

There is a strong influence of sympathetic nervous system on myocardial contractility and some effect on heart rate control, whereas vagal effect is essentially on heart rate control (2). Three basic aspects of myocardial activity can be distinguished both theoretically and practically, inotropic, chronotropic and dromotropic. Each kind of activity has its own idiosyncratic relationship with the two divisions of autonomic nervous system. Functionally the cardiovascular autonomic control parameters can be divided into two broad categories, activity (tone) and reactivity. Both the limbs of ANS can be tested for these two measures. Autonomic reactivity refers to cardiovascular responses to potential stimuli, which are essentially reflexive in nature. Under resting conditions cardiovascular system is under the influence of both the divisions of autonomic nervous system. The extent of control of the cardiovascular system differentially by the two limbs of the ANS varies from individual to individual and is also affected by many diseases. By and large a tilt towards vagal dominance is beneficial for the cardiovascular system in health as well as for the outcome of some diseases especially after myocardial infarction (3). The autonomic profile of the individual changes during the exercise as well as recovery phase and is also dependent on the intensity of the exercise (4). Regular indulgence in physical exercise is known to affect the cardiovascular status of the individual, and autonomic nervous system is the prime mediator of the response. It has been a well-established fact now that regular physical training causes a decrease in sympathetic tone and an increase in parasympathetic tone (5, 6, 7). There are a number of studies

showing effect of a long duration of physical training on the autonomic status, but there are very few studies involving a short duration of moderate exercise training on the autonomic profile covering most autonomic parameters. Cardiovascular autonomic responses are quantified by changes in the heart rate and blood pressure in response to some of the physiological stimuli. These changes have both amplitude as well as temporal characteristics, this means that latency of the cardiovascular reflexive response can also give us an insight about the autonomic status of an individual. To our best of knowledge, no study has looked at the autonomic response latencies as an assessment of autonomic status of an individual. So, in the present study we aim to study the effect of 15 days of moderate exercise training on the cardiovascular autonomic response amplitude and latencies.

METHODS

The study was conducted on 25 healthy adult males (mean age : 32.08 ± 8.32 years). Subjects were screened and a detailed medical history was taken to exclude any morbid state, which can influence the autonomic responses or poses a contraindication for exercise training.

Measurement of autonomic drive (activity) at rest

Autonomic activity was assessed by performing heart rate variability (HRV), which quantifies autonomic drive to the myocardium. Power spectral analysis of the resting EKG signal was done using Fast Fourier Transformation (FFT). The analogue to digital

conversion of the EKG signal was done using A/D converter with the sampling frequency of 128 Hz. Both frequency and time domain analysis of the data was done. In the frequency domain analysis, entire spectrum of frequencies was divided into three major bands, very low frequency (VLF, 0–0.04 Hz), low frequency (LF, 0.04–0.15 Hz) and high frequency (HF, 0.15–0.4 Hz). HF component denotes parasympathetic activity and LF component denotes sympathetic drive to the myocardium (8, 9). By frequency domain analysis following parameters were obtained: VLF, LF, HF, Total power (TP), LF:HF ratio, and normalized LF and HF (LF nu and HF nu). From the same data, time domain measures of HRV were obtained. Sympathetic drive to the myocardium at rest can be assessed by the ratio of electrical and electromechanical systole (QT/QS_2). This was achieved by simultaneous measurement of EKG on a polyrite and heart sound with the help of a phonocardiograph unit (Electronic engineering corporation, Chennai, India).

Measurement of autonomic reactivity

For autonomic reactivity tests, EKG and respiration were recorded continuously on a moving chart. Both the limbs of autonomic nervous system were assessed for autonomic reactivity. For parasympathetic reactivity, deep breathing test (DBT), Valsalva maneuver (VM) and lying to standing test (LST) were performed. In DBT, average of 6 shortest inspiratory and 6 longest expiratory R-R intervals were taken into account for the calculation of expiration to inspiration ratio (E:I ratio) and heart rate difference between inspiration and expiration. E:I ratio was calculated by dividing the average of maximum expiratory

R-R intervals by the average of minimum inspiratory R-R intervals. In VM subjects were asked to raise the intrathoracic pressure to 40 mm of Hg through a mouthpiece connected to mercury column and maintain at this level for 15 seconds. Valsalva ratio (VR) was calculated as the ratio of longest R-R interval during phase 4 of VM and shortest R-R interval during phase 2 of VM. In LST, subjects were instructed to stand within 3 seconds from lying posture. 30:15 ratio was calculated as the ratio of longest R-R interval around 30th beat and shortest R-R interval around 15th beat from the EKG. For sympathetic reactivity diastolic blood pressure responses to sustained hand grip and cold stimuli was seen in hand grip test (HGT) and cold pressor test (CPT). Also systolic pressure change during lying to standing test (LST) was seen.

