Anthropologist, 3(2): 91-97 (2001)
PRINT: ISSN 0972-0073 ONLINE: ISSN 2456-6802
DOI: 10.31901/24566802.2001/03.02.04

A Comparison of Cardiopulmonary Responses of Elite Indian Distance Athletes with Certain Selected Elite Power Event Groups

Suman Mukhopadhyay[1], L.S. Sidhu[2] and S.K. Verma[3]

1. Sport Authority of India, NS NIS, Patiala, Punjab, India
2. Department of Human Biology, Punjabi University, Patiala 147 002, Punjab, India
3. Department of Sports Sciences, Punjabi University, Patiala 147 002, Punjab, India

KEY WORDS Physical Fitness. Muscular Development. Fat Free Body Mass. Athletes.

ABSTRACT Cardiopulmonary Exercise Testing (CPET) was carried out on 43 elite Indian sports persons belonging to the power (anaerobic) disciplines of Sprints (n=12), jumps (n=21) and weightlifting (n=10), by graded exercise consisting of incremental treadmill running, using a computerized breath-by-breath analyzer. Similar CPET was carried out on 50 elite long distance runners (3000 m and above). The physical and physiological responses, including the total duration of exercise, time taken to reach the anaerobic threshold, time spent beyond the anaerobic threshold, were measured and compared. Significant intra-group differences were observed between the elite anaerobic event athletes and with the elite long distance athletes in certain physical as well as in their cardiopulmonary responses. The study concluded, among others, that the elite sprinters displayed significant higher endurance capacities, ventilatory responses and exercise time as compared with jumpers and weightlifters and had the highest physical as well as physiological fitness amongst the anaerobic group athletes. The elite long distance (aerobic) athletes displayed significantly higher values of oxygen consumption and fractional utilization of oxygen at the anaerobic threshold and other cardiopulmonary transients, as compared to the anaerobic athletes both as a group as well as separately. The study also concluded that the elite long distance athletes possessed the highest physical and physiological fitness.

INTRODUCTION

Athletic competition represents the classical test of physical fitness or performance capacity of an individual whose success will depend on the physiological demands of the actual event, which must be perfectly matched by his supply capability. It is realistic to say that sports scientists have merely begun a systematic research on performance capacity and the many factors, which influences it.

The maximum attainable VO_2 (VO_2 max), is an old idea in itself. It reflects a situation at very high work rates where, despite increases in power out put by the subject, VO_2 fails to increase significantly. The maximum oxygen consumption, (VO_2 max) has been generally accepted as the physiological variable that best describes the capacities of cardiorespiratory systems.

Cardiopulmonary Exercise Testing (CPET) has become a common procedure to objectively assess the cardiac and respiratory responses of individuals to exercise (Inbar et al., 1994). The general pattern of cardiopulmonary responses are known (Astrand, 1960; Inbar et al., 1987; Jones et al., 1982; Wassermann et al., 1987), and the same has been used to carry out physiological evaluation abroad and in our country (Malhotra et al., 1972; Verma et al., 1978; 1986). However, the earlier Indian studies did not use the breath-by-breath analyzer, nor were they limited only to the elite Indian athletes.

It has long been established that for the elite Indian distance athletes, to achieve a level equivalent to the world elite, a VO_2 max close to or preferably above 80 ml/kg/min is necessary in case of men (Saltin and Astrand, 1967). However, recent studies have elucidated factors, which have a more critical bearing on distance running than VO_2 max alone. It was Daniels et al., 1984, who introduced the term 'Velocity at VO_2 max' and the abbreviation 'vVO_2 max', and reported that vVO_2 max is a useful variable that combines VO_2 max and running economy into a single factor which identifies aerobic differences between various runners or categories of runners. vVO_2 max explained individual differences in performances that VO_2 max or running economy alone did not. The importance and significance of vVO_2 max is giving a practical assessment of aerobic demands and capacity during running performance has been comprehended only recently (Billat and Koralsztein, 1996). Moreover, elite distance athletes (marathoner) have been observed to be able to utilize 86% of their VO_2 max at the anaerobic threshold (Sjodin and Jacobs, 1981). A high aerobic-anaerobic transition level (AT-Level) reflects a high fractional utilization of oxygen without building up significant amount of anaerobic metabolites. Further, the O_2 consumption at the anaerobic threshold was also found to have a greater correlation with distance running time than VO_2 max (Ghosh et al., 1988).

