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ОРИГИНАЛЬНОЕ ИССЛЕДОВАНИЕ

Association between maximal aerobic capacity and heart rate variability

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Abstract. *Relevance.* Cardiovascular status could be assessed by maximal aerobic capacity (VO_2max) through direct analysis of the gases involved in pulmonary ventilation and monitoring fluctuations in intervals between beats over time as heart rate variability. *The aim* of the study was to investigate the relationship between VO_2max and heart rate variability in young adults. *Materials and Methods.* A total of 100 young adults between the ages of 18 and 25 were included in observational study, who did not engage in any strenuous physical activity, 50 of whom were male and 50 of whom were female.There were measured Heart rate variability in the frequency domain; LF, HF, LF/HF, and time domain; SDNN, RMSSD, pNN50, and VO_2max were assessed using a treadmill test according to Graded Exercise Protocol. *Results and Discussion.* There was weak positive correlation of VO_2max with LF ($r = 0.177$) and weak negative correlation with HF ($r = -0.141$). Male participants had a weak negative relationship between $_{VO2}$ max and LF ($r = -0.075$), whereas female respondents had a weak positive relationship(r = 0.286). There was weak negative correlation of VO_2 max with LF/HF ratio for male subjects but weak positive correlation ($r = -0.101$) for female subjects. For male and female participants, there was a weak negative association of VO_2max with SDNN ($r = -0.170$) and ($r = -0.301$), respectively. Male and female participants had a weak negative association of VO_2 max with RMSSD, with ($r = -0.154$) and ($r = -0.284$) respectively. Male and female participants had a slight negative association of VO_2max with pNN50, with ($r = -0.062$) and ($r = -0.441$) respectively. *Conclusion.* Significant variations were found in the time domain and frequency domain indices including HF and LF/HF ratio which represents the balance between sympathetic and parasympathetic responses.

Key words: frequency domain, graded exercise protocol, heart rate variability, time domain, VO_2max

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Introduction

Cardio-respiratory fitness (CRF), also known as maximal aerobic capacity (VO_2max) refers to the maximum rate at which the body can take in and utilize oxygen during exercise or the capacity of cardiovascular and respiratory systems to exercise for a longer duration [1]. To assess fitness levels and monitor intervention effects, VO_2max, serve as a standard for determining cardiorespiratory fitness, as well as understanding the process of exercise tolerance and performance [2]. The body must boost its delivery and usage of oxygen to fuel the working muscles to do physical work or exercise [3]. VO_2 max can be determined using direct and indirect approaches. The most common are walking/running tests, followed by cycling and step tests [4]. By using direct method VO_2max can directly be measured by analyzing the gases involved in ventilation during exercise but indirect techniques assess a person's aerobic capacity based on their heart rate, distance traveled, and/or time of trial while utilizing a specific protocol [5].

Measuring heart rate variability (HRV) to quantify cardiac autonomic activity can provide sensitive, quantitative, and non-invasive assessment and prognostic information in clinical populations [6]. HRV is typically calculated using the intervals between the observed QRS-reference points, also known as the R-R intervals. Because heart rate and variability are time series phenomena, time series analytic techniques may be applied. HR variability can be measured using both time and frequency domain parameters. When it comes to frequency-domain measurements HRV may be separated into its component ULF, VLF, LF, and HF rhythms [7]. Circadian rhythms might be the major driving force behind the ULF band. Very low-frequency powers are strongly correlated with the SDNN time-domain measure. The original LF/HF ratio was predicated on the fact that both PNS and SNS activity contributes to LF power, whereas PNS activity contributes largely to HF power. The goal was to calculate the ratio of SNS to PNS activity [8]. LF band region was originally known as the baroreceptor range because it mostly reflects baroreceptor activity while resting [9]. The HF band also known as the respiratory band represents parasympathetic activity associated to the HR fluctuations during breathing [10]. The pNN 50 and RMSSD time-domain measurements are substantially linked with high-frequency power [11].

A review of the literature highlighted limited evidence for the relationship between maximal aerobic capacity and heart rate variability, and more research into the full range of HRV parameters is required, as most of the study focussed on heart rate itself [12]. In previous studies to measure maximal aerobic capacity, the indirect method was used more due to its simpler, faster, and safer approach [13]. Despite the complexity associated with the direct method, still, the gas analyzer measures VO_2max more accurately and reliably [14]. Hence, this study was designed to find the relationship between maximal aerobic capacity and HRV by the direct method of a gas analyzer and a wide range of parameters in both the time and frequency domain for HRV.