Measurement of autonomic response latencies

For the measurement of autonomic response latencies, two tests of parasympathetic reactivity were chosen. They were VM and LST. These tests are based on heart rate responses, which have characteristic tachycardia and bradycardia responses.

During phase 2 of VM, there is a peak tachycardia and during phase 4 there is a rebound bradycardia. Tachycardia latency was measured as the time elapsed from the beginning of the maneuver till the appearance of peak tachycardia in phase 2 and bradycardia latency was measured as the time elapsed from the end of the maneuver till the appearance of peak

bradycardia during phase 4.

During LST, there is a peak tachycardia at or around the 15th beat and peak bradycardia at or around 30th beat. Conventionally this forms the basis of calculating the 30:15 ratio for the postural test. Since we were interested in the latency of heart rate responses the tachycardia and bradycardia latencies were calculated as the time elapsed since standing and the appearance of peak tachycardia and bradycardia respectively.

Physical training schedule

All the volunteers underwent supervised physical exercise on stationary bicycle ergometer (Ergo Zimmer, Electromedizin, Germany). Physical training programme in this study consisted of bicycling 15 minutes per day, 6 days a week for 15 days. The workload was monitored by cordless monitoring of heart rate (Polar sports tester, Polar electro OV, GBR, Finland). The load on the bicycle ergometer was adjusted so that the hear rate was kept between 60–70% of the maximum heart rate (HRmax).

All the tests were performed by the subjects before and after 15 days of physical training. An ethical clearance was obtained from the Institute Ethics Committee and an informed written consent was obtained from all the volunteers.

Statistical analysis of the data was done by applying paired t test. Statistical analysis of heart rate variability data was done by non-parametric method applying Wilcoxon signed rank test.

RESULTS

Autonomic activity (tone)

PNS activity: PNS activity as measured by time domain and frequency domain analysis of HRV showed no significant change in any of the variables after physical training, but there was a trend showing an increase in PNS activity as reflected in an increase in HF and HF nu values in the frequency domain analysis and an increase in mean R-R interval, SDNN, RMSSD, CV, NN50, and pNN50 in the time domain analysis (Table I and II).

SNS activity: SNS activity also showed no significant change after the physical training, however there was a trend showing a decrease in SNS activity as reflected in

TABLE I: The effect of physical training on frequency domain measures of HRV.

<i>Variable</i>	<i>Pre training</i>	<i>Post training</i>
TP	977.31 (351.55–4008.97)	963.68 (401.32–4108.3)
VLF	519.56 (129.2–1565.59)	600.34 (135.35–1653.25)
LF	412.11 (83.17–1568.51)	400.59 (92.24–1627.33)
HF	134.08 (42.9–1874.87)	137.29 (24.36–1764.26)
LF:HF ratio	2.72 (0.82–8.27)	2.43 (0.93–6.28)
LFnu	87.08 (44.12–102.97)	68.34 (19.20–86.27)
HFnu	16.08 (7.47–55.84)	16.64 (6.85–52.27)

[The data are expressed as median (range) for pre training (n = 25) and post training (n = 25). The power of the given frequency band calculated as area under curve within a particular frequency band is expressed in arbitrary units. Abbreviations: TP– total power of entire frequency spectrum of heart rate variability; VLF–power of very low frequency band; LF–power of low frequency band; HF–power of high frequency band; LF:HF ratio–ratio between LF and HF; LFnu - low frequency in normalized units; HFnu - high frequency in normalized units].

TABLE II: The effect of physical training on frequency domain measures of HRV.