Men who engage in resistance training often exhibit remarkable muscular development. Excess levels of muscle development and fat-free body mass have been estimated in Olympic weight lifters (Katch et al., 1980). Sprinters and jumpers were also found to exhibit a very high Lean Body Mass (LBM) as a fraction of their total weight, although they were significantly lighter than weight lifter (De Gray, 1974). Since skeletal muscle hypertrophy is associated with increased capillarisation and vascularisation, it is pertinent to elucidate whether this will cause an enhanced oxygen uptake capacity in these group of athletes as compared with the long distance athletes. Further, although the events of weight lifting, sprinting and jumping are all highly anaerobic events, yet, so sustain the rigorous training programme for as many as three sessions a day for as long as three hour per session, requires at least a level of endurance much higher than a sedentary individual.

It was with this background that the present study was conducted not only to reassess the VO_2 max and related parameters of our elite athletes but to make a comparison available also amongst the various anaerobic groups, which will be more pertinent to the actual physiological profile of our elite athletes and be used as pointers for the evolution of credible training programmes. Moreover, as mentioned, the Indian studies, in most cases, did not use a breath-by-breath analyzer. The breath-by-breath measurement, a state of art precision measurement technology has, possibly for the first time in India, helped to elucidate the accurate maximum and anaerobic threshold values of the different cardiopulmonary transients, which constitutes the very basis of physiological profiling.

MATERIALS AND METHODS

Subjects: The study was conducted on 93 volunteer, all elite sport persons, consisting of around 50 in each of the two groups mentioned below, in which the athletes have been categorized. The volunteers were taken from elite male sports persons belonging to various national camps that were held in the Sports Authority of India, Netaji Subhas National Institute of Spots, Patiala. All volunteers were adults, within the age range of 18 to 26 years. The volunteers were divided into two groups, based on their game/event, and the energy system that predominantly caters to their metabolic need as under:

a) Anaerobic Group (n=43): This included volunteers of events of athletics (n=33) [belonging to sprints (n=12), and jumps (n=21)], and weight lifting (n=10).

b) Aerobic Group (n=50): This included volunteer of events of long distance running (3000 m and above: n = 50).

Each volunteers was first subjected to a physical examination that included measurement and/or recording of the following:

Date of Birth (from which the decimal age was calculated).

Stature (height in cm).

Weight (in kg).

Body Surface Area (BSA: in sqm).

Subsequent to the above, each volunteer was explained in detail as to what he was required to do and the efficacy of carrying out the CPET. Only those volunteers participated in the study who were willing, and prior verbal consent was obtained from each of them. Thereafter, the volunteers were subjected to CPET to assess their following physiological measures:

VO_2 (oxygen consumptio: L/min and ml/kg/min).

VCO_2 (carbon dioxide production: L/min and ml/kg/min).

V_E (pulmonary ventilation: L/min).

HR (heart rate: beats/min).

TV (tidal volume: ml).

f_R (frequency of respiration: No. of expirations/min).

O_2 Pulse (oxygen consumption / heart rate: ml).

Method

Exercise tests were perfotmed on an electronically operated motor driven treadmill (LE 6000 : Erich Jaeger, Germany), using a test protocol consisting of administration of a graded running. The initial speed was prefixed at 8 km/h and this was increased every two minutes at the rate of 2 km/h, till exhaustion (Leger and Boucher, 1980), consequent to which, the volunteers were asked to walk briskly at a recovery speed of 6 km/h. The peak treadmill running speed or the maximal velocity attained, that could be maintained for a whole minute during the test was taken as the 'velocity at VO_2 max' or vVO_2 max. If an athlete failed to sustain 60 seconds at his peak speed, the velocity of the immediately preceding completed work stage (treadmill speed) was recorded as his velocity at the VO_2 max or the vVO_2 max (Noakes, 1996). The tests were carried out in an air-conditioned room with temperature and humidity levels controlled at 23° ± 2° C and 55 ± 5% respectively. The tests were carried out at least 3h after last meal and after a minimum of 12h of limited exertion.

