PHYIOLOGICAL FACTORS ASSOCIATED WITH THE SUCCESS IN MARATHON RUNNING

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Summary : Marathon running is the most gruelling athletic event in international sport. Success of well trained athlete largely depends upon his perfect coordination of movements in relation to speed and optimum physiological adjustments. In order to identify the physiological factors which play crucial contributory role in successful marathon runners an evaluation study was conducted on 7 successful Indian athletes from among many competitors. Results of the study were compared between the 1st and the 7th rankers vis-a-vis the world champion in this event.

Results indicated that the maximal aerobic power and economy in 'work' involved in marathon running were most important factors for the success in this event. In addition, a comparison of the blood lactic acid level of Indian with that of the world champion revealed that the latter could sustain at 85% of his maximal aerobic power for 2 hours compared to 78% and 62% of1st and 7th ranker Indian athletes. There was not much of a difference between the world and Indian champion in this respect.

Further, thermoregulatory efficiency was also found to play an important contributory role in determining success in this event.

It is considered that a suitable index incorporating all the above factors is likely to be the most appropriate screening procedure in the evaluation programme of marathon runners for the reasons as discussed.

Key words : marathon performance; physiology of marathon runners; factors in marathon success

INTRODUCTION

Among the varieties of athletic events, few offer a greater challenge than the marathon running in which one has to tolerate the prolonged exhaustive efforts more than 2 hrs to cover a distance of 42 *km* (26.2 miles). Success in marathon performance is therefore depends upon a perfect integration of various physiological processes leading to a superior oxygen transport mechanism in this class of athletes. Many workers (6,9,10, 13, 21, 22) have reported extremely large $\dot{V}o_2$ max values of long distance runners. However, Costill (4) reported a poor relationship between $\dot{V}o_2$ max values and best marathon performance in 27 marathon runners and further suggested that running economy (6) and utilisation of percentage $\dot{V}o_2$ max (7) are more important for success in long distance running events. Studies have, therefore, been conducted to identify the various physiological factors associated with the success in long distance running performance in the Indian runners.

MATERIAL AND METHODS

Seven long distance runners of the Indian army were studied one week after a marathon competition. Out of these 7 runners, 3 represented the national squad for various long distance events. The winner of the present event was reigning national record holder in marathon performance. The detailed physiological and performance characteristics of these athletes have been shown in Table I. These athletes reported to the laboratory in the morning after a light breakfast and were given 1 hr rest after which physiological responses in sub-maximal and maximal exercises were recorded in separate occasion.

TABLE I : Physical and performance characteristics of the long distance runners.

Sl. No.	*Name*	*Age (yrs)*	*Height (cm)*	*Weight (kg)*	*Performance time in Marathon run*	*Relative position in the race*
1	SNS	34	167.4	54.4	2 hrs 15 min	First
2	RY	25	166.0	60.0	2 hrs 17 min	Second
3	IS	26	174.0	60.3	2 hrs 21 min	Third
4	PS	27	177.6	60.5	2 hrs 23.5 min	Fourth
5	Pr.S	22	168.7.	53.0	2 hrs 24 min	Fifth
6	PR	25	177.3	57.4	2 hrs 27 min	Sixth
7	NS	28	172.2	64.2	2 hrs 37 min	Seventh

Maximum oxygen uptake capacity ($\dot{V}o_2$ max) : This was determined by giving the subject a graded exercise on a bicycle ergometer. The work rates were increased until there was no further increase in oxygen consumption with successive increase in work rate. Each exercise lasted for four minutes and expired air was collected during the last min and was analysed for oxygen and carbon dioxide content. The expired air composition was determined either by using paramagnetic 0_2 analyser and infrared Co_2 analyser or by using scholander microgas analyser. The oxygen consumption was plotted against the work rate and the flattening of the oxygen curve was taken as the maximum oxygen uptake capacity of the subjects.

Maximum exercise ventilation ($\dot{V}E$ max) : Maximum ventilation during maximal exercise on the bicycle ergometer was noted by using Cowan-Parkinson, gas meter.

Maximum heart rate (max HR) : This was recorded during the maximal exercise on the bicycle ergometer, by means of an ECG. On few occasions, palpation method was also resorted to by well-trained workers.

Maximum blood lactate (max LA) : This was estimated five min after the maximal exercise (1). Physiological responses in different rates of submaximal exercises were also recorded on these athletes after 10 min of exercise. Pre-armed capillary blood was drawn 5 min after the exercise to determine the lactate level in blood.