Variable	Pre training	Post training
Mean R-R	843.7 (641–1071.04)	882.38 (714.64–1120)
SDNN	42.19 (18.84–49.82)	44.30 (19.92–76.09)
SDNN	141.91 (22.31–350.75)	134.29 (23.96–323.79)
RMSSD	29.39 (14.91–80.11)	32.62 (4.25–64.38)
CV	5.02 (2.25–23.13)	5.1 (3.24–26.29)
NN50	8 (1–85)	10 (1–84)
PNN50	3.57 (0.95–28.78)	4.09 (1–24.49)

[The data are expressed as median (range) for pre training (n = 25) and post training (n = 25). The parameters: R-R intervals, SDNN, SDSD, RMSSD were measured in milliseconds. Mean R-R - median value of mean R-R interval; SDNN - standard deviation of R-R intervals; SDSD - standard deviation of successive R-R interval differences; RMSSD - root of mean of squared successive R-R interval differences; CV - coefficient of variation of R-R intervals = (100 x SD) / mean; NN50 - number of R-R interval differences equal or more than 50 milliseconds; pNN50 - percentage of NN50].

TABLE III: The effect of physical training on frequency domain measures of HRV.

Variable	Pre training	Post training
QT	338.2±20.6	342.6±22.68
QTc	350.6±24.4	354.8±26.9
QS ₂	383.9±40.6	384.6±38.1
QT/QS ₂	0.89±0.03	0.87±0.03
QTc/QS ₂	0.92±0.06	0.91±0.06

The data are expressed as mean ± S.D. for pre training (n = 25) and post training (n = 50). Abbreviation: QT - the interval between beginning of Q wave and the end of the T wave in EKG; QTc - corrected QT interval using Bazett's formula; QS₂ - total electromechanical systole (the interval between beginning of Q wave in EKG and beginning of first high frequency component of second heart sound in phonocardiography)].

a decrease in QT/QS₂ and QT_C/QS₂ ratio (Table III).

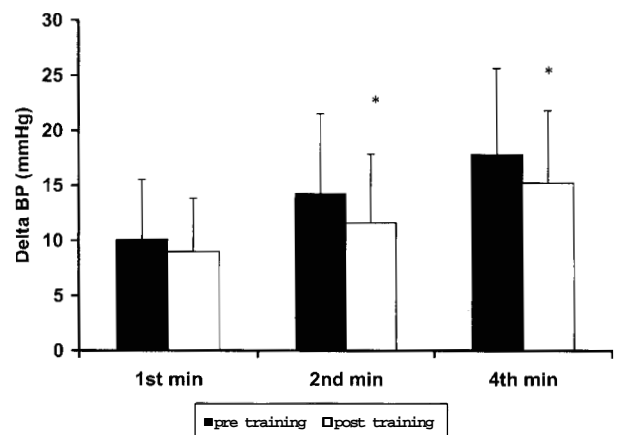
Autonomic reactivity

PNS reactivity: E:I ratio and difference in maximum and minimum heart rate achieved

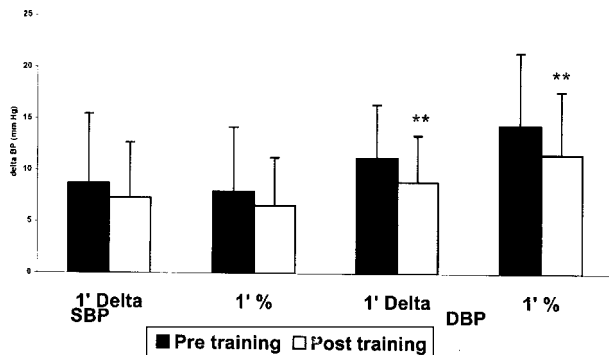
during DBT showed no significant change. (1.51 ± 0.19 vs. 1.47 ± 0.16, 27.6 ± 8.77 vs 28.2 ± 7.63). 30:15 ratio during LST and VR during VM also did not change significantly (1.43 ± 0.20 vs. 1.49 ± 0.27, 1.80 ± 0.43 vs. 1.81 ± 0.39) after the physical training.

SNS reactivity: The diastolic blood pressure response to HGT at 2nd minute showed a significant decrease in both delta (14.24 ± 7.24 mm of Hg vs. 11.6 ± 6.21 mm of Hg, P<0.05) and percentage values (18.47 ± 10.2 mm of Hg vs. 15.27 ± 8.24 mm of Hg, P<0.05) after physical training. The decrease in diastolic blood pressure was also significant at 4th minute of HGT both in delta (17.76 ± 7.81 mm of Hg vs. 15.2 ± 6.53 mm of Hg, P<0.05) and percentage values (22.38 ± 11 vs. 19.52 ± 8.63, P<0.05) (Graph-1).

