

JEPonline
Journal of Exercise Physiologyonline

Official Journal of The American
Society of Exercise Physiologists (ASEP)

ISSN 1097-9751
An International Electronic Journal
Volume 7 Number 1 February 2004

Fitness and Training

**VARIATIONS IN BASAL METABOLIC RATE WITH INCREMENTAL TRAINING LOAD
IN ATHLETES**

VENKATA RAMANA Y, SURYA KUMARI MVL, SUDHAKAR RAO S, BALAKRISHNA N

Dept. Of Physiology, Biophysics Division, National Institute of Nutrition, Indian Council Of Medical Research,
Hyderabad, India

ABSTRACT

VARIATIONS IN BASAL METABOLIC RATE WITH INCREMENTAL TRAINING LOAD IN ATHLETES. **Venkata Ramana Y, Surya Kumari Mvl, Sudhakar Rao S, Balakrishna N. JEPonline.** 2004;7(1):26-33. This study was conducted to measure the basal metabolic rate of athletes during three different phases of training; Transition (TP), Pre-competition (PP) and Competition (CP). Twelve national level male athletes, aged between 18 and 20 years were recruited. Anthropometry, body composition and BMR were measured. The quantification of training was done by time allocation pattern combined with measurements of oxygen consumption, heart rate and mechanical power output relationships in all three phases. The results showed an increase of 1.2 folds in training intensity and 2 folds in training duration from transition to competition phase of training. These training changes resulted in a 1.5 kg weight gain, 1.6 kg LBM gain and 9% increase in 24-hour BMR. There was also an increase in 1.5 Kcal/kg body weight (2.8 Kcal/M² and 1.7 Kcal/kg LBM when expressed in terms of BMR) and 12 L/min in M_{VE} Max from TP to CP of training. This study concludes that the BMR varies with the quantum of training and hence it must be measured periodically to identify energy needs. From the data of this study an attempt was made to provide phase wise prediction equations of BMR for athletes.

Key Words: Training Intensity, VO_2 max, work rate, Quantification, Prediction Equations.

INTRODUCTION

It is well established that measurement of basal metabolic rate (BMR) provides an important energy baseline for the formulation of a sound diet, as it contributes about 50-70% of the total daily energy expenditure (1). In addition to BMR, the additional variables than combine to influence the quality of an athlete's diet and training are age, sex, climate and body composition (2,3).

The FAO/WHO/UNU (1985) study on energy and protein requirements of humans, suggested that various components of energy expenditure be expressed as multiples of BMR (4). Even though many prediction equations are available for BMR, the validity of their application to athletes can be questioned due to the limited involvement of athletes in the subjects used to formulate these equations. For the BMR equations that have been developed with athletes (5,6), none provide an assessment of the change in BMR with changes in training. Therefore, the present study was carried out to measure BMRs of athletes during different phases of training. It was theorized identification of changes in BMR would detect needed changes in caloric intake, which in turn would support the maintenance of desirable weight, body composition and peak performance.

Methods

This study was carried out on twelve healthy national level male sprinters, aged between 18 and 20 years, who were recruited from the Sports Authority of Andhra Pradesh, Hyderabad, India. The subjects were briefed about the purpose and scope of the study and their written consent was obtained for participation. The ethical committee of the institute had approved the design and protocol of the study. The subjects were brought to the laboratory, between 5.30 am and 6.00 am, self transported in a vehicle and were given rest for one hour. Anthropometric measurements such as height (anthropometric rod, SECA, Germany) up to 0.1cm accuracy and weight (weighing scale, SECA, Germany) with 0.1 kg accuracy were measured using standard procedures. The body mass index (BMI) and body surface area (BSA) were calculated using standard equations (7,8). Body composition was assessed from skin-fold thickness measurements taken at four sites; biceps, triceps, sub-scapular and supra iliac (Holtain calipers, U.K.) with 0.2 mm accuracy. Body density was derived from the sum of the skin-folds using the age and sex matched equations of Durnin & Womersley (9). Body density was converted to body fat using the Siri equation (10), from which lean body mass (LBM) and fat mass were calculated.