Materials and methods

This observational study was done at the research laboratory of the department of physiology at the RUHS College of Medical Sciences in Jaipur, Rajasthan, from December 2020 to May 2021. Prior to starting the study institutional ethical committee clearance (EC/P-31/2020) was taken. After ensuring an appropriate description of the process to be followed during the study, all participants provided their informed consent. By convenience sampling, 100 healthy young adults were recruited in total for the study by the method of convenience sampling.

A total of 100 young adults between the ages of 18 and 25 were included who did not engage in any strenuous physical activity, 50 of whom were male and 50 of whom were female.

Subjects with a recent hospitalization history, smokers, alcoholics, people with high blood pressure, diabetes, psychological disorders, cardiac diseases, people associated with respiratory diseases like asthma, COPD, pneumothorax, and infections of the respiratory tract, people associated with musculoskeletal diseases, and person who takes medications which impacts cardiovascular system were all excluded from participating.

All participants' basic demographic data, such as height, weight, gender, and age, were collected. Before the exercise stress test, subjects were allowed to lie down for 5 minutes in the supine position on a couch. ECG leads were connected from the subject to the bio amp (using the leads provided in the bio-Amp connected to hardware). The basal lying down the heart rate of the subject was noted. The standard deviation of all RR intervals (SDRR), a measure of overall HRV, root mean square of consecutive RR interval differences (RMSSD), a measure of parasympathetic activity, and pNN 50, a measure of HRV in the time domain, are the variables employed in the analysis [15]. Additionally, HRV was evaluated in the frequency domain by calculating high-frequency power (HF 0.15—0.40 Hz), which represents parasympathetic modulation, low-frequency power (LF 0.04—0.15 Hz), which represents sympathetic modulation, and LF/HF, which determines the equilibrium between sympathetic and parasympathetic nervous system activity [16].

All individuals were told to fast the night before the test and stop working out for 48 hours. For the previous 24 hours, they were asked to refrain from drinking alcohol, smoking, or taking caffeine. After arriving in the lab, subjects were advised to relax for around 30 minutes before being made to wear a mask that enabled only them to breathe in and out. With the aid of a connecting pipe and a gas mixing chamber, the mask was linked to the gas analyzer. The subjects were told to reach their maximum capacity while the treadmill speed and intensity were increased gradually according to the Graded exercise protocol, which includes a warm-up at 0 % elevation for 3 minutes, and then the subject was told to walk at a speed (between 4.3 and 7.5 mph) of self-selected, for 3 minutes at the same incline. The treadmill inclination was then increased by 2.5 % every minute with a constant self-selected speed until the subject reached a heart rate (HR) of approx. 180 beats per minute or became too fatigued to terminate the exercise [17]. A monitor screen is connected to the equipment used during the procedure, and every 10 seconds it updates the volume of oxygen (VO_2).

*Statistical analysis.*The study's findings are reported as mean + S.D. VO_2 max and HRV data were compared using a student t-test. SPSS version 16.0 (Chicago, Inc., USA) was used for the analysis, with a significance level of *p*-value set at 0.05.

Results and discussion

This observational study was conducted in the department of physiology, RUHS College of medical sciences, Jaipur on 100 apparently healthy students (50 male and 50 female) of 18—25 years of age who were recruited by convenience sampling.

Mean age of 21.03 ± 2. 5 years, a height of 1.6 ± 0.08 m, a weight of 59.66 ± 11.15 kg, a BMI of 22.08 ± 3, 75 kg/m^2 was found for total subjects. Statistically, a significant difference was found between the height of males and females having a mean height of 1.69 ± 0.06 m, and 1.58 ± 0.06 m respectively. Similarly, a statistically significant difference was found between the weight having a mean of 62.52 ± 9.52 kg and 56.80 ± 11.6 kg for male and female subjects respectively mentioned in table 1.

Table 2 represents distribution of total subjects according to GPAQ, VO_2 max. Mean ± S.D. of GPAQ Score was 1588.6 ± 747.10 MET per week, while mean ± S.D. of VO_2 max was 41.58 ± 9.02 mL/kg/min.

Table 1

Distribution of 50 male and 50 female subjects according to demographic parameters

№	Parameters	Male Subjects (n= 50) mean ± S.D.	Female Subjects (n= 50) mean ± S.D	*p*-value
1.	Age (years)	20.82 ± 2.46	21.2 ± 2.43	0.219
2.	Height (m)	1.69 ± 0.06	1.58 ± 0.06	0.00001
3.	Weight (kg)	62.52 ± 9.52	56.80 ± 11.64	0.004
4.	BMI (kg/m^2)	21.57 ± 3.06	22.59 ± 4.3	0.870

Note: the result is significant at $p < 0.05$.