The diastolic blood pressure response to CPT showed a significant decrease both in delta (11.2 ± 5.19 mm of Hg vs. 8.88 ± 4.51



Graph 1: Effect of physical training on diastolic blood pressure (DBP) response during handgrip test (HGT) after physical training (n = 25); *P<0.05.



Graph 2: Effect of physical training on blood pressure responses during cold pressor test (n = 25); *P<0.01.

mm of Hg, P<0.01) and percentage values (14.38 ± 7.0 mm of Hg vs. 11.55 ± 6.09 mm of Hg, P<0.01) after physical training. There was no significant change in systolic blood pressure during CPT (Graph-2).

Autonomic response latencies

The tachycardia latency in lying to standing test (LST) significantly increased after the physical training (6.44 ± 1.53 sec vs. 8.02 ± 1.77 sec, P<0.01), whereas bradycardia latency during Valsalva

TABLE IV: Effect of physical training on autonomic response latencies.

Variable	Variable	Pre training	Post training
LST	T _L	6.44±1.53	8.02±1.77**
	B _L	15.56±3.34	14.81±3.36
VM	T _L	11.05±2.23	10.68±2.06
	B _L	9.23±3.72	7.78±3.90*

The data are expressed as mean ± S.D. for pre training (n = 23) and post training (n = 23). T_L and B_L are measured in seconds in seconds. Abbreviations: LST - lying to standing test; VM - Valsalva maneuver; T_L - tachycardia latency; B_L - bradycardia latency. Statistical notations: *P<0.05; **P<0.01]

maneuver (VM) was found to be significantly decreased after physical training (9.23 ± 3.72 sec vs. 7.78 ± 3.90 sec, P<0.05) (Table IV).

DISCUSSION

A large number of studies have been done to observe physiological effects of prolonged physical training. Surprisingly, there are few studies in the literature, which explore the short-term effects of physical training. In the present study we observed that a physical training of fifteen days duration can alter autonomic variables such as sympathetic reactivity but fails to change the autonomic tone. We intended to study the autonomic responses not only in the amplitude domain, which is the convention, but also in terms of latency of responses. For this, we studied the effect of 15 days of physical training on autonomic response latencies in two of the tests of parasympathetic reactivity, LST and VM. We observed an increase in the tachycardia latency during LST and a decrease in bradycardia latency during VM.

Both the handgrip test (HGT) and cold pressor test (CPT) showed lowered diastolic blood pressure responses after physical training. Winder et al (10) showed a decrease in catecholamines responses to heart rate in acute exercise in men after 3 weeks of physical training (10). In certain diseases, short-term exercise training is known to affect cardiorespiratory parameters and aerobic capacity. In one study conducted on depressive patients, 3 weeks of submaximal exercise training induced changes in aerobic capacity (11). It has been shown both in normotensive and

hypertensive populations that exercise training results in reduction of resting diastolic blood pressure at different duration of physical training (12, 13, 14, 15). Central command arising from the mesencephalic locomotor region (MLR) as well as the exercise pressor reflex is capable of resetting the carotid baroreflex response during exercise. Resetting probably occurs rapidly at the start of exercise and most likely is initiated by central command. Once the muscles have started to contract, the exercise pressor reflex contributes to resetting as well (16). It has now been well documented that exercise pressor reflex is one of the important contributor in changes in blood pressure response seen after regular physical training. Autonomic nervous system is one of the most important mediator of this response and these changes may be responsible for the present observations in HGT and CPT. In this study, we measured the changes in the cardiovascular status both in terms of amplitude and latency (time taken by the system to manifest peak change). We measured latencies in terms of peak heart rate changes that occurred in response to physiological disturbances. These latencies were measured in terms of Tachycardia latency (T_L) and Bradycardia latencies (B_L) for lying to standing test and Valsalva maneuver. Both exercise and autonomic reactivity testing are characterized by sequential tachycardia and bradycardia responses, and most significantly autonomic nervous system is the prime mediator in both responses. To the best of our knowledge this is the first study undertaking latency parameter in autonomic function studies. In our study, physical training resulted in a decrement in bradycardia latency (B_L) of

