10-subject (4 Male, 6 Female) having an age of in between 20 to 30 and it were analyzed by the signal processing tool in LabVIEW. The entire study was performed for five weeks and above parameters were observed every one-week interval at three different conditions: pre-exercise, immediate after exercise (12-minute running) and after 5 min recovery of exercise.

METHODOLOGY

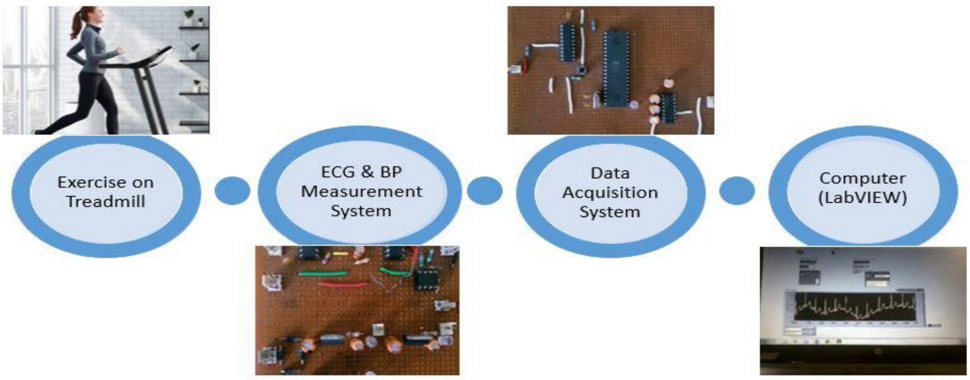

Figure 1:Schematic diagram of the experimental setup

In the present study the exercise were caried out on the treadmill (Allengers Gemini A-DX) with 0.8 to 16 km/h speed and 30^{0} inclination for 15 minutes. Figure 1 shows a schematic diagram of the experimental setup.
All the physiological parameter, including heart rate (HR), blood pressure (BP), and rate pressure product (RPP), had been evaluated to observe the R peak wave of the human body. All this parameter had been measured from the 10-subject and it were analyzed by the signal processing tool in LabVIEW 13.0 followed by the data acquisition system. The entire

study was performed for five weeks and above parameters were observed every one-week interval at three different conditions: pre-exercise, immediate after exercise (12-minute running) and after 5 min recovery of exercise.

I. Subject/Participants

In the present study all parameters had been measured from the 10-subject (4 Male, 6 Female) having an age of in between 20 to 30. The consent had been taken from all subjects before the experiments. The physical and hemodynamic characteristics of all subjects had been listed in table 1.

Table 1 Physical and Haemodynamic Characteristics of the Participants

Variables	**Mean ± SD**
No of Subjects	10
Gender (M/F)	4M, 6F
Age (years)	25 ± 3.12
Weight (Kg)	61.47 ± 4.73
Height (cm)	161.4 ± 4.93
BMI (kg/m2)	23.62 ± 1.91
SBP (mmHg)	125.3 ± 7.75
HR (BPM)	90.7 ± 9.71
RPP	11347.6 ± 1203.50

II. ECG & BP Measurement System

The ECG of all subjects had been carried out using inhouse fabricated ECG Hardware. The electrodes were placed on the right hand, Left hand and right leg as per the LEAD-I Configuration (**Rahman, M.A. et al., 2024**). In the present study all the electrodes had been placed on the subject (Figure 2) in a such way that to maintain the impedance between skin and electrode was less than 5 ohms. The ECG signal received from the different electrode had been passed to the passive band pass filter having a frequency range 0.5 to 3 Hz after that it amplified by the low noise amplifier having a gain 13 which was the part of signal conditioning circuit. The last component of ECG measurement system was summing amplifier, employed for the signal summation within the 0 to 5-volt range. The output of the ECG measuring system had been transferred to the data acquisition system. Data acquisition system comprises the different components such as analog to digital (A to D) converter, microcontroller, where the data can be processed and transferred from RS232 to USB converter for acquiring and recoding of real-time ECG signal and analyzed by NI-LabVIEW software as shown in figure 3. In the software the ECG signals had been denoise using the second ordered Daubechies (db02) wavelet filter. Daubechies wavelet with order N in the resolution space j, the supports for φ_N (x) was expressed by equation 1

$$Supp\ \varphi_N = [0, 2N - 1] \quad (1)$$

Figure 2:(a) Real time images of Data Recording system, (b) Signal conditioning circuit, (c) data acquisition system, (e) ECG signal

