Chapter 5

GENERAL DISCUSSION
Thesis was broadly classified into three phases. First phase was about the alterations in respiratory functions immediately after physical activity of sports to resting condition. The second phase deals with the comparative study of respiratory function in athletes and non-athletes. The third phase of the study was based on the respiratory function of athletes to identify the maximum capacity for each parameter among different disciplines of athletic events.

Reports on systematic studies on pulmonary functions, immediately after exercise and resting condition in Indian athletes are scanty. The present study throws light on the lung volumes and flow rates exhibited by athletes, immediately after physical activity as compared to resting condition. When the mean values of pulmonary functions at rest and after exercise in runners, snake-boat rowers, athletes engaged in warm-up, freestyle strokers and butterfly strokers were compared, a reduction in lung volumes and flow rates was observed immediately after exercise as compared to resting condition. But there are exceptions to this, i.e., increase in lung volumes and flow rates exhibited in some of the parameter in these athletes. A primary reason for the decline in lung volumes after exercise bout, found out from several reports is that it may be due to the fatigue of respiratory muscle. So a discussion was made on how the respiratory muscle fatigue arises and how it affects the lung functions.

Diaphragmatic muscle fatigue plays a major role among respiratory muscles during exercise. Fregosi and Dempsey (1984 and 1986) reported a progressive
increase in lactate accumulation of the diaphragm with heavy exercise in rats. Thus it is possible that the diaphragm becomes progressively acidic with exercise leading to fatigue (Babcock, Pegelow, Mc Claran, Suman and Dempsey, 1995). The alternative explanation for the diaphragmatic fatigue may be that at high levels of metabolic demand, cardiac output is limited and blood flow to the respiratory muscle begins to compete with the locomotor muscles. It is unlikely that cardiac output is sufficient to supply all the active vascular beds with blood flow to respiratory muscles and previous studies have demonstrated a fall in muscle force output that parallels a reduction in blood flow (Saltin, 1988 and Ward, Magder and Hussain, 1992). Thus it is possible that blood flow is not available for adequate oxygen delivery to the diaphragm or for removal of metabolic by-products during high-intensity-whole-body exercise. Aaron, Seow, Johnson and Dempsey (1992) have shown that VO₂ of the respiratory muscle may approach 10-15% of total body VO₂ with heavy exercise which implies that a substantial portion of the total cardiac output is required by the respiratory muscle.

Although diaphragm is the most widely studied inspiratory muscle, recent experiments have demonstrated that the parasternals (Powers, Criswell and Lawler, 1994) and external intercostals (Powers, Griston, Lawler, Criswell and Doss, 1992), both inspiratory muscles also respond to endurance training. Studies of Powers et al. (1992) showed that action of external intercostals on the chest wall depends on the lung volume at which the muscle is activated. Studies on expiratory muscle fatigue during exercise are inconclusive (Powers et al., 1992).

Johnson, Babcock, Oscar and Dempsey (1993) reported that heavy whole body endurance exercise causes diaphragmatic fatigue in spontaneously breathing healthy humans with a variety of fitness levels. National Heart Lung Blood Institute (1990) defined “fatigue” as a condition in which there is a reduction in the
force-generation capacity of the muscle resulting from muscle activity under load which is reversible by rest. According to Johnson et al. (1993), this reduction may be due to the decline in trans-diaphragmatic pressure (Pdi) from pre to post exercise. Significant decrease in stimulated Pdi was observed following endurance exercise with varying exercise intensities.

Okroy et al. (1992) showed that several indices of pulmonary functions decrease after exercise, either short duration and high intensity or longer duration with low intensity exercise and that some of these changes seem to be related to the combination of intensity and duration of the exercise bout. The decrease in FVC after exercise, with corresponding decrease in maximal expiratory pressure (MEP), was suggested to be due to respiratory muscle fatigue with a reduced ability to exhale residual volume. The significant reduction in FEV₁ and FVC was reported to be due to subjects inability to provide full effort by not contracting the expiratory muscles as forcefully as they might normally be contracted. So according to Okroy et al. (1992), if expiratory muscle fatigue has occurred, a similar reduction in FEV₁ and FVC can be expected. So the pattern of muscle fatigue seen in Okroy’s study is manifested in the expiratory muscles and not in the inspiratory muscles as reported earlier.

The recovery from these reductions of pulmonary functions after exercise bout is delayed in the case of higher-intensity exercises, compared with lower-intensity exercise. This could be indicative of greater respiratory muscle fatigue incurred in the higher-intensity exercise. The complete recovery of FVC values to pre exercise levels takes 30 min (Okroy et al., 1992).