Whole body BMR was measured by open circuit indirect calorimetry using the Douglas bag method. Each athlete was studied between 7.00am and 8.00am while lying awake in a post-absorptive state. The collected expired air samples in the Douglas bags were analyzed for volume (Singer dry gas meter, DTM325, USA), for oxygen (Taylor's Servomex- paramagnetic analyzer-OA272, UK), for CO₂ (LB-2, Beckman's infrared analyzer, USA), after prior calibration. The values were corrected to STPD. The BMR was calculated by using the Weir equation, assuming one liter of oxygen consumed approximates 5 Kcal in a mixed diet (11). The respiratory exchange ratio (RER) was derived using the ratio between carbon dioxide production and oxygen consumption. Heart Rates (HR) were also recorded using heart rate monitor (POLAR, PE-3000, Finland).

A graded exercise test (GXT) was given to each athlete to identify HR-O₂ and HR-power output (PO) relationships. Each athlete was given necessary instructions and precautions prior to the test and a familiarization trial was given one week prior to actual testing. The graded exercise test (GXT) was conducted on a treadmill (Venky, India) using the modified Bruce Protocol (12) to evaluate maximal oxygen consumption (VO₂max) and maximal power output (PO-max) of the athletes. The protocol continued till the subject expressed his inability to continue further or the subject attained the predicted maximal heart rate, whichever occurred first.

The time-allocation pattern (13) (TAP; recording of the time spent by each individual in various day-to-day physical activities both in occupational (training) and non-occupational hours) was noted for each athlete separately. This information was recorded by a trained investigator who stayed with the subject for 24 hours/7day a week and the average of seven days was taken to represent the 24 hour activity pattern. The total

daily energy expenditure (TDEE) was measured by recording the TAP and measuring energy cost of various day-to-day physical activities both in non-occupational and training hours by use of a portable respiratory gas meter (KM-Meter, Max Planck Institute, Germany). The quantification of training in terms of intensity and duration was done by TAP combined with measurement of oxygen consumption, heart rate monitoring method as well as HR-O₂, HR-PO relationships (14,15). All these parameters were studied during the Transition (TP), Pre-competition (PP) and Competition (CP) phases. Each phase constituted of four months duration.

Statistical Analyses

Changes in the physical and physiological parameters were analyzed using SPSS (10.1 package). Means and standard deviations, repeated measure methods of ANOVA and multiple regression analyses were done on all the parameters studied to note the differences between the phases. Data are presented as mean \pm SD and significance was accepted at $p < 0.01$.

RESULTS

The results of the physical characteristics including anthropometry and body composition are given in Table 1. The mean height of these athletes was increased by 0.5 cm with a considerable increase in weight by 1.5 kg from TP to CP, without any significant variation between first two phases (TP to PP). The BMI was increased from TP to CP by about 2%. The body surface area was also significantly increased from TP to CP. However, no significant difference between first two phases was found in all these parameters.

It can be understood from the results that the body composition was altered by an increase in LBM by 1.6 kg (2.6%) with a 0.1 kg reduction (not significant) in fat mass. However, no significant alteration was found in LBM in first two phases of training.

Table 1: Physical Characteristics of the Athletes (n=12)

Parameter	TP	PP	CP
Height (cm)	170.0	170.5	170.5
Weight (kg)	65.0	66.5	66.5
BMI (kg/m ²)	22.2	22.5	22.5
Body Surface Area (m ²)	1.75	1.78	1.82
LBM (kg)	55.0	56.6	56.6
Fat Mass (kg)	10.0	9.9	9.9

Values are expressed as mean \pm SD; variation in superscript indicates significance of difference between mean values of phases. **P<0.01, ***P<0.001, NS=Not Significant.