The obtained ECG signal from the subject had noise frequency, hence to eliminate these frequencies, two steps had been performed for the better and accurate signal: 1) ECG signal Pre-processing and 2) ECG feature extraction. Daubechies (db02) wavelet is used for pre-processing of ECG Signal. The db02 wavelet is similar to the real time ECG signal and it is used to remove the baseline wandering from the ECG Signal. After removing above artefacts, the resulting signal is more stationary and explicit than the original ECG signal. However, wavelet block is used to remove the wideband noises in

LabVIEW. The VI Block diagram is shown in Figure 3. In the present study 0.0009 Optimized value was used as threshold frequency for wavelet filter.

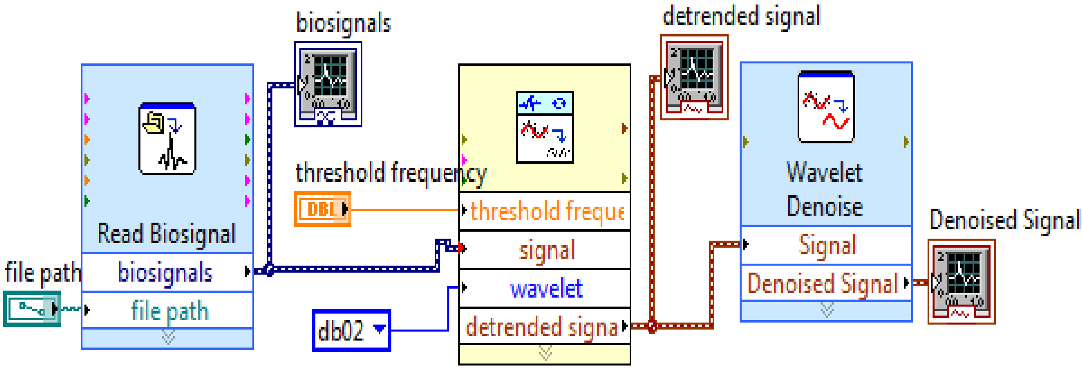

Figure 3: VI used for the measurement of ECG signal in LabVIEW obtained from the subject after Exercise

All ECG feature extraction such as R wave location, R wave amplitude, isoelectric level, QRS wave on-set, QRS wave off-set, P wave on-set, P wave off-set, T wave on-set, and T wave off-set had been carried out in LabVIEW plays a critical role to calculate the HR.

Blood pressure (BP) measurement is taken into consideration a great index of the reputation of the cardiovascular system. In the present study the non-invasive BP measurement had been carried out using the digital BP machine (model no:). The accuracy of this BP machine was with an error of ±2 mm of Hg.

III. Measurement of Rate Pressure Product (RPP)

Rate pressure product (RPP) is a critical component for calculating the cardiac oxygen consumption. RPP had been influenced by the exercise and it was an essential parameter for estimating the ventricular function. Heart rate (HR) and systolic blood pressure (SBP) are the two parameters that are utilized for the measurement of the rate pressure product (RPP), which had been used to measure of myocardial oxygen demand. The RPP was product of heart rate (HR) in bpm that was received from ECG and the systolic blood pressure (SBP) in mmHg that was obtained from the BP machine in section II of methodology. During the measurements, the patient should hold a seated or supine position while maintaining a relaxed state. This will help to assure consistency and limit physiological variability. After the HR and SBP have been recorded, the RPP is calculated by multiplying these two parameters. The RPP was expressed in terms of mmHg-bpm, constitutes an indicator of the workload that the heart is experiencing.