Table 2

Distribution of total subjects according to GPAQ, VO_2 max

№	Parameters	Total Subjects (n = 100) mean ± S.D.
1.	GPAQ score (MET per week)	1588.6±747.10
2.	VO_2 max (mL/kg/min)	41.58±9.02

Note: GPAQ — global physical activity questionnaire, VO_2max — maximum oxygen consumption.

Table 3 represents the distribution of GPAQ score and VO2max. statistically, a significant difference was there for GPAQ Score having Mean ± S.D. 1754±820.93 (MET) and 1347.4 ± 577.10 (MET) for male and female subjects respectively, which was found to be. Similarly, a statistically significant difference was found for maximal aerobic capacity having Mean±S.D. of VO_2 max 45.69±8.57 mL/kg/min and 37.47±7.50 mL/ kg/ min for male and female subjects respectively.

Table 4 represents the distribution of different Heart Rate Variability parameters in 50 male and 50 female subjects. LF: mean±S.D. of LF was 55.54±21.49 nu for male subjects and 45.92±18.75 nu for female subjects. HF: mean±S.D. of HF was 40.70±19.37 nu for male subjects and 49.68±17.59 nu for female subjects. LF/HF: mean±S.D. of LF/HF was 2.20±2.15 for male subjects and 1.24±1.04 for female subjects. SDNN: mean±S.D. of SDNN was 60.95±39.23 ms for male subjects and 62.63±40.78 ms for female subjects. RMSSD:

mean ± S.D. of RMSSD was 56.22±55.06 ms for male subjects and 62.05 ± 59.19 ms for female subjects. pNN 50: mean ± S.D. of pNN 50 was 16.08 ± 18.81 % for male subjects and 20.03 ± 17 % for female subjects.

LF: low frequency, HF: high frequency, SDNN: standard deviation of all NN intervals, RMSSD: square root of the root mean square of sum of all differences between NN intervals, pNN 50: percentage of successive intervals that differ by more than 50ms.

Table 5 represents correlation of maximal aerobic capacity (VO_2max) with heart rate variability. There was weak positive correlation (r =0.177) of VO_2 max with LF and the association was not statistically significant. There was weak negative correlation (r =–0.141) of VO_2 max with HF and the association was not statistically significant. There was weak positive correlation (r =0.135) of VO_2 max with LF/HF ratio and the association was not statistically significant. There was weak negative correlation (r = –0.215) of VO_2 max with SDNN and the association was statistically significant. There was weak negative correlation of VO_2 max with RMSSD (r = –0.215) and the association was statistically significant. There was weak negative correlation of VO_2 max with pNN 50 (r = –0.253) and the association was statistically significant.

Table 3

Distribution of 50 male and 50 female subjects according to GPAQ, VO_2max

№	Parameters	Male Subjects (n= 50) mean ± S.D.	Female Subjects (n = 50) mean±S.D.	*p*-value
1.	GPAQ score (MET)	1754 ± 820.93	1347.4 ± 577.10	0.002
2.	VO_2max (mL/kg/min)	45.69 ± 8.57	37.47 ± 7.50	0.00001

Note: GPAQ: global physical activity questionnaire, VO_2 max: maximum oxygen consumption; the result is significant at ***p***< 0.05

Table 4

Distribution of male and female subjects according to Heart Rate Variability parameters (LF, HF, LF/HF, SDNN, RMSSD, pNN 50)

№	HRV parameters	Male Subjects (n = 50) Mean ± S.D	Female Subjects (n = 50) Mean ± S.D.	*p* — value
1.	LF (nu)	55.54±21.49	45.92±18.75	0.009
2.	HF (nu)	40.70±19.37	49.68±17.59	0.010
3.	LF/HF	2.20±2.15	1.24±1.04	0.002
4.	SDNN (ms)	60.95±39.23	62.63±40.78	0.417
5.	RMSSD (ms)	56.22±55.06	62.05±59.19	0.305
6.	pNN 50 (%)	16.08±18.81	20.03±17	0.136

Note: The result is significant at ***p*** < 0.05.