The basal metabolic rates (BMR) data are presented in Table 2. The 24-hour BMR was significantly increased from TP to CP, without any significant rise between first two phases of training. On the other hand, the BMR was found to increase from TP to PP with no further rise to CP when expressed in terms of unit mass of body weight. Similar observations were made when BMR was expressed per unit LBM. However, the BMR when expressed in terms of unit BSA increased from TP to PP and then to CP.

Table 2: Basal Metabolic Rate of the Athletes (n=12)

1.008 ^a ? 0.10	1451.8 ^a ? 145.16	23.7 ^a ? 1.84	34.9 ^a ? 2.61	26.3 ^a ? 1.52	
1.041 ^a ? 0.09	1499.8 ^a ? 138.15	24.6 ^b ? 1.51	36.2 ^b ? 0.06	27.9 ^b ? 2.45	
1.100 ^b ? 2.69	1584.4 ^b ? 151.19	25.2 ^b ? 1.71	37.7 ^c ? 0.07	28.0 ^b ? 4.27	
16.35	16.35	9.26	12.38	5.63	
***	***	***	***	*	

Values are expressed as mean ? SD; variation in superscript indicates significance of difference between mean values of phases. *P<0.05, ***P<0.001, NS=Not Significant.

During the exercise test, the energy expended in terms of BMR (BMR multiple factor) at maximal workload was almost similar in all the 3 phases of training (Table 3), but the athletes could perform more work (WR) in CP than the other two phases.

Table 3: Physiological Characteristics of Athletes at Maximal Load of Graded Exercise Test (n=12)

3015.4 ^a	71.6 ^a	188 ^a	14.6 ^a	16.1 ^{ab}	2099.3 ^a
? 541.6	? 4.99	? 10.3	? 3.16	? 2.79	? 171.66
3254.8 ^a	83.94 ^b	188 ^a	15.0 ^a	17.3 ^b	2319.3 ^b
? 258.8	? 10.64	? 11.2	? 1.75	? 1.07	? 206.63

Values are expressed as mean?SD; variation in superscript indicates significance of difference between mean values of phases. *P<0.05, ***P<0.001, NS=Not Significant.

Quantification of training (Table 4) showed that the duration of training was significantly increased by 1.8 fold and 2.0 fold from TP to PP, and TP to CP, respectively. The energy expenditure (Kcal/min) minute was comparable in first two phases and significantly increased in CP. The intensity of training expressed in terms of work rate (kpm/min) increased significantly by 1.20 fold (20.5%) from TP to CP (Table 4).

The percent contribution of 24 hr BMR in total daily energy expenditure along with the BMR multiple factor of athletes in different phases of training are given in Table 5. The percent contribution of BMR was about 50.2% in both TP and PP, while it was reduced to 46.5% in CP. The BMR multiple factor (the ratio between TDEE and 24 hr BMR) was found to be 1.81, 1.98 and 2.15 during TP, PP and CP of training respectively. Based on the results of the present study, the 24-hour BMR prediction equations were developed and presented for each phase using subject height and weight as independent variables (Table 6).

Table 4: Energy Cost And Quantification Of Training In Athletes (n=12)

<i>Training Phase</i>	<i>Duration (min)</i>		<i>Training Intensity (kpm/min)</i>
	88.0 ^a ? 3.85	7.987 ^a ? 1.47	825.6 ^a ? 120.73
	158.0 ^b ? 14.73	7.330 ^a ? 0.44	883.8 ^a ? 1.51
	171.0 ^c ? 16.24	8.987 ^b ? 5.19	994.7 ^b ? 1.71
<i>F-Ratio</i>	403.27	11.99	11.92
<i>P-Value</i>	***	***	***

Values are expressed as mean?SD; variation in superscript indicates significance of difference between mean values of phases. ***P<0.001.