RESULT

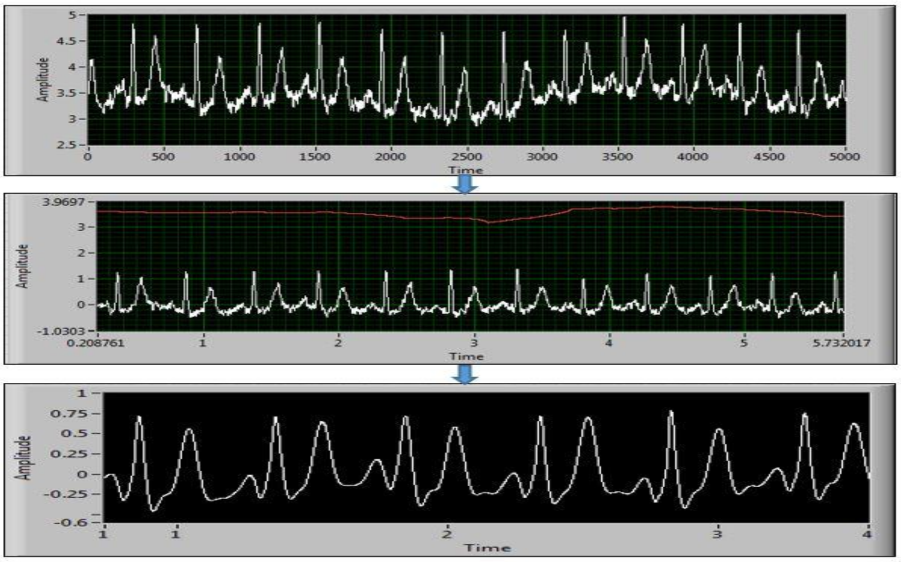

Figure 4:Result of Denoising and Detrending from original signal in LabVIEW

Figure 4 shows the result of result of Denoising and Detrending signal in LabVIEW. Figure 4a shows the noise included actual ECG signal that are obtained from the subject. Figure 4b shows that the that the db02 wavelet filter are effectively remove the baseline noise from the original signal. Figure 4c shows that the outcome is a refined signal featuring distinct high-frequency elements such as the P, QRS, and T waves, which improves the precision of analysis for arrhythmias or other cardiac irregularities.

Extracting features from ECG signals as shown in figure 5, such as the QRS complex, P wave, T wave, PR interval, ST segment, and QT interval, yields essential information for determining heart rate and diagnosing cardiac conditions. The QRS complex plays a vital role in recognizing ventricular depolarization and calculating heart rate, whereas the P wave and PR interval indicate atrial depolarization and conduction pathways. The QT interval quantifies the duration of ventricular activity, while the ST segment is utilized to evaluate ischemic changes. The integration of these features facilitates precise rhythm analysis and the identification of abnormalities.