High intensity and moderate intensity exercise of longer duration can result in changes in FVC, MEP and MIP, which suggest respiratory muscle fatigue due to high intensity or duration. So this indicates that the intensity and duration of
exercise may be important determinants in the changes seen in lung function after
exercise. Respiratory muscle fatigue, bronchoconstriction, pulmonary oedema,
small airway closure and central blood volume changes cannot be ruled out for the
alterations in pulmonary function (Okroy et al., 1992).

As mentioned earlier, there is a synchronisation between the breathing
frequency and rhythm of exercise. But, continuous co-ordinated volley of impulses
for fixed breathing frequency with exercise rhythm results in fatigue neural drive.
This fatigue of neural drive may be due to the slower average rate of firing of
neurons. Thus breathing synchronisation is lost with rhythm of exercise. The
alterations in the electrophysiological characteristics of conducting mechanism may
result in electrolyte leakage. The slowing of calcium pumping and leakage of
potassium ions within the active muscle fibres results in alterations in the
electrophysiological characteristics of the conducting mechanism (Shephard and
Astrand, 1992). Thus an alteration in the synchronisation of the motor neurones
(α- and γ-motor neurons) together with leakage of electrolytes results in respiratory
muscle fatigue. The alterations in neuromuscular co-ordination and respiratory
muscle fatigue during exercise result in alterations of decreased lung volumes and
flow rates in athletes immediately after exercise as compared to resting state.

The present study has observed an increase in mean values of some of the
parameters of lung functions in gymnasts (except VC and RV), kalaripayattu
warriors (except VC and RV), breast strokers (except IVC and RV), back strokers
(except FEV₁, FEF₇₅-₈₅%, FEF₅₀%, PIF, FIF₅₀%, and FIF₂₅%) and rowers
(increase in VC, PEF, FEF₀.₂-₁.₂, FEF₂₅-₇₅%, FEF₂₅%, FEF₅₀%, PIF, FIF₇₅%, FIF₅₀%
and FIF₂₅%, only) after exercise bout as compared to resting condition. This clearly
shows the fitness level of athletes and better status of respiratory system. The
increase in lung volumes and flow rates exhibited by athletes was in agreement with the work of Johnson et al. (1996). Their reports suggest that during exercise, even though diaphragmatic pressure has lowered, there is every possibility that the lung capacities continue to rise. Since, there is no fatigue to the respiratory muscles, they continue to meet the required demands. On the contrary, several reports have suggested that the respiratory muscle fatigue during strenuous exercise results in bringing down the lung volumes and flow rates (Okroy et al., 1992; Powers et al., 1992; Johnson et al., 1993).

The prime reason for the increased flow rates in athletes may be due to the higher lung volumes expressed after exercise bout compared to resting condition as noticed in kalaripayattu warriors, rowers, breaststrokers and gymnasts. In other disciplines of athletes, flow rates were reduced with decrease in lung volumes after exercise bout as compared to resting lung functions. This can be explained with the earlier report of West (1990) at higher lung volumes, the flow rates continue to increase as the intrapleural pressure is raised. But as intrapleural pressure goes up, it takes alveolar pressure with it. Then the alveolar and intrapleural pressure remain constant. This explains the fact that flow rate is not effort-dependent and it can be altered only with the alterations in lung volumes.

Breathholding exercise involved in kalaripayattu warriors (yoga exercise) and breast stroke swimmers show an increase in lung volumes and flow rates after exercise bout as compared to resting condition. As aerobic demand is less in gymnastic exercise, the O₂ uptake is less and results in less burden on respiratory muscles. Due to less burden to respiratory muscles during gymnastic exercise, gymnasts are able to improve their lung volumes and flow rates after exercise bout, as their respiratory muscles are in active condition. The improved efficiency of
airway status and respiratory muscles may be the reasons behind the improved lung function in rowers, after rowing session as compared to resting condition.