RESULTS

The energy cost of running a 42 *km* race in little over 2 hrs of the winner and seventh position holder, with that of the world record holder, is presented in Table II. The average speed maintained by the world champion was 321.8 m/min at an average energy cost of 20.7 KCal/min and the totalenergy cost of the performance was 2656 KCal; while running the same distance, the winner of the present race maintained an average speed of 305.1 m/min and the seventh position holder's average speed was 262.4 m/min. The average energy spent by the winner and tne seventh ranker were 18.0 and 15.9 kCal/min respectively. However, on the total energy cost for the performance was of the same order. The physiological responses during maximal effort in the present marathon participants have been shown in Table III. On appraisal, it is observed that the maximal aerobic power ($\dot{V}o_2$ max) ranged between 3.08 to 4.40 L/min in different athletes. However, when the $\dot{V}o_2$ max value is expressed in terms of relative body weight, it is observed that there is a distinct gradient between the athletes performance data and the $\dot{V}o_2$ max value.

TABLE II : Energy cost of Marathon performance by different athletes.

Name	Position	Total time taken to complete the the run	Av. speed maintained during the the run (m/min)	Av. energy spent (kCal/min)	Total energy required to complete the run (kCal)
DC	World Champion	2 hrs 8 min	321.8	20.7	2656
SNS	Frst position in the present race	2 hrs 15 min	305.1	18.0	2430
NS	Seventh position in the present race.	2 hrs 37 min	262.4	15.9	2499

It is, therefore, presumed that superior performance ability in long distance running is associated with higher maximal aerobic power. Thus the winner of the present race was having the highest value of 79.0 *ml/kg/min* as against 53.7 *ml/kg/min* of the seventh position holder. However, this trend was not maintained uniformly. In respect of other functions, i.e. maximum exercise ventilation ($\dot{V}_E$ max), maximum heart rate, maximum 0_2 debt and blood lactate levels, none of these parameters indicated any significant difference between these athletes.

TABLE III : Physiological responses during maximal effort in bicycle ergometer.

Sl No.	Name	$\dot{V}O_2$ max (L/min)	$\dot{V}O_2$ max (ml/kg/min)	VE max (L BTPS/min)	HR max (beats/min)	L Acid (max) (ml/100 ml)	O_2 debt (max) (L/O)	O_2 debt (max) (ml/kg)
1	SNS	4.40	79.0	76.3	176	110	5.71	105
2	RY	4.23	70.5	85.6	182	125	6.60	110
3	IS	4.12	68.4	79.2	181	113	5.60	93
4	PS	4.00	66.1	76.4	180	85	5.93	98
5	Pr.S	3.29	62.0	78.5	184	92	5.40	102
6	PR	4.20	65.4	74.4	181	76	5.78	90
7	NS	3.08	53.7	71.7	183	104	6.02	105

To identify the other factors, associated with success in marathon run, it was thought worthwhile to evaluate the efficiency in work in the winner as well as in the seventh ranker in the present event. It has been shown in Fig. 1. It is apparent that the winner (SNS) used his energy more economically than the seventh position holder (NS) in terms

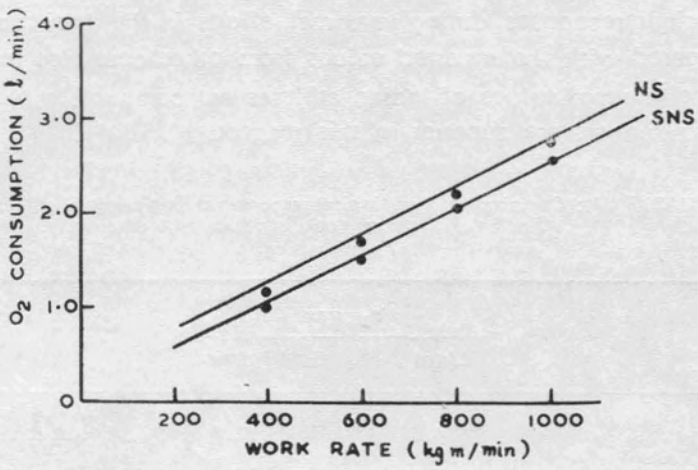

Fig. 1 : Oxygen consumption in different grades of activity on bicycle ergometer in the winner (SNS) and seventh position holder (NS) in a marathon run.