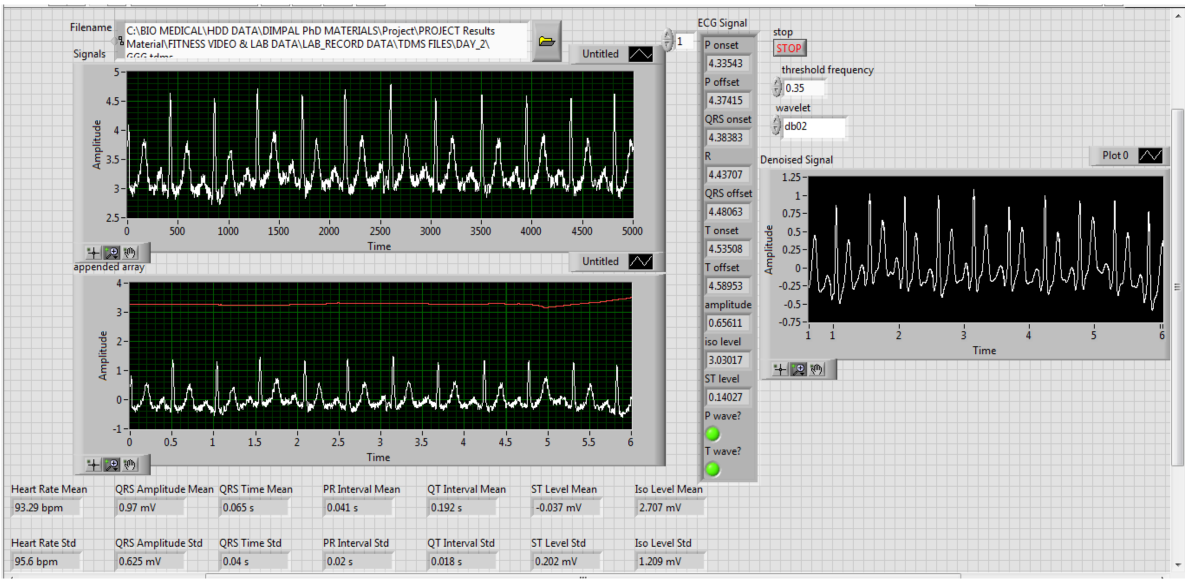

Figure 5: Schematic of extracted features and there value using LabVIEW

Figure 6 shows that the result of HR of all 10 subject in the pre-exercise condition at resting state. For individual subject, it had been observed that the minimum HR was recorded at pre-exercise condition and maximum HR was recorded after the exercise and comparative lower HR was observed after 5 min recovery. It was also observed that after five weeks of consistent exercise, the HR at rest has lowered from the previous weeks for all the subject. The statics and graph of HR was shown in figure 6 and table respectively.

Figure 6:Graphical representation of 5 weeks HR value of all 10 subject at different conditions

Table 2: Statistics of 5 weeks HR value of all 10 subject at different conditions

Subject No.	Variables	1st Week			2nd Week			3rd Week			4th Week			5th 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	Pre Exercise	Immediate after Exercise	After 5 min of Recovery	Pre Exercise	Immediate after Exercise	After 5 min of Recovery
1	HR	93	122	109	89	119	105	84	110	95	84	108	95	83	108	95
2	HR	101	131	121	93	116	102	89	111	98	90	109	98	90	108	98
3	HR	76	98	89	75	94	76	72	87	75	72	86	76	72	85	74
4	HR	90	131	97	87	134	91	85	105	87	85	101	87	84	101	87
5	HR	100	132	113	94	111	107	83	111	89	80	109	87	78	109	86
6	HR	91	134	122	89	116	108	87	115	109	85	115	104	85	114	102
7	HR	87	103	96	84	108	91	76	93	88	74	93	82	74	92	82
8	HR	98	125	118	87	119	108	85	102	90	84	98	90	83	97	90
9	HR	73	117	97	70	95	82	70	87	76	70	85	76	70	84	74
10	HR	98	124	109	97	117	99	82	110	86	78	93	87	78	90	85

The variations in rate pressure product value during pre-exercise condition (at resting conditions) and after five minutes of recovery conditions was shown in Table 3. The oxygen requirement of the myocardium and workload are accurately represented in the form of peak RPP. The RPP rises right after exercise, suggesting that the heart muscles are under a great deal of stress in terms of their demand for oxygen supply. The results of table 2 suggest that the RPP was significantly reduced during a state of relaxation. Results obtained immediately following exercise reveal that the RPP has increased by greater than 10,000, which no longer predicts a higher risk of cardiac problem. This is most likely due to an increase in SBP, which demonstrates an improvement in the myocardial activities.