Valsalva maneuver during recovery phase (phase 4). This suggests quick recovery of severe autonomic disturbances initiated by Valsalva maneuver. Bradycardia latency of Valsalva maneuver signifies the return of cardiovascular status to normal after the test stimulus has been withdrawn by the subject performing the maneuver. It is a well-known fact that physical training leads to enhanced recovery after exercise. This is effected through autonomic nervous system, which in turn gets reflected in appropriate adjustments in cardiovascular status. It may be that the physiological changes, which act to mediate the change in cardiovascular status after exercise, are acting in autonomic response testing to decrease the latency parameters especially in bradycardia response in VM. In other words, like cardiovascular recovery after training leads to quick recovery of heart rate response during VM. Tachycardia response in lying to standing test is due to the physiological disturbances caused by transient fall in stroke volume upon standing due to the pooling of blood in dependent parts of the body. We observed that after physical training tachycardia latency (T_L) in lying to standing test showed increment after physical training suggesting a delayed response to same stimuli. Also the magnitude of tachycardia decreased after training. Increase in tachycardia latency denotes a delayed activation of the system. These responses may be beneficial for the homeostatic control of the body and may be a reflection of an efficiently working autonomic nervous system.

Our study reveals some of the effects of physical training on systolic time interval measurements. Although there was no

statistically significant change in electrical (QTc) and electromechanical (QS₂) systole, there was lengthening of QTc after physical training. This lengthening of QTc may be an early phenomenon resulting in resting bradycardia. QTc/QS₂ ratio is a better index of sympathetic activity as it presents a relative value of mechanical systole, which is directly controlled by sympathetic influences. There was a decrease in QTc/QS₂ ratio although the change was not statistically significant. Such a fall in sympathetic tone would have resulted due to repeated episodes of exercise stress, which leads to blunting of sympathetic reactivity responses.

Heart rate variability (HRV) is now considered as an important tool to assess the influence of resting autonomic tone on cardiovascular system. It is now known that among the prominent frequency bands in HRV frequency spectra, high frequency (HF) component is attributed to parasympathetic influences on the heart and low frequency (LF) component is due to both PNS and SNS activity. We did not get any significant change in either time domain or frequency domain measures of HRV. There was a trend towards an increase of PNS activity as measured by LF:HF ratio, absolute HF and HF_{nu}. This trend may be a forerunner of increased PNS activity (tone) for a longer duration of physical training. Similar time domain measures of HRV showed an increase in mean R-R interval, SDNN, RMSSD, CV, NN50 and pNN50.

There was no statistically significant change in terms of parasympathetic reactivity parameters like E:I ratio,

difference between maximum to minimum heart rate during deep breathing test (DBT), 30:15 ratio during lying to standing test (LST) and Valsalva ratio during Valsalva maneuver (VM), although all the variables showed a trend of an increment after physical training. This observation raises a question as how long a training schedule results in changes in PNS reactivity? It is hard to answer this question at this stage, but it has been shown from our lab that sympathetic reactivity changes appear earlier than parasympathetic reactivity changes (17).

Present study explored the changes in autonomic responses both in amplitude and time domain after a short duration of physical training of 15 days. A large number of autonomic parameters both for activity (tone) and reactivity ensured that a proper assessment of autonomic nervous system was done. To our present knowledge assessment of autonomic responses in time domain (latency) during autonomic function testing is done for the first time by us. But the question arises, as to what added information this parameter can impart in better understanding of the system? A system apart from a highly reactive in amplitude may be a slow reactor in certain situations especially during exercise. This is particularly so because a rapid rise of heart rate or blood pressure during immediate onset of exercise is not so beneficial compared to immediate vasodilation caused by sympathetic cholinergic stimulated increase in blood flow followed by withdrawal of sympathetically mediated vasoconstrictor response to skeletal muscle blood flow. This is

particularly relevant homeostatically because local factors apart from central responses like autonomic modulation take part in maintaining increased perfusion required during exercise. This becomes more important during mild to moderate intensities of exercise. After regular physical training the peak heart rate and blood pressure achieved at the height of a physical exercise is less than novice individuals. A modulation of the autonomic status results in these changes and is well studied. It seems that the autonomic response latencies are also changed in such a way that it leads to a delayed activation

of the system and a faster recovery from the perturbation.

The present study could have given more valuable insights about the autonomic status if beat-to-beat blood pressure recording and thereby quantification of blood pressure variability and baroreceptor sensitivity be possible.

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