All measurements were carried out breath-by-breath, using the computerized metabolic analyzer, "Oxycon Champion", (Erich Jaeger, Germany). The heart rate (HR) and ECG were continuously monitored during the period of test and recovery. The volunteers breathed through a small dead space (35 ml), low resistance mouthpiece and Triple V volume transducer. Respired gases were withdrawn automatically from the mouthpiece and passed on to the CO_2 and O_2 analyzers for breath-by-breath display and recording of the various physiological variables. Temperature and pressure sensors of the instrument automatically read the ambient temperature and atmospheric pressure, and data about existing relative humidity was fed to it. All gas volumes were automatically corrected for, and expressed in STPD, and V_E was expressed as V_E BTPS.

The CO_2 and O_2 analyzers, as well as the volume transducer were calibrated before each test using a precision gas mixture (5% CO_2; balance N_2), and a 2 liter calibration pump (both Erich Jaeger, Germany).

A test was considered maximal only if a change in load did not produce a corresponding significant change in HR and VO_2 (± 4 bpm and 100 ml respectively), and if the HR values are within 15% of the age – predicted Hrmax (Bruce et al., 1974; Jones et al., 1985). The RQ was greater than 1.13 also (Inbar et al., 1994). The Anaerobic Threshold (AT) point was determined from the deviation point of the V_E-VO_2 linearity (Beaver et al., 1985), and confirmed from plot of VCO_2 vs VO_2 (modified V-slope technique, Sue et al., 1988). The VO_2, measured at the anaerobic threshold (AT) level was taken as the AT-VO_2. Similarly, the other cardiopulmonary transients measured at the maximum of exercise, for example, VE, HR, etc. were suffixed with the word 'max', like V_E max and HRmax, and their values obtained at the anaerobic threshold level were prefixed with AT, like, AT-V_E and AT-HR.

The breath-by-breath data of the cardiopulmonary transients were then averaged for over 10 second periods by the analysis software of the metabolic analyzer. The Physiological profiling was then conducted. The values of the cardiopulmonary transients during the maximum of exercise, sustained for atleast 30 seconds, were taken as the maximal values and those values established at the anaerobic threshold (AT), were taken as the AT-value. The measurements included estimations of the HR_{max}, AT-HR, VO_2 max, AT-VO_2, VCO_2 max, AT-VCO_2, V_E max, AT-V_E, fRmax, AT-fR, TVmax, AT-TV, O_2 Pulse-max and AT-O_2 pulse.

Statistical Analysis

The means and standard deviations of the physical characteristics of decimal age, height, weight and body surface area were calculated by the statistical packages of the Microsoft Office (MS 6.0) / MS Excel. The total exercise time, the time spent below the AT and the time spent beyond the AT (Supra-AT) were computed and means and ± SD was calculated for comparisons.

Means and standard deviations of these transients were than computed by the same software and compared between the different groups by students' 't' test. Correlations were then computed between certain selected cardiopulmonary transients and total exercise time, supra-AT time and AT-Time.

RESULTS AND DISCUSSIONS

Table 1 (A), compared physical profile and exercise duration of the athletes belonging to the anaerobic group, taken separately and a group along with the aerobic group.

also revealed that the anaerobic and aerobic groups differed significantly ($p<0.01$), in their weights. The BSA of the aerobic group was significantly lesser than the anaerobic group ($p<0.01$). The total exercise time of the aerobic group was found to be significantly higher than

Table 1(A): Table shows the means (±SD) of physical profiles and exercise duration of Anaerobic Group Athletes of jumps, sprints and weight lifting and long distance runners