TABLE 3: Statistics of 5 weeks RPP for all 10 Subjects

Subject No.	Variables	1st Week			2nd Week			3rd Week			4th Week			5th 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	Pre Exercise	Immediate after Exercise	After 5 min of Recovery	Pre Exercise	Immediate after Exercise	After 5 min of Recovery
1	RPP	11811	16470	12535	10858	15351	11655	9828	13310	10640	9912	13176	11400	9794	13068	11400
2	RPP	12625	18078	14641	11346	16124	11220	11481	14985	10290	10980	13843	12250	10890	13716	12054
3	RPP	10944	14798	11214	8700	14476	9576	8496	12963	9525	8496	10836	9196	8568	10710	8880
4	RPP	11340	18078	12028	10614	17554	10465	10965	13230	10701	10370	12726	10788	10164	12625	10614
5	RPP	12200	18084	13221	11186	13986	12412	9960	13542	10769	9600	13407	10440	9360	13298	10320
6	RPP	11739	19162	16226	11214	15312	13824	11049	14835	13298	10370	14720	13000	10370	14478	12546
7	RPP	10266	12875	10752	9996	13932	10920	8892	11439	10472	8658	11346	9922	8658	11132	9840
8	RPP	11662	16250	14396	10527	15232	12852	9945	12546	10530	9912	12054	10800	9794	11834	10710
9	RPP	8541	14859	11640	8540	12160	10250	8470	10875	9272	8470	10540	9348	8400	10416	9102
10	RPP	12348	16988	14061	12028	15210	12474	9840	13860	10492	9360	11625	10701	9360	11160	10370

The R-Peak improvement chart was derived from data collected from 10 subjects after a 5-minute recovery period post-exercise. The data indicates a consistent rise in R-Peak amplitude throughout a standard 5-week exercise program. As the weeks progressed, a steady increase in R-Peak values was noted, signifying enhanced cardiac electrical activity. This enhancement indicates improved myocardial health and an increase in overall cardiac efficiency, as a higher R-Peak is associated with more robust ventricular depolarization. The R-Peak amplitude of ECG Wave increased during resting condition was shown in Figure 7.

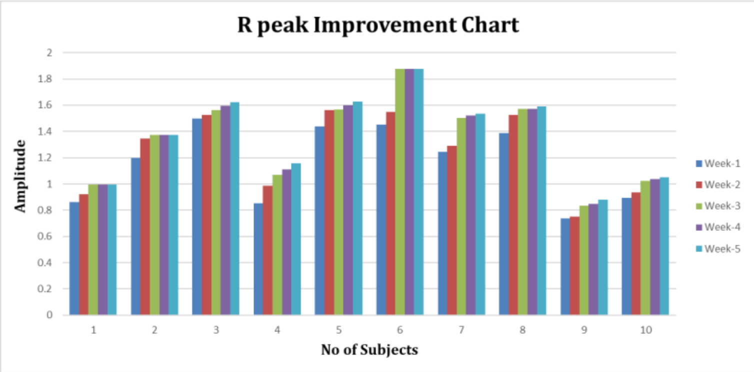

Figure 7: R-Peak Improvement Chart of 10 healthy people.

DISCUSSION

The Daubechies wavelet (db02) is especially effective for noise reduction in ECG signals, owing to its compact support, smooth characteristics, and proficient time-frequency localization capabilities. ECG signals consist of low-frequency components (**Xue et al. 2021**) that correspond to heart rhythms, layered with higher-frequency noise and artifacts, including powerline interference or muscle activity. The db02 wavelet achieves an effective equilibrium between temporal and spectral resolution (**Brahim et al. 2021**), facilitating accurate segmentation of the signal into various frequency bands. The orthogonality guarantees energy conservation throughout the wavelet transformation process, thereby reducing signal distortion. Moreover, the streamlined design of the db02 wavelet is in close correspondence with the morphological characteristics of ECG signals, including the P, QRS, and T waves, which enhances its efficacy in isolating signal components and minimizing noise interference (**Belkadi et al. 2021, Rahman et al. 2024**).