During exercise, breathing frequency is synchronised with rhythm of exercise. This fixed breathing pattern can be noticed in breathing frequency of athletes, breathing of swimmers corresponding to each single stroke, rowers during each paddle stroke of rowing, runners with each stride of footsteps etc. So the frequency of breathing in each athlete is determined by the stroke or rhythm of each sports events. Bramble and Carrier (1983) point out that there is a strict locomotor respiratory coupling, especially in exercise where the stress of locomotion tends to deform the thoracic complex. When the duration of physical exertion of exercise prolongs, there will be accumulation of lactic acid in muscles and corresponding increase in arterial $P_{CO_2}$ which in turn will stimulate the chemoreceptors to augment breathing frequency. Certain leg movements and joint movements during physical exertion of exercise influence the proprioceptor activity to increase the ventilation. Similarly Hult, Horvath and Spurr (1958) and Dixon, Steward, Mills, Varvis and Bates (1961) suggested that proprioceptor impulses from exercising limbs can cause an increase in ventilation. The compensatory mechanism to get rid of this imbalance in acid-base equilibrium depends on both proprioceptors and chemoreceptors that stimulate respiratory centre of brain. The co-ordinated volley of impulse reaches the respiratory muscles through the $\gamma$-motor neuron system. Thus respiratory muscles contract vigorously for achieving hyperventilation. The stretch receptors of airways and lungs also stimulate the process of hyperventilation which results in increased lung compliance and lower airway resistance. The hyperventilation might have resulted in alterations of increased lung volumes and
flow rates, as observed in athletes of the present study, from resting condition to after exercise.

The alterations in lung volumes and flow rates in different disciplines of athletes of the present study from resting condition to immediately after exercise condition are not consistent. Gymnasts, kalaripayattu warriors, breast strokers, back strokers and rowers showed an increased trend in lung volumes and flow rates from resting condition to after exercise condition. But runners, freestyle swimmers, butterfly strokers, athletes engaged in warm-up and snake-boat rowers showed a decreased trend. Physical training benefits of neuromuscular co-ordination during breathing process may vary in athletes of different disciplines. The intrasubject variation of physical characteristics among different groups of athletes selected for the study may be another reason for the inconsistency of the results.

In the present study, efforts were made to study the lung function during post exercise session in athletes ‘immediately’ after the physical activity by conducting respiratory functions of each athlete of different disciplines to carry out the session individually. But some athletes had to perform re-tests during the study, which resulted in excess time for conducting tests. This may be the possible reason for the lower values or basal levels of lung functions in athletes after post-exercise session. As reported earlier by Mrunal et al. (1998) that when exercise stops, ventilation decreases rapidly towards baseline. By 2-3 min. after exercise, it falls to approximately $1/3^{rd}$ of its highest value (Gallagher and Younes, 1986).

The second phase of the investigation deals with respiratory functions between athletes and non-athletes. This study was carried out to assess whether respiratory function benefited from physical training in athletes. In general, higher lung volumes, viz. VC, IVC, FVC, MVV and RV and timed volumes, viz. FEV₁
and FEV$_{0.5}$ and lower FEV$_1$/FVC% ratios were observed in all athletic groups as compared to non-athletic groups. Exceptions for the earlier observations were noticed in snake-boat rowers and gymnasts.

The large metabolic demand of strenuous exercise requires an efficient O$_2$ transport system from the atmosphere to the active tissues. So the capacity of one to perform exercise depends largely upon the functional capabilities of the oxygen transport system (Astrand, 1956; Dempsey and Rankin, 1967 and Andrew, Becklake, Guleria and Bates, 1972). The results of the present study support the idea that physical training has a facilitative effect on the ventilatory function. The observed results of the present study are in agreement with the earlier reports of Lakhera et al. (1984) and Ghosh et al. (1985) in Indian athletes. Similarly, Stuart and Collings (1959), Newman et al. (1961), Rash and Brant (1967) and Ness et al. (1974) were of the opinion that the athletic training benefits respiratory functions resulting in increased lung functions. Similar reports of higher lung functions in athletes were earlier reported by Newman et al. (1961), Andrew et al. (1972), Holmer et al. (1974) and Curistian and Zauner (1981).

The possible explanation for the higher lung volumes in athletes was earlier reported by Prateek Mehrotra, Narsingh Varma, Sunita Tiwari and Prabhat Kumar (1998) that regular forceful inspiration and expiration for prolonged periods during playing, leads to the strengthening of the respiratory muscles, both voluntary and involuntary. This helps the lungs to inflate and deflate maximally. This maximum inflation and deflation is an important physiological stimulus for the release of lung surfactant (Hildebran, George and Clements, 1981) and prostaglandins into the alveolar spaces thereby increasing the lung compliance and decreasing the bronchial smooth muscle tone respectively.
Another explanation for the higher lung volumes is the breathholding ability of athletes like swimmers and kalaripayattu warriors in the present study, which presumably increases the strength of respiratory musculature (Hamilton and Andrew, 1976). The respiratory adaptations to frequently increased metabolic demands of athletic training and performance of the athletes in the present study may therefore be expected to equip with a more efficient respiratory muscle power and more efficient ventilatory function, as suggested earlier by Singh (1959). Moreover, this probably reflected in their ability to expel a larger proportion of air per unit time as observed in the higher timed volumes (FEV₁ and FEV₀.₅) in the athletes of present study.