Event	*n*	*Dec. Age (yr.)*	*Height (cm)*	*Weight (kg)*	*BSA (sqm)*	*Total exercise duration (mins)*	*AT-time (mins)*	*Supra-AR Time (mins)*
Athlete (Jumps)	21	18.9 (1.31)	174.5 (6.56)	65.0 (6.30)	1.97 (0.10)	10.7 (1.48) [10:42.0]	4.0 (2.04) [6:48.0]	(1.46) [4:00.0]
Athlete (Sprints)	12	20.9 (1.87)	179.7 (5.00)	69.2 (8.25)	1.87 (0.12)	12.2 (2.20) [12:12.6]	7.9 (1.55) [07:53.4]	4.3 (1.45) [04:20.4]
Weight lifting	10	23.4 (3.14)	167.0 (7.41)	77.9 (22.63)	1.86 (0.28)	9.7 (3.13) [9:42.0]	4.9 (0.68) [4:54.0]	4.0 (0.91) [4:00.0]
Anaerobic Group (Total)	43	21.4 (2.66)	174.2 (7.73)	69.17 (13.17)	1.83 (0.17)	11.2 (2.46) [11:12.0]	6.9 (1.94) [6:54.0]	4.2 (1.33) [4:12.0]
Aerobic Group (Total)	50	20.7 (2.97)	169.3 (5.53)	56.6 (7.92)	1.65 (0.13)	16.7 (3.58) [16:42.0]	10.9 (2.24) [10:54.0]	5.8 (2.47) [5:48.0]
Grand Total	93	20.5 (2.82)	171.6 (7.05)	62.4 (12.33)	1.73 (0.17)	14.2 (4.14) [14:10.8]	9.0 (2.91) [9:03]	5.0 (2.18) [5:2.4]

Note: Figures in parenthesis denotes ±SD; Figures in [ ] denotes time in min : sec.

The athletes belonging to jumps were found to be significantly younger than weightlifters ($p<0.01$). The sprinters were tallest and the weightlifters shortest and heaviest, as compared with others. The BSA of the jumpers were the lowest, significantly so from both other groups ($p<0.05$). The sprinters also exercised for the longest time in this group (mean = 12.2 min), corresponding to a vVO_2 max of 18 km/hr, significantly higher than weightlifters. Their sub-AT threshold exercise time was also significantly longer than weightlifters. But there were no significant difference in the time spent in the supra-AT zone. The results revealed that the sprinters were the physically fittest in the anaerobic group, followed by the jumpers and the weightlifters.

Table 1 (A) also revealed that the differences in ages between the aerobic and anaerobic group (taken as a whole), was not significant. The anaerobic group was found to be significantly taller than the aerobic group ($p<0.01$). The table

the anaerobic group ($p<0.01$). The anaerobic group exercised for a significantly shorter period than the aerobic group ($p<0.01$). The aerobic group, on their part exercised for a significantly longer duration with a mean vVO_2 max of 22kh/hr ($p<0.01$). The time to reach the anaerobic threshold level, or the AT-Time was significantly longer for the aerobic group than the anaerobic group ($p<0.01$). The time spent beyond the anaerobic threshold level, or the Supra-AT Time for the aerobic group athletes was found to be longer than the anaerobic group athletes ($p<0.01$). The results revealed that the aerobic group athletes had predictably the largest endurance in terms of total exercise tolerance time, AT-Time and Supra-AT Time.

Table 1 (B) depicted the means (±SD) of some selected cardiopulmonary transient of Anaerobic Group Athletes of Jump, Sprints and Weight lifting, individually and as combined, together with the aerobic group.

Table 1 (B) revealed a significantly lower

Table 1(B): Table shows the means (±SD) of some selected cardiopulmonary transients of Anaerobic Group Athletes of jumps, sprints and weight lifting and aerobic (long distance runners) group

Event	*n*	*HR max (bpm)*	*AT-HR (bpm)*	*VO_2 max (ml/kg/min)*	*AT-VO_2 (ml/kg/min)*	*AT-VO_2 max%*	*VCO_2 (ml/kg/min)*	*AT-VCO_2 (ml/kg/min)*
Athlete (Jumps)	21	183 (10.65)	156 (11.71)	52.5 (7.75)	40.3 (8.69)	76.4 (8.28)	54.6 (7.81)	73.2 (6.52)
Athlete (Sprints)	12	185 (6.76)	159 (6.79)	61.8 (13.62)	48.7 (13.57)	77.4 (15.16)	66.0 (11.16)	48.9 (10.71)
Weight lifting	10	181 (5.46)	149 (5.89)	46.6 (6.55)	31.00 (6.06)	66.4 (6.71)	19.1 (10.00)	26.8 (6.80)
Anaerobic Group (Total)	43	183 (8.59)	155 (9.83)	54.8 (10.52)	42.2 (10.81)	74.3 (11.06)	56.6 (9.39)	37.9 (8.18)
Aerobic Group (Total)	50	180 (5.97)	156 (6.51)	74.9 (10.52)	64.8 (9.01)	83.0 (5.16)	85.8 (11.15)	65.8 (8.55)
Grand Total	93	181 (7.50)	156 (8.17)	64.7 (14.95)	53.1 (16.03)	79.0 (9.44)	72.1 (10.72)	61.7 (16.00)