Table 5: Percent Contribution of BMR In TDEE and BMR Multiple Factor of Athletes In Different Phases of Training (N=12)

<i>Training Phase</i>	<i>BMR Kcal/day</i>	<i>TDEE Kcal</i>	<i>BMR Multiple Factor</i>
	1451.8 ^a ? 145.6	2629.3 ^a ? 214.67	
	1499.8 ^a ? 138.15	2980.6 ^b ? 324.12	
	1584.4 ^b ? 144.07	3409.8 ^c ? 148.18	

Values are expressed as mean?SD; variation in superscript indicates significance of difference between mean values of phases.

Table 6: Prediction Equations for 24-hr BMR of Athletes using Height and Weight During Different Phases of Training

<i>Training Phase</i>	<i>Equation</i>	<i>R²</i>	<i>F-Ratio</i>
	(Ht ? 9.629) ? (Wt. ? 14.968) ? 1140.2		
	(Ht ? 0.584) ? (Wt. ? 19.257) ? 211.01		
	(Ht ? 7.529) ? (Wt. ? 14.305) ? 628.27		

Ht = Height in cm, Wt = Weight in Kg.

DISCUSSION

BMR plays a crucial role in human energy metabolism by providing a strong basis for the understanding and formulation of a sound diet (1,2). In the present study, the 24-hour BMR of athletes significantly increased from TP to CP by 9% without any significant variation between first two phases of training. The increase in BMR might be due to an over-all increase in body surface area and/or body weight, resulting in an increase in metabolically active tissue. This was also evident from the studies of Schneider and Foster (16), Durnin (17), Brozek & Grande (18), and Dalzeal & Potteger (19). There were also some close evidences to show that BMR increases with an increase in body weight and lean body mass (4,18,19). Similar observations were found in the present study in that there was a significant increase in 24 hour BMR with an increase in body weight and lean body mass from TP to CP as a consequence to incremental training load. This association is also evident from the high positive correlation between 24-hour basal metabolic rates (BMR) and body weights as well as between BMR and LBM.

It is difficult to make comparison of BMR of these athletes with other athletes since there is scant literature available from India and other parts of the world. In a study carried out by Poelhman (20) BMR was measured in male athletes, resulting in a 24 hour BMR of 1712 Kcal/day. On the other hand, the studies carried out by Ramana et al (21,22) had shown the BMR of Indian athletes ranged between 1300-1450 Kcal/day. Interestingly, the 24-hour BMR of normal healthy untrained males (18-30 years, 60 kg) was found to be 1430 Kcal/day, as reported by ICMR in the recommended energy allowances for Indians (23). However, to compare the BMR of trained and untrained individuals a suitable approach might be to normalize BMR for LBM. The study reported by Poelhman et al (20) found no difference in BMR between long-distance runners and untrained men. On the other hand, many studies reported 5-19% higher BMR values when expressed as percent LBM (BMR/LBM) in trained individuals when compared to untrained individuals (20,24). It is also important to note that such comparative studies must be analyzed carefully by considering various other factors like nutritional status, physical activity pattern and degrees of adaptation to training.

A limited number of studies were available in healthy human subjects about the assessment of changes in BMR with training. The studies of Parizkova (25) showed a decrease in BMR among men at different stages of training from which it appears that longer and more strenuous training correlates with decreases in BMR. In another study carried out by Schneider & Foster (16), training was associated with average decreases in BMR approximating 7% (range 3-14%) in athletes participating either in football, swimming or basketball, while it did not change in swimmers and increased 12% in cross country runners. Apart from this, in three non-athletes who were trained for 6 weeks, the impact was variable. One had shown a fall below control over the first 28-35 days and then increased to 9% higher than control by 42nd day.