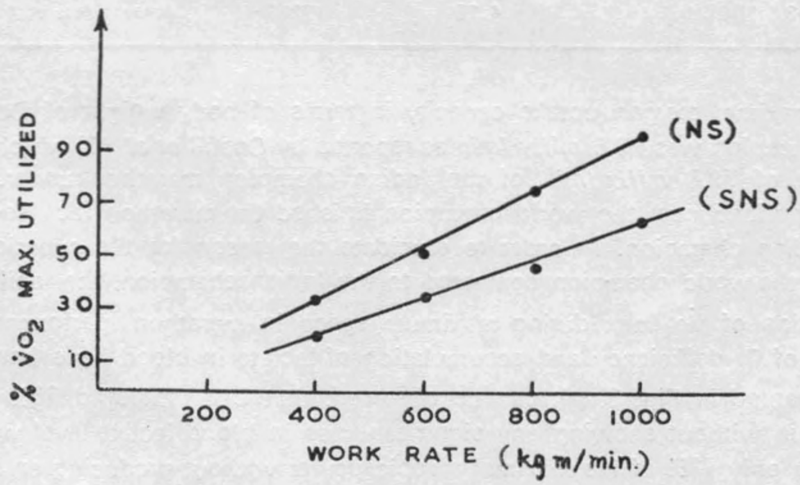

Fig. 2 : Percentage of $\dot{V}o_2$ max utilized in different grades of activity in the winner (SNS) and seventh position holder (NS) in a marathon race.

of cost for a given work. When the same data is presented as percentage of $\dot{V}o_2$ max utilization in Fig. 2 the difference between them is more clear and is better appreciated. The economy in work as well as superior maximal aerobic power of SNS who was the winner of the race is clearly discriable from Fig. 2.

Physiological responses during maximal efforts in the Indian marathon runners have been compared with the reported values from other countries in Table IV. It is observed that the $\dot{V}o_2$ max values of Indian athletes are comparable to the US runners, whereas Swedish runners are superior in this respect.

TABLE IV : Comparative physiological responses during maximal efforts in Indian and other national Marathon champions.

Country		$\dot{V}o_2$ *max*		*Reference*
		L/min	*ml/kg/min*	
USA	4	4.66	72.9	Costill *et al.* (6)
U.K.	1	4.15	70.0	Menier and Pugh (17)
Sweden	3	4.75	79.5	Saltin and Astrand (22)
India	3	4.25	72.9	Present data on Indian athletes

The maximal oxygen uptake capacity in terms of body weight of Derek Clayton the world champion was 79.6 *ml/kg/min* as reported by Costill *et al.* (7) which was similar to the value of 79.0 *ml/kg/min* of the Indian champion marathon runner. However, in terms of performance, the world champion finished the marathon race seven minutes ahead of Indian champion. In order to elucidate the reason for the superiority of performance of the world champion compared to the Indian champion, the ability to utilize a large fraction of $\dot{V}o_2$ max during maximum speed in marathon performance without contribution of 0_2 defficiency and accumulation of lactate in blood have been examined and are presented in Fig. 3. It can be observed, that DC employed 85% of max $\dot{V}o_2$ during the run without showing any significant rise in blood lactate level whereas SNS could utilize only 78% of his maximal aerobic power without producing an significantly higher lactate level, while the seventh ranker (NS) could extend upto 62% of $\dot{V}o_2$ max only during prolonged work.

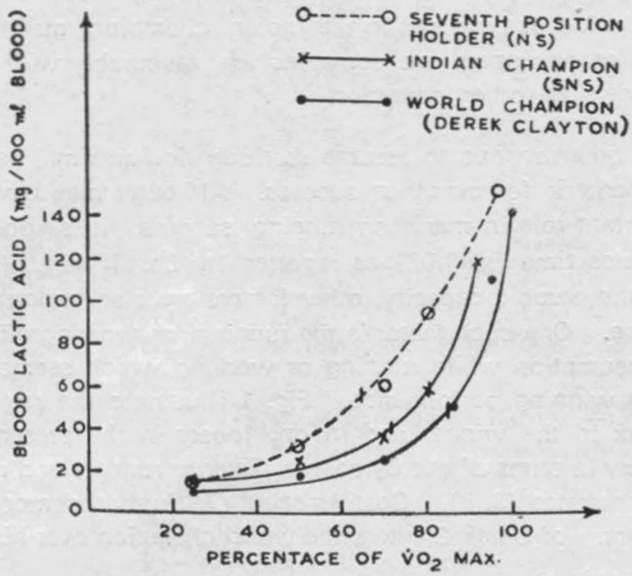

Fig. 3 : Relationship betwen percentage $\dot{V}o_2$ max of work and lactate level in blood in different marathon runners.