The reduction or stabilization of heart rate after one minute of recovery post-exercise (refer table no 2 and figure no 6), noted after at least five weeks of regular training was responsible for enhanced cardiovascular efficiency and autonomic control. It had been (**Sjúrðarson et al. 2022, Wang et al. 2023**) observed that consistent physical activity improves stroke volume, which refers to the volume of blood ejected with each heartbeat, as a result of myocardial hypertrophy. This adaptation leads to a decreased heart rate while sustaining adequate cardiac output. Furthermore, it had (**Freire et al. 2022**) also found that physical activity enhances parasympathetic function and diminishes sympathetic influence during the recovery phase, facilitating a quicker reduction in heart rate. This adaptation demonstrates enhanced oxygen utilization and metabolic efficiency in trained muscles, leading to a decreased requirement for sustained elevated cardiac output following exercise.

The rate-pressure product (RPP) is determined by multiplying heart rate (HR) by systolic blood pressure (SBP), serving as an indirect indicator of myocardial oxygen demand and cardiac workload. The statement indicates the energy demands of cardiac tissue, especially during times of heightened physical exertion or stress. It had been (**Neto et al. 2022**) observed that an increased systolic blood pressure results in a rise in RPP, signifying enhanced cardiac workload. From table 3, it had been (**Mishra et al. 2024**) observed that decreased in RPP following five weeks of consistent exercise during the recovery phase indicates enhanced cardiovascular efficiency and better autonomic regulation. A deep exercise leads to physiological changes including increased parasympathetic tone, decreased sympathetic activity, and enhanced vascular compliance. The adaptations result in a reduction of resting and submaximal heart rates, attributed to a more efficient stroke volume. Additionally, systolic blood pressure during recovery is lowered as a consequence of enhanced vascular function and decreased peripheral resistance (**Tomlinson, S. and Naemi, R., 2024**). Furthermore, the heart's capacity for rapid recovery following exercise, demonstrated by a quicker reduction in heart rate, serves as an indicator of enhanced cardiovascular fitness. The decrease in cardiac workload correlates with improved myocardial efficiency and oxygen utilization, leading to a reduced RPP during recovery phases. The observed reduction in RPP after five minutes of recovery, subsequent to five weeks of exercise, indicates both the immediate impacts of training-induced autonomic modulation and the long-term enhancements in cardiovascular health and myocardial oxygen economy (**Oliveira et al. 2024**).

It had been found (**Dual et al. 2024**) that during physical activity, the heightened sympathetic response improves cardiac contractility, potentially leading to a temporary decrease in R-wave amplitude as a result of increased depolarization speed and diminished ventricular filling. During recovery, there is a gradual decline in heart rate and RPP, which signifies a rebalancing of autonomic tone, characterized by a reduction in sympathetic drive and an increase in parasympathetic activity. **Mirzajani, H. and Kraft, M., 2024** had reported that self-regulating adjustment enhances ventricular repolarization and increases myocardial electrical stability. Furthermore, the decrease in myocardial oxygen demand during recovery facilitates improved ventricular filling and stroke volume, which further aids in the normalization and possible enhancement of R-wave amplitude. The physiological adjustments highlight the relationship between post-recovery metrics and enhanced R-wave characteristics.

CONCLUSION

The results of this study build upon and reinforce previous findings regarding the variations in ECG and RPP data in healthy individuals before and after exercise. The evaluation parameters such as heart rate, RRP and R peak improvement consist in this study are therefore suitable for these experiments. The amplitudes of the T and S waves in the ECG exhibit a significant increase, while the amplitude of the R peak shows a decrease following a 12-minute treadmill exercise session. The R-Wave Amplitude in the ECG at Rest showed improvement, indicating an increase in Left Ventricular Volume and enhanced Heart Function. The 12-minute running routine effectively enhances cardiac function while reducing the strain on the heart. Engaging in treadmill exercise for a duration of 12 minutes consistently can enhance the heart's compensatory mechanisms, resulting in an increase in stroke volume and a reduction in heart rate which responsible for the improving the cardiac function.

Code Availability : The code supporting this study can be made available upon reasonable request to the corresponding author.

Authors' contributions : Chirag Patel had formulated the problem and Structure, Dimpal Khambhati executed the problem and prepared the draft of manuscript. Khemraj deshmukh had reviewed the manuscript.

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