Poelhman et al (26) carried out a well-controlled endurance training study lasting for 22 days and observed that BMR per unit LBM remained unchanged when measured about 36 hours after the last training bout. Similarly, a study reported by Segal et al (27) had shown that training of one hour a day for 4 times/week on cycle ergometer at an intensity of 74% VO_2max for 12 weeks did not alter BMR that was measured 72 hours after the last training bout in 10 lean and 10 obese men. When assessing the results of the present study, the percent contribution of BMR in the 24 hour daily energy expenditure of these athletes during different phases it can be understood that it was slowly decreasing from 55.2% to 50.3% to 46.5% during TP, PP & CP respectively. Therefore, the conserved energy from BMR might be diverted to cope with the increased intensity of training load from TP to CP. In addition to this, when BMR is expressed in terms of unit lean body mass, it was significantly increased during PP and reached a near plateau during CP. Further increases in training volume or intensity may then decrease BMR. As shown by Parizkova (25), when the athletes receive overload training, the 24-hour BMR or per unit LBM reduced, presumably to conserve energy to support adaptation processes.

Based on the extensive review of literature available on the influence of various factors on BMR, the FAO/WHO/UNU (1985) expert committee reiterated that age, sex and body composition are the main influential variables to BMR. They worked out an equation to predict BMR based on the body weight (Kg) for different age and sex groups for normal healthy population that did not include athletic population. The BMR prediction equation for 18-30 years males was $13.3 \times \text{Body Wt (Kg)} + 679$. Based on this equation, and considering the body weight of the study group, the predicted value of BMR was derived. It was observed that these predicted values were estimated higher by 11%, 8% and 4% during TP, PP and CP, respectively when compared to the measured values. Hence, these equations may not be applicable to the athletic population. Therefore, an effort was made to derive phase wise 24-hour BMR prediction equations using simple anthropometric indices such as heights and weights based on the data of the study subjects using multiple regression analysis and the same were given.

CONCLUSIONS

It can be concluded from this study that the BMR should be evaluated periodically for athletes to determine variations in energy allowances so as to maintain desirable body weight and composition. The phase-dependent BMR prediction equations can be of greater use for the sport nutritionists in recommending energy allowances for the athletes.

ACKNOWLEDGMENTS

We are grateful to the athletes who have participated in the study. The help and time-to-time co-operation extended by the coaches and the administrators of Sports Authority of Andhra Pradesh are greatly acknowledged. We are also thankful to our colleagues Mr.Ashok and Mr.Premraj for the technical support extended throughout the study.

Address for correspondence: Venkata Ramana Y, Dept. Of Physiology, Biophysics Division
National Institute of Nutrition, Indian Council Of Medical Research, Hyderabad – 500 007 (A.P.), India. ;
Phone: 91-40-27008921 ext. 333; FAX: 91-40-27019074; Email: vryagnam@yahoo.com

REFERENCES

1. Astrand PO and Rodahl K. *Textbook of Work Physiology* 3rd ed, New York: McGraw-Hill 1986.
2. McArdle WD, Katch FI and Katch. VL *Exercise physiology: Energy Nutrition and Human performance*. Philadelphia: Lea and Febiger 3rd ed, 1991.
3. Davis CTM and Knibbs AV. The training stimulus: The effects of intensity, duration and frequency of effort on maximum aerobic power output. *Int Z Angew Physiol* 1971;29:299-306.
4. FAO/WHO/UNU. Energy and protein requirements Report of a joint FAO/WHO/UNU Expert Consultation. *Technical Report Series No 724, World Health Organization* 1985.
5. Sjodin AM, Forslund AH, Westeterp KR, Anderson AB, Forslund JM and Hambraeus LM. The influence of physical activity on BMR. *Med Sci Sports Exerc* 1996;28(1):85-91.
6. Thompson J and Manore MM. Predicted and measured resting metabolic rate of male and female endurance athletes. *J Am Diet Assoc* 1996;96(1):30-34.
7. Shetty PS and James WPT. Body mass index: A measure of chronic energy deficiency in adults. *FAO, Food & Nutrition Report* 1994;56:1-57.
8. Du Bois D and Du Bois EF. Clinical calorimetry Tenth paper A formula to estimate the approximate surface area if height and weight be known. *Arch Intern Med* 1916;17:863-872.
9. Durnin JVGA and Womersley J. Body fat assessed from the body density and its estimation from the skin fold thickness measurements on 481 men and women from 16-72 years. *Brit J Nutr* 1974;32:77-97.
10. Siri E. The gross composition of the body. *Adv Biol Med Phys* 1956; 4:239-280.
11. Weir JB de. New methods of calculating metabolic rates with special reference to protein metabolism. *J Physiol* 1949;109:1-9.
12. Bruce RA. Exercise testing of patients with CAD Principles and normal standards for evaluation. *Ann Clin Res* 1971;3:323-332.
13. Satyanarayana K, Venkataramana Y, Someswara Rao M, Anuradha A and Narasinga Rao BS. Quantitative Assessment of Physical Activity and Energy Expenditure Pattern among rural workingwomen. In: Agarwal KN and Bhatia BD. editors, *Update Growth*. Varanasi, Banaras Hindu University India 1985;197-205.