Note: Figures in parenthesis denotes ±SD

AT-HR in weigh lifter as compared with the jumper and sprinters ($p<0.01$). The sprinters exhibited a significantly higher value of VO_2 max and VCO_2 max as compared with weight lifters and jumper ($p<0.01$). The fractional utilization of VO_2 max at the AT was also the highest in sprinters, significantly differing from weightlifters ($p<0.01$). Table 1 (B) reiterated the fact that the sprinter had the best cardiopulmonary responses and within the anaerobic group, they were the fittest, both physically and physiologically.

The table also illustrates that the maximum heart rate was not found to be significantly different amongst the aerobic and anaerobic groups. The AT-HR value of the aerobic group was not found to be significantly different from the anaerobic group also. The VO_2 max and AT-VO_2 values of the aerobic group were found to be significantly higher than those of the anaerobic group ($p<0.01$). The fractional utilization of VO_2 max at the AT level, or AT-VO_2 max% of the aerobic and the anaerobic group was found to be significantly different at $p<0.01$. The VCO_2 max and AT-VCO_2 values of the aerobic were significantly different from the anaerobic group at $p<0.01$. Significant differences ($p<0.01$) also existed between the VCO_2 max and AT-VCO_2 values of the anaerobic group with the aerobic group.

Table 1 (C) depicted certain other selected cardiopulmonary transients in the athletes of Jumps, Sprints and weight lifting, taken together as the anaerobic group and the long distance athletes, constituting the aerobic group.

The table revealed that the sprinters exhibited the highest pulmonary ventilation within the group, both at the maximum and at the AT-Level

Table 1(C): Table shows the means (±SD) of some selected cardiopulmonary transients of Anaerobic Group Athletes of jumps, sprints and weight lifting and the aerobic group athletes of long distance running

Event	*n*	*V_E max (L/min)*	*AT-V_E (L/min)*	*fR max (min)*	*AT-fR (mon)*	*TV max (ml)*	*AT-TV (ml)*	*O_2Puls e max (ml)*	*AT-O_2 pulse (ml)*
Athlete (Jumps)	21	133.2 (19.39)	78.6 (18.49)	63.8 (10.75)	43.4 (10.93)	2093.0 (341.54)	1684.4 (322.35)	19.0 (2.93)	16.5 (3.07)
Athlete (Sprints)	12	154.3 (13.73)	78.7 (16.62)	72.2 (18.50)	43.2 (8.10)	2199.8 (308.53)	1894.8 (276.16)	23.5 (5.12)	19.8 (2.74)
Weight lifting	10	93.4 (13.52)	51.1 (7.85)	44.9 (7.16)	34.9 (5.11)	2079.7 (468.06)	2016.9 (411.32)	15.7 (2.68)	12.4 (1.86)
Anaerobic Group (Total)	43	129.8 (27.60)	72.2 (19.67)	61.7 (16.02)	41.4 (9.62)	2119.7 (360.55)	1820.4 (372.21)	19.5 (4.54)	16.5 (3.77)
Aerobic Group (Total)	50	132.4 (20.77)	82.9 (13.80)	65.7 (11.610	49.0 (10.46)	2450.8 (266.93)	2075.0 (226.01)	26.8 (5.94)	23.6 (5.45)
Grand Total	93	131.6 (24.17)	78.0 (17.51)	63.7 (13.91)	45.5 (10.72)	2286.2 (317.3)	1974.7 (290.41)	23.4 (6.45)	20.3 (5.91)

Note: Figures in parenthesis denotes ±SD

($p<0.01$). The jumpers also exhibited significant differences in VE and AT-V_E with weight lifters. The fRmax and TVmax, AT-O2 Pulse and O_2 Pulsemax of the sprinters were the highest by comparison, differing significantly from the jumper ($p<0.05$) and weightlifters ($p<0.01$). The result of Table 1(C) reaffirmed that the sprinters were the physiologically fittest within the anaerobic group, followed by the jumpers and weightlifters.