Table 5

Correlation of VO_2 max with heart rate variability parameters in total subjects

№	VO_2 max with Heart rate variability parameters	Total subjects (n = 100)	
		r- value	*p*- value
1.	VO_2 max and LF (nu)	0.177	0.078
2.	VO_2 max and HF (nu)	-0.141	0.161
3.	VO_2 max and LF/HF	0.135	0.180
4.	VO_2 max and SDNN (ms)	-0.215	0.031
5.	VO_2 max and RMSSD (ms)	-0.215	0.031
6.	VO_2 max and pNN 50 (%)	-0.253	0.011

Note: The result is significant at $p < 0.05$.

VO_2 max: maximum oxygen consumption, LF: low frequency, HF: high frequency, SDNN: standard deviation of all NN intervals, RMSSD: square root of the root mean square of sum of all differences between NN intervals, pNN50: percentage of successive intervals that differ by more than 50ms. Table 6 represents correlation of maximal aerobic capacity (VO_2max) with heart rate variability in male and female subjects.

The present observational study was done to assess the correlation of maximal aerobic capacity (VO_2max) with HRV (Heart rate variability) in young adults. This study was done at the research laboratory of the department of Physiology, RUHS College of medical sciences, Jaipur. 100 medical students between the ages of 18 and 25 who were evaluated as part of the study included 50 male and 50 female students.

In the present study, higher values of maximal aerobic capacity (VO_2max) was found in males than females which were similar to the findings of a study conducted by Loe H. et al [18]. Muscle is the main consumer of oxygen during physical activity. Men have more muscle mass than women, which contributes to their greater absolute VO_2max. These differences are due to central oxygen supply restrictions caused by low cardiac output value as a result of small amount of stroke volumes and lower capacity of oxygen transport. Because of low hemoglobin levels, capacity for oxygen transport in women is decreased [19].

Table 6

Correlation of VO_2 max with heart rate variability parameters in male and female subjects

№	VO_2 max with Heart rate variability parameters	Male (n = 50)		Female (n = 50)	
		r- value	*p*- value	*r*- value	*p*-value
1.	VO_2 max and LF (nu)	-0.075	0.604	0.286	0.044
2.	VO_2 max and HF (nu)	0.128	0.373	-0.245	0.086
3.	VO_2 max and LF/HF	-0.101	0.485	0.272	0.056
4.	VO_2 max and SDNN (ms)	-0.170	0.237	-0.301	0.033
5.	VO_2 max and rMSSD (ms)	-0.154	0.285	-0.284	0.045
6.	VO_2 max and pNN 50 (%)	-0.062	0.668	-0.441	0.001

Note: The result is significant at $p < 0.05$.

In this present study, heart rate variability was assessed for the frequency domain and time domain. In the case of the frequency domain, the mean LF value was higher in males than in females, which is similar to other several studies done by Sammito et al [20], and Dantas et al [21] who believed that sympathetic responses are higher in males than females. Mean HF was higher in females than males, which shows a higher parasympathetic response in females than males. Additionally, for both genders, there were significant gender differences for the normalized frequency domain indices and for the LF/HF ratio which describe the balance between the two arms (sympathetic and parasympathetic) of the cardiac autonomic control system as observed by Grant et al [22].

In the present study, heart rate variability was also assessed in the time domain in which mean SDNN which represents autonomic balance was higher for females than males. It is the standard deviation of the NN interval (SDNN), i.e. the square root of variance. SDNN reflects all the cyclic components responsible for variability in the period of recording. Mean RMSSD and mean pNN50 for females were higher than for male subjects. RMSSD and pNN50 reflect parasympathetic responses in the time domain, demonstrating that female subjects exhibited a stronger parasympathetic response than male subjects. In our study mean values for time domain parameters for SDNN, RMSSD and pNN50 were found to be higher than the similar studies conducted by Grossman P. et al, Voss A. et al [23, 24]. According to a study by Geovanini et al, male subject mean RMSSD was lower, but their mean pNN50 for males was similar to the present study [25].

In the present study, maximal aerobic capacity (VO_2max) was correlated with heart rate variability parameters. There was weak positive correlation of VO_2 max with LF (r =0.177) and weak negative correlation with HF (r = –0.141). In the study conducted by Yamamoto et al there was a higher HF and lower LF component after physical exercise, which shows endurance-trained subjects have stronger parasympathetic activity than their untrained counterparts after mild and moderate exercise [26].