14. Spurr GB, Prentice AM, Murgatroyd P, Rgoldberg GR, Reina JC and Christman NT. Energy expenditure from minute-by-minute heart rate recording: Comparison with indirect calorimetry. *Am J Clin Nutr* 1988;48:552-559.
15. Christensen CG, Frey HM, Foensteliën E, Aadland E and Refsum HE. A critical evaluation of energy expenditure estimates based on individual O₂ consumption/heart rate curves and average daily heart rate. *Am J Clin Nutr* 1983; 37:468-472.
16. Schneider EC and Foster AO. The influence of physical training on the metabolic rate of men. *Am J Physiol* 1931;98:595-601.
17. Durnin JVGA. The use of surface area and body weight as standards of reference in studies on human energy expenditure. *Br J Nutr* 1959; 13:68-71.
18. Brozek J and Grande F. Body composition and Basal Metabolism in men: Correlation Analysis versus physiological approach. *Hum Biol* 1955;27:24-31.
19. Dolezal BA and Potteiger JA. Concurrent resistance and endurance training influences BMR in normal dieting individuals. *J Appl Physiol* 1998;85(2):695-703.
20. Poelhman ET, Melby CL and Badylak SF. Resting Metabolic Rate and Post-Prandial Thermogenesis in the highly trained and untrained males. *Am J Clin Nutr* 1988; 47:793-798.
21. Venkataramana Y, Someswara Rao M, Sudhakar Rao S and Satyanarayana K. Energy cost of graded workload and mechanical efficiency of sportsmen. *Indian J Med Res* 1995;101:120-124.
22. Venkataramana Y, Vindhya Ponnappa, Kapoor RN and Satyanarayana K. Energy intake Energy expenditure and Physical activity pattern of selected sports persons. *J Rehab Med Asia* 1997;1:36-45.
23. Recommended dietary allowances for Indians. *Indian Council of Medical Research* 1989.
24. Trembley A, Fontaine E, Poelhman ET, Mitchell D and Person L. The effect of exercise training on resting metabolic rate in lean and moderately obese individuals. *Int J Obesity* 1986;10:511-517.
25. Parizkova J. Role of Body Dimensions and Body Composition in Physical Fitness and Performance During Growth and Adulthood. *Curr Anthropology* 1979;3:49-54.
26. Poelhman ET, Trembley A, Nadeau A, Dussault J and Theriault G. Heridity and changes in hormones and metabolic rates with short term training. *Am J Physiol* 1986;250:E711-717.
27. Segal KR, Thomas M, Sutang L, Cadang VP and Sunyer FX. Effect of physical training on resting metabolic rate and carbohydrate metabolism in lean and obese men. Abstract *Med Sci Sport Exer* 1989; 21: 554-559.