During different types of physical exercise, the respiratory frequency tends to become fixed to the exercise rhythm (Jasinski et al., 1980). Bramble and Carrier (1983) earlier pointed out that there is apparently a strict locomotor respiratory coupling especially in exercise where the stress of locomotion tends to deform the thoracic complex. This perhaps results in the larger thoracic complex with increased chest surface area and chest mobility. Armour et al. (1993) suggested that increase in surface area and mobility of chest can influence lung capacities.

Better neuromuscular co-ordination, increased elastic recoil of lungs, improved lung compliance, respiratory muscle hypertrophy, less airway resistance and increased alveolar diffusion rate achieved by the athletes during athletic training may have worked together for the higher lung volumes in the athletes of the present study.

Reduced lung volumes of snake-boat rowers and gymnasts compared to controls can be explained on the basis of their physical activity. Gymnastic
exercise is considered as less strenuous with regard to physical training of other sports. Less strenuous physical training may not perhaps lead to much significant improvement in the lung function (Lakhera et al., 1984). As snake-boat rowers are traditional rowers, they are not supposed to engage in rowing practice regularly. So the study has shown that without regular physical training the efficiency of respiratory system, as observed in other athletic groups, may not be possible. Thus only strenuous and systematic regular physical training can benefit athletes with better lung volumes.

The conductive properties of airways can be assessed from the status of expiratory and inspiratory flow rates of athletes. The physical training of athletes and its benefit on air flow rates was assessed by comparing with flow rates of age- and height-matched controls. In fact, athletic groups, viz., rowers, kalaripayattu warriors, runners, freestyle strokekrs, back strokekrs, breast strokekrs and butterfly strokekrs showed a remarkably higher expiratory and inspiratory flow rates than non-athletic group. The inspiratory and expiratory flow rates tend to increase with higher lung volume, because flow rates are dependent on lung volume. Higher lung volumes were found in athletic groups, viz., rowers, kalaripayattu warriors, runners and different swimming strokekrs, compared to normal controls. So this presumably was responsible for any increased flows. This was in agreement with the earlier report made by West (1990). Contrary to the above observation, the result of snake-boat rowers, athletes engaged in warm-up and gymnasts fail to obtain higher flow rates.

The present study supports the earlier observation made by Courteix, Obert, Lecoq, Tuenon and Koch (1997) that intensive endurance training induces a significant increase in improvement of flow-volume relationship in athletes in
comparison with non-athletic groups. Concerning the flow-volume relationship, similar observation has been reported by Farrel (1981) where he found MEF (mid expiratory flow rate) between 200 and 1200 ml of FVC increased after eight weeks of endurance training. It has been suggested earlier that ventilatory muscles can increase their strength and endurance capacity in response to specific training which also benefits the conductive properties of airways (Leith and Bradley, 1976). Overall, the increase of expiratory and inspiratory flow rates in the present study suggests that the athletic training improves the conductive properties of smaller and larger airways.

The breast strokers in the present study showed a higher inspiratory flow rate and lower expiratory flow rates as compared to non-athletes. Butterfly strokers showed a higher expiratory flow rate and lower inspiratory flow rate when compared with non-athletes. The above observation can be explained with the findings of Fanta, Leith and Brown (1983). Fanta et al. (1983) explained that swimming enhances inspiratory rather than expiratory muscle force. Thus specific training of ventilatory muscles influences the ability of the inspiratory muscles to achieve a minimal length during contraction. Zinman and Gaultier (1986) later reported that swimming significantly augments the inspiratory, but not expiratory muscle. The other factors which affect the higher expiratory flow rates of butterfly strokers include elastic recoil of lungs and the characteristics of the intrathoracic airways (Beardsmore et al., 1989).

Gymnasts, athletes engaged in warm-up and snake-boat rowers showed reduced flow rates unlike the non-athletic groups. The decrease in flow rates of snake-boat rowers may be due to the low fitness level and the absence of systematic physical training. Gymnasts and athletes engaged in warm-up can be classified
under the age group of children. Several authors have shown that in children there
is disproportionate maturation within different compartments of lung (De Troyer
et al., 1978; Hibbert et al., 1984). From childhood to adolescence, the lung-airway
system does not grow isotropically, the alveolar space developing at a faster rate
than the airway system. In fact, airway resistance (Raw) has been reported to be
higher in sedentary children until puberty (Hogg et al., 1970; De Troyer et al.,
1978). The increased airway resistance of gymnasts and athletes engaged in
warm-up group may be due to declined flow rates.