The table also exhibited that the V_E max was not found to be significantly different between the two groups. The AT-V_E values of the anaerobic group was however significantly different with the values of the aerobic group ($p<0.01$). The AT-fR value of the aerobic group was found to be different from the anaerobic group also ($p<0.05$). The TVmax and the AT-TV values of the anaerobic group were found to be significantly lower than the aerobic group at $p<0.01$. The O_2 pulse max and the AT-O_2 Pulse values of the aerobic group were found to be significantly higher that the corresponding values of the other group ($p<0.01$). The tables 1 (B) and (C) elucidated that the physiological profiles of the aerobic group was the highest or best, differing significantly from the anaerobic group.

Next, correlations were studied between the parameters of Total duration or exercise, AT-Time, Supra-AT Time, HRmax, VO_2 max, AT-VO_2 max%, AT-HR and AT-VO_2. Data of all 193 athletes (including 100 other elite athletes, belonging to games / events not discussed here), were computed by the analysis software of excel, version 5, to study the relationships between time and other important and relevant cardiopulmonary transients. The result is presented below :

The result reveals that the total exercise time was highly correlated with AT-Time, supra-AT time, VO_2 max and AT-VO_2, The AT-Time (time to reach AT), was also correlated positively with VO_2 max. The VO_2 max was also highly correlated with AT-VO_2 and AT-VO_2 with AT-VO_2 max%. The results substantiate that the total exercise time (and also vVO_2 max, since it depends on the total exercise time), is highly correlated with VO_2 max, which has been found to be an important physiological variable influencing performance. It also revealed that the vVO_2 max is highly related to VO_2 max and total exercise time.

CONCLUSIONS

The above study concluded that the aerobic (long distance) group had a very high vVO_2 max (22 km/hr), significantly higher AT-Time and Supra-AT Time, as compared with anaerobic group athletes. The VO_2 max of the aerobic group athletes was also predictably higher than their anaerobic counterparts. The vVO_2 max and VO_2 max were found to be significantly correlated with each other as well as with the total exercise time, indicating that vVO_2 max should be used as a predictor of performance, especially, endurance performance. The Physiological profile of the Indian elite long distance athletes (in terms of VO_2 max, vVO_2 max, AT-VO_2 max%, and others) were found to be comparable to international standards. Previous Indian studies (who had not used a breath-by-breath analyzer) did not report such high values for the Indian sports persons, particularly, the long distance athletes.

The anaerobic group displayed significant intra-group differences in both physical as well as in their physiological attributes. The sprinters displayed the best physical and physiological status, followed by the jumpers and lastly, weightlifters. The last group displayed an endurance capacity (VO_2 max), similar to those observed

	Ex Time	*AT-Time*	*Supra AT-Time*	*HRmax*	*VO_2max*	*AT-VO_2%*	*AT-HR*	*AT-VO_2*
Ex Time	1							
AT-Time	0.849374	1						
Supra AT	0.728198	0.309509	1					
HR max	0.034996	-0.120661	0.197439285	1				
VO_2 max	0.525161	0.550917	0.27806816	-0.07051248	1			
AT-VO_2%	0.23051	0.37833	-0.031599295	-0.22111902	0.31821531	1		
AT-HR	-0.070441	0.012296	-0.134139389	0.3764415	0.05921646	0.26546058	1	
AT-VO_2	0.526749	0.600687	0.224303141	-0.12157271	0.91133643	0.557455342	0.101269563	1

in untrained persons, indicated that the aerobic system may not be taxed to a large extent during either competition or training.

The correlations drawn, revealed that vVO_2 max, VO_2 max and allied parameters were well correlated, particularly with the total exercise time, thus corroborating the recent studies claiming a close relationship amongst these parameters and endurance performance.

REFERENCES

Astrand, I.: Aerobic work capacity in men and women, with special reference to age. *Acta. Physiol. Scand.*, **40 (Suppl. 169)** (1960).