Male participants had a weak negative relationship between VO_2 max and LF (r= –0.075), whereas female respondents had a weak positive relationship between VO_2 max and LF (r =0.286). This could be because LF power has a parasympathetic component in addition to being a sign of sympathetic impact. There was weak positive correlation of VO_2 max with HF (r =0.128) for male subjects but weak negative correlation of VO_2max with HF (r = –0.245) for female subjects. This may be due to the effect of higher physical activity for males than females There was weak negative correlation of VO_2max with LF/HF ratio for male subjects but weak positive correlation of VO_2max with LF/HF ratio (r = –0.101) for female subjects. The balance between the sympathetic and parasympathetic branches of the ANS that LF/HF depicts may be the cause of this. These HRV findings are consistent with research Gilder et al [27], which shows that consistent exercise (greater VO_2 max) benefits the resting ANS by reducing the sympathetic effect on the heart and boosting the parasympathetic influence.

For male and female participants, there was a weak negative association of VO_2max with SDNN (r = –0.170) and (r = –0.301), respectively. Male and female participants had a weak negative association of VO_2max with RMSSD, with (r = –0.154) and (r= –0.284) respectively. Male and female participants had a slight negative association of VO_2 max with pNN50, with (r= –0.062) and (r = –0.441) respectively. Nakamura et al in their study observed that PNS activity withdrawal occurs primarily up to a moderate level of exercise. Whereas SNS activity predominates during moderate to heavy exercise [28]. In our study VO_2 max represented moderate to severe level of exercise so SNS dominance was seen in HRV parameters.

Limitations

Small sample size and only a healthy young adult population were included in the study. More research into the wide range of HRV parameters, various exercise protocols, and other physiological parameters including VO_2max in MET, REE, and tidal volume, may be needed.

Conclusion

By the assessment of heart rate variability, significant variations were found in the frequency domain indices including HF and LF/HF ratio which represents the balance between sympathetic and parasympathetic responses but in the case of time domain indices, sympathetic responses were found more in males and parasympathetic responses were more in females. There was a weak positive correlation between VO_2 max and heart rate variability measures in the frequency domain of study participants, namely LF and LF/HF, but a weak negative correlation between VO_2max and HF. A weak negative correlation was seen between VO_2max and the time domain heart rate variability parameters SDNN, RMSSD, and pNN 50. Research on a large population with a wider range of age of people is advised for the validity of results.

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Связь между максимальной аэробной способностью и вариабельностью сердечного ритма

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Аннотация. *Актуальность*. Сердечно-сосудистый статус можно оценить по максимальной аэробной емкости (VO^2max) путем прямого анализа газов, участвующих в легочной вентиляции и наблюдения за колебаниями интервалов между сокращениями во времени как вариабельностью сердечного ритма. Целью исследования было изучение взаимосвязи между VO_2max и вариабельностью сердечного ритма у молодых людей. *Материалы и методы*. В обсервационное исследование было включено 100 молодых людей в возрасте от 18 до 25 лет, которые не занимались какой-либо тяжелой физической деятельностью, 50 из которых были мужчинами и 50 женщинами. Измерялась вариабельность сердечного ритма в частотной области; НЧ, ВЧ, НЧ/ВЧ и временная область; SDNN, RMSSD, pNN50 и VO_2max оценивали с помощью теста на беговой дорожке в соответствии с протоколом поэтапных упражнений. *Результаты и обсуждение*. Отмечена слабая положительная корреляция VO_2max с LF ($r = 0,177$) и слабая отрицательная корреляция с HF ($r = –0,141$). У участников мужского пола была слабая отрицательная связь между VO_2 max и LF ($r = –0,075$), тогда как у респондентов женского пола была слабая положительная связь ($r = 0,286$). Отрицательная корреляция VO_2max с соотношением LF/HF была слабой у мужчин и слабой положительной корреляцией ($r = –0,101$) у женщин. Для участников мужского и женского пола наблюдалась слабая отрицательная связь VO_2max с SDNN ($r = –0,170$) и ($r = –0,301$) соответственно. Участники мужского и женского пола имели слабую отрицательную связь VO_2 max с RMSSD, с ($r = –0,154$) и ($r = –0,284$) соответственно. У участников мужского и женского пола была небольшая отрицательная связь VO_2max с pNN50 с ($r = –0,062$) и ($r = –0,441$) соответственно. *Вывод*. Значительные вариации были обнаружены во временной и частотной областях, включая HF и отношение LF/HF, которое представляет собой баланс между симпатическими и парасимпатическими ответами.

Ключевые слова: частотная область, поэтапный протокол упражнений, вариабельность сердечного ритма, временная область, VO_2max

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