The expiratory flow rate, FEF\textsubscript{75-85\%}, which comes under the last part of FVC,
alone showed a noticeable decline in kalaripayattu warriors, runners, gymnasts,
snake-boat rowers, breast strokers and athletes engaged in warm-up than the
control group. All the athletic groups of the present study showed an increase
in FEF\textsubscript{25-75\%}. This can be explained with findings of Ashapherwani et al. (1989)
that the initial part of expiratory FVC curve (FEF\textsubscript{25-75\%}) depends on
non-bronchopulmonary factors like neuromuscular factors and mechanical
equipment factors, e.g. inertial distortion of lungs. The terminal portion of the
FVC curve (FEF\textsubscript{75-85\%}) is relatively variable due to factors like maintenance and
coordination of efforts which are to some extent exercise-dependent. Another
explanation is that although the FEF\textsubscript{75-85\%} indicates the efficiency of smaller
airways, the FEF\textsubscript{25-75\%} of FVC is more sensitive measurement for diagnosing
airway calibre of smaller airways (Garbe and Chapman, 1988).

The athletes engaged in sports involving higher aerobic demand like
long distance running, different swimming strokes and rowing showed comfortably
higher lung volumes and flow rates when compared with their age- and
height-matched control group. Athletic group involving greater anaerobic capacity
like the gymnastics in the present study showed a reduction in lung functions as compared to their control group. The present study clearly shows a difference between the lung functions of athletes involved in aerobic and anaerobic events of sports.

While the second phase of the present study tried to assess the benefits of physical training on the lung functions of the athletes, the third phase aimed at finding out the particular lung function parameter that benefited athletes most, and also the particular type of athletes that had the greatest benefit. Highest recorded lung volumes VC, IVC, FVC, FEV₀.₅, FEV₁, MVVᵢⁿᵈ and RVᵢⁿᵈ were observed in rowers as compared to other athletic group. This clearly indicates the strenuous training involved in the rowing event and its implications on lung volumes in rowers. Lakhera et al. (1984) observed strenuous training benefits higher lung functions by respiratory muscle hypertrophy, better mechanical properties like elastic recoil of lungs and compliance with greater neuromuscular co-ordination. Cunnigham et al. (1975) observed in rowing, the frequency of breathing was in complete synchronisation with the stroke rate of the oar. Bramble and Carrier (1983) pointed out that there is a strict locomotor respiratory coupling especially during rowing when the stress of locomotion tends to deform the thoracic complex. Deformation of thoracic complex leads to increase in surface area and mobility of chest which favours greater lung capacities (Armour et al., 1993). The higher timed volumes like FEV₁ and FEV₀.₅ indicate better status of larger airways as reported earlier by Garbe and Chapman (1988). Lakhera et al. (1984) were of the opinion that better MVV of rowers denotes calibre of airways, tone of respiratory musculature and maximum ability to sustain ventilation continuously. Improved RV indicates better diffusion rate from lungs to Capillaries (Mc Ardle et al., 1991).
The overall efficiency of the mechanical properties of the lung and chest wall can be noticed from data of higher MVV observed in rowers (Astrand and Rodahl, 1986).

Kalaripayattu warriors showed a better inspiratory flow rate as compared to other athletic groups. The breathhold yoga technique, greater involvement of chest muscles during exercise and systematic physical training may have benefited bettering conductive properties of airways with higher flow rates.

Back stroke swimmers showed improvement in conductive properties of smaller airways as compared to the other athletic groups. The highest recorded expiratory flow rates like FEF25-75%, FEF75% and FEF25-85% in back strokers were sensitive indicators of better calibre of smaller airways. Although earlier reports of Ashapherwani et al. (1989), Mohan Rao et al. (1993) and Courteix et al. (1997) suggested that swimming practice is beneficial for improved lung function. To be more specific, the present study has shown that among swimmers and other athletes, back strokers exhibit higher expiratory flow rates.

Runners in the present study have clearly demonstrated a higher PEF, FEF0.2-1.2, FEF50% and FEF25% than other athletic groups. Arunkumar De (1992) has expressed that PEF measurement denotes the overall efficiency of respiratory muscles. Higher FEF0.2-1.2 denotes better efficiency of larger airways while higher FEF25% indicates efficiency of smaller airways. Therefore it can be said that the long distance runners appear to have an efficient airway function as compared to other athletic groups.

The last part of the study shows considerably higher lung volumes in rowers as compared to other athletic group. But there was no consistency in flow rates with reference to all groups of athletes in the present study.