DISCUSSION

Long distance runners are expected to maintain an extremely high rate of energy expenditure for 2.1 to 2.5 hrs. The total energy cost for such a performance works out to be 2400 to 2650 kCal (approx) depending upon terrain, air resistance (12, 19) running economy and body weight of the athlete (14). In order to maintain an average speed of 20–21 kmph, the physiological system of the body need to be geared up to supply energy at a high rate, for a prolonged period. After the early findings Hill and Lupton (11), exercise physiologists have associated the limits of human performance with the ability to consume oxygen maximally ($\dot{V}o_2$ max). The maximal oxygen uptake is thus a measure of maximal motor power by the aerobic responses (24). The aerobic work power is, therefore accepted as a dominant factor for a good performance in endurance events (3, 10, 17, 21, 22, 25). From these evidences, it is natural to presume that the highest values for maximal oxygen uptake capacity are achieved by the long distance runners. Many workers (6, 10, 13, 22, 23) have examined runners who hold world record in various running events and reported extremely large $\dot{V}o_2$ max values. In an earlier study (23), the various physiological functions associated with O_2 transport mechanism in Indian and world athletes have been compared. In the present study also we find that the $\dot{V}o_2$ max values in the Indian champion marathon runner is much higher than all the other runners and compares very favourably with values of champion long distance runners of other countries.

But, it will be erroneous to assume that superior maximal aerobic power is the only physiological criteria for marathon success. Although max oxygen transport capacity plays an important role in marathon running, success, it is poorly correlated with marathon performance time ($r=0.08$) as reported by Costill *et al.* (7). In addition to the actual size of the aerobic capacity, other factors are also important in determining a winning performance. One such factor is the running or working efficiency as measured by the oxygen consumption while running or working which seems to play an equally important role in a winning performance. Fig. 1 illustrates the rate of O_2 consumption during bicycle work in the winner and in one looser in the present study. Similarly the running economy in terms of net O_2 cost in distance runners and middle distance runners has been demonstrated (3, 5). Costill, *et al.* (7) further demonstrated the superiority in running economy of Derek Clayton, the world champion over his other counterparts.

In addition to the maximum oxygen uptake capacity and running efficiency, another factor which is important for long distance running is the ability to utilize large fraction of the aerobic capacity during actual competitition Fig. 3 demonstrates that the world champion marathon runner was able to tolerate 85% $\dot{V}o_2$ max during his marathon performance (5) whereas the Indian champion marathon runner could maintain 78% $\dot{V}o_2$ max during his marathon performance and the seventh position holder maintain only 65%. This obviously indicates that the rate of oxygen utilization during marathon running is not limited by maximum O_2 transport capacity alone but also by the individual's capability in maintaining the maximal rate of oxidative phosphorylation by the working muscles. This observation is in confirmity with many other studies (2, 5), where it has been demonstrated that well trained runners are capable of maintaining energy expenditure in excess of 50 *ml/kg/min* or between 70–80% of $\dot{V}o_2$ max during the marathon. It has also been reported (15) that runners with a longer training and competitive history are capable of tolerating greater relative work loads during the marathon than the younger non experienced runners. However, it is not clearly understood whether this ability is actually a factor of training or age *per se*.

Thermoregulation forms an integral part of marathon race. Evidences from various studies (8, 16, 18) indicate that tolerance of a very high body temperature and fluid loss is a necessary condition of success in marathon running. Robinson (20) reported a fluid loss of 5.1 lit or 6.7% of body weight after a successful marathon run. Dehydration of this magnitude if rapid and combined with heat stress reduces endurance performance and is a cause of collapse in many athletes. It has been concluded from these studies that heat elimination limits performance for some runners even in comparatively mild conditions and that successful runners have sweat rates equal to the highest values seen in heat acclimatized individual and can tolerate exceptionally high rectal temperature. However, this aspect could not be examined in the present study.

It is thus observed that success in marathon performance depends on (i) superior O_2 transport mechanism, (ii) economy in running, (iii) utilization of greater $\dot{V}o_2$ max during maintainance of top speed without developing O_2 deficiency and lactate accumulation and (iv) capacity to tolerate higher core temperature and efficient heat dissipation mechanism are essential physiological factors. Costill *et al.* (7) proposed MPQ (marathon performance quotient) = M/S where 'M' is the percent max $\dot{V}o_2$ during marathon competition and 'S' is the percent max $\dot{V}o_2$ at 268 m/min speed.

It is, therefore, proposed that marathon performance efficiency (MPE) can be better assessed if a combined index is worked out consisiting of maximal aerobic power, economy in running power, capacity to utilize higher fraction of $\dot{V}o_2$ max without anaerobiosis and thermoregulatory efficiency. However, the relative contribution from each of these four factors has to be worked out on larger number of successful marathon runners.

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