Beaver, W.L.: A new method for detecting anaerobic threshold by gas exchange. *J. Appl. Physiol.*, **60**: 2020 (1985).

Billat, L.V. and Koralsztein, P.: Significance of the velocity at VO2 max and time to exhaustion at this velocity. *Sports Med.*, **22(2)**: 90-107 (1996).

Bruce, R.A., Gey, G.O., Cooper, M.N., Fisfer, L.D. and Peterson, D.A.: Seattle heart watch. Initial clinical, circulatory and electrocardiographic responses to maximal exercise. *Am. J. Cardiol.*, **33**: 459-565 (1974).

Daniels, J., Scardina, N., Hayes, J.: Elite and subelite female middle and long distance runners. Landers, D.M. (Ed.). Sport and elite performers. *Proceedings of the 1984 Olympic Scientific Congress.* 19-23 July. 1984. Human Kinetics, Oregon, Champaign (IL), 57-72 (1984).

De Gray: *Genetic and Anthropometric Studies of Olympic Athletes.* Academy Press, New York (1974).

Ghosh, A.K., Majumdar, P., Goswamy, A. and Khanna, G.L.: Aerobic-anaerobic Transition Level of Indian Middle and Long Distance runners. *Indian J. Med. Res.*, **88**: 371-375 (1988).

Inbar, O., Gefen, Y. and Carel, R.: Cardiopulmonary exercise testing-rationale, characteristics, and application. *Med. J. Israel. Med. Assoc.*, **12(5)**: 232-238 (1987).

Inbar O., Oren, A., Scheil, M., Owitz, M., Roftein, A., Dlim, R. and Casabury, R.: Normal cardiopulmonary responses during incremental exercise in 20 to 70 year old men. *Med. Sci. Sports Exerc.*, **26(5)**: 538-546 (1994).

Jones, N.L. and Campbell, E.J.M.: *Clinical Exercise Testing.* 2nd Ed. WB Saunders, Philadelphia, 22-47 (1982).

Jones, N.L., Makridef, L., Hitchcock, C., Chypchar, T. and Mc Carteney, N.: Normal standards for an incremental progressive cycle ergometer test. *Am. Rev. Respir. Dis.*, **131**: 700-708 (1985).

Leger, L and Boucher R.: An indirect continuous running multistage field test. The Universite de Montreal track test. *Can. J. Appl. Sport Sci.*, **5**: 77-84 (1980).

Malhotra, M.S., Ramaswamy, S.S., Joseph, N.T. and Sengupta, J.: Physiological assessment of Indian athletes. *Ind. J. Physiol. Pharma*, **16**: 55-62 (1972).

Noakes, T.: Challenging beliefs: there is always something new from South Africa. *Mobiltape of Wolffe Memorial Lecture. 43rd Annual Meeting of American College of Sports Medicine.* Cincinnati, OH (1996).

Saltin, B and Astrand, P.O.: Maximal oxygen uptake in athletes. *J. Appl. Physiol.*, **23**: 353 (1967).

Sjodin, B and Jacobs, I.: Onset of blood lactate accumulation and marathon running performance. *Int. J. Sports Med.*, **2**: 23 (1981).

Sue, DY., Wasserman, A., Moricca, B. and Casabury, R.: Metabolic acidosis during exercise in patients with chronic obstructive pulmonary disease. *Chest*, **94**: 1143-1150 (1988).

Verma, S.K., Kansal, D.K. and Sidhu, L.S.: A study of maximum oxygen uptake and heart rate during work recovery as measured on cycle ergometer on national Indian sportsmen. *Brit. J. Sports Med.*, **13**: 24-28 (1978).

Verma, S.K.: A study of the body composition in relation to functional characteristics in the top level Indian athletes. *Annli. del isef.*, 4: 37-52 (1986).

Wasserman, K., Hansen, J.E., Sue, D.Y. et al.: *Principles of Exercise Testing and Interpretation.* Lea and Febiger, Philadelphia, 12-42 (1987).

Whipp, B.J. and Ward, S.A.: Physiological determinants of pulmonary gas exchange kinetics during exercise. *Med. Sci. Sports Exerc.*, **22(1)**: 62-71 (1990).