Physiol. Res. 53: 165-170, 2004

Effects of Body Mass Index on Maximal Work Production Capacity and Aerobic Fitness During Incremental Exercise

O. OZCELIK, M. ASLAN, A. AYAR, H. KELESTIMUR

Department of Physiology, Faculty of Medicine, Firat University, Elazig, Turkey

Received February 17, 2003
Accepted May 15, 2003

Summary

The aim of this study was to investigate the relationship between cardiopulmonary fitness as indicated by maximal work rate (Wmax) production and aerobic capacities (W_{AT}), body mass index (BMI) and heart rate reserve. A total of 60 sedentary subjects (30 males, 30 females, aged 18-25 years) were enrolled in the study. Each subject performed an incremental exercise test (15 W/min) to the limit of tolerance on an electromagnetically-braked cycle ergometer. There was a negative correlation between increased BMI to Wmax capacity per kilogram body weight in male (r=–0.846, P=0.0001) and in female (r=–0.896, P=0.0001) subjects. In addition, W_{AT} for each kilogram body weight also negatively correlated with increased BMI in male (r=–0.870, P=0.0001) and in females (r=–0.807, P=0.0001). The heart rate reserve correlated negatively with increasing BMI: r=–0.699, P=0.0001 (males) and r=–0.655, P=0.0001 (females). The results of the present study have suggested that, due to the inverse correlation between BMI, Wmax capacity, aerobic fitness and heart rate reserve, it may be useful to consider BMI in establishing cardiopulmonary fitness in various subjects..

Key words
Body mass index • Exercise test • Aerobic fitness

Introduction

Exercise tests are commonly used for assessing the cardiopulmonary system functions in subjects with a different health status. It is well established that cardiopulmonary responses to exercise can be used to define pathophysiological processes that limit exercise and diagnose various diseases (Wasserman *et al.* 1994, Whipp *et al.* 1997).

A progressively increasing work rate exercise testing which provides a smoothly graded stress to the subjects is considered to be one of the most objective methods providing relevant information in impairment-disability evaluation compared to resting cardio-pulmonary measurements (Wasserman *et al.* 1994, Whipp *et al.* 1997). During exercise, cardiopulmonary system functions are associated with increased metabolic demands. When the oxygen providing capacity of the cardiopulmonary system to exercising muscles falls behind their demands during high intensity exercise, increased energy demands are compensated by the anaerobic metabolism (Wasserman *et al.* 1994). During exercise, the metabolic transition point from aerobic to anaerobic metabolism, which is called the anaerobic threshold, is a widely used concept for determining the level of aerobic fitness, muscular strength and endurance in clinical medicine and sporting activities (Wasserman *et al.* 1994).

Fax +420 241 062 164
E-mail: physres@biomed.cas.cz http://www.biomed.cas.cz/physiolres

Importantly, it has been reported that reduced cardiopulmonary fitness is associated with an increased mortality rate (Lee *et al*. 1999, Wei *et al*. 1999). Reduced aerobic fitness and exercise capacity are closely related with the level of cardiopulmonary fitness and commonly observed findings in patients with high body mass index (BMI) (Rowland 1991, Reybrouck *et al*. 1997). A reduced aerobic fitness expressed as decreased work production capacity is an important factor affecting the energy intake to consumption ratio and leading to a positive energy balance and excess fat mass (Johnson *et al*. 2000). In addition, studies in young children and adolescents showed that high aerobic fitness is associated with a reduction in risk factors related to later cardiovascular system diseases (Despres *et al*. 1990, Young *et al*. 1995). Thus, it is important to determine the relation between BMI, aerobic fitness and exercise capacity in young subjects, which can be useful as a marker of cardiopulmonary system functions.

The aim of this study was to investigate the relationship between cardiopulmonary fitness as indicated by maximal work rate (Wmax) production and aerobic capacities (W_{AT}), the body mass index (BMI) and heart rate reserve in response to progressively increasing work rate exercise test in young sedentary male and female subjects.

Methods

Thirty male (age 20.5±0.3 years, weight 76.8±3.4 kg, height 178.4±0.9 cm, BMI 24.1±1.0 kg/m^2) and 30 female (age 21.1±0.3 years, weight 66.9±2.9 kg, height 161.7±1.2 cm, BMI 25.8±1.3 kg/m^2) subjects were asked to perform a cardiopulmonary exercise test. In the present study, to eliminate the age-related decline in work production capacity, the subjects' age was limited to 18 to 25 years. The subjects had to be healthy, without known cardiac symptomatology (determined by personal history and by electrocardiography), lung disease and musculoskeletal impairment, not to be on regular medication, and to be able to complete safely a full incremental exercise test. The study was approved by the local Ethics Committee and informed consent was obtained from all subjects.

BMI was calculated as the ratio of body mass/height^2 (kg/m^2). Body weight and height were measured, in light clothing without shoes, to the nearest 0.1 kg and 0.5 cm, respectively, before the cycling test. Body compositions were assessed using the leg-to-leg bioelectrical impedance method (Tanita Body Fat Analyzer, model TBF 300), which has been shown to provide accurate measurements (Utter *et al*. 1999). In female subjects, the body compositions were determined in the follicular phase of menstrual cycle to avoid water and electrolytes imbalance, which can affect the results obtained by the bioelectrical impedance method.

The subjects were requested not to eat a heavy meal or smoke at least 2 h before the test and also refrain from taking any drug, or caffeine for a period of 12 h before the test. After becoming familiar with the testing equipment, a symptom limited maximal exercise test was performed by each subject to assess cardiopulmonary and metabolic functional capacity.

Each subject performed an incremental ramp test (Whipp *et al*. 1981) using a calibrated electro-magnetically braked cycle ergometer (LODE, Groningen, The Netherlands). The exercise test began with a warm-up of 4 min at 20 W. Pedaling speed remained between 50-70, generally 60 rpm throughout the test, and the work rate was increased by 15 W every minute with a work rate controller until the subjects could no longer continue to maintain the work rate. The cycle ergometer power was reduced abruptly again to 20 W and the subjects continued to cycle for a further 4 min.

Throughout the test, the heart rate was measured and recorded continuously at 5-second intervals using the Polar heart watch; these data were later downloaded to a computer for analysis. Heart rate reserve was estimated from the difference between heart rate at Wmax and at rest. Oxygen uptake in response to the progressively increasing work rate exercise test was estimated indirectly (Wasserman and Whipp 1975).

During exercise, minute ventilation (V_E, l/min, at body temperature saturated with water vapor at ambient pressure, BTPS) was measured with a spirometer (Pony, Cosmed). Aerobic fitness was assessed by determining the work rate at the anaerobic threshold (W_{AT}). During exercise, anaerobic threshold was estimated non-invasively using a close relationship V_E and metabolism (Hollmann 1985).

Data were expressed as mean ± S.E.M. For statistical comparison between the males and females Student's *t*-test was used. $P<0.05$ was accepted as significant. Correlation analysis was performed by using Pearson correlation test to analyze the correlation between BMI and Wmax and W_{AT} capacities for each kilogram body weight (Wmax/BW and W_{AT}/BW) and heart rate reserve.

Results

Wmax and W_{AT} were found to be 208±5 W and 120±2 W for male and 121±3 W and 75±1 W for female subjects, respectively (Table 1). The work rate at the anaerobic threshold to Wmax ratio was 58% in male and 61% in female (Table 1). Estimated peak VO_2 for each kilogram body weight was found to be 36.60±1.2 ml/min/kg in male and 27.85±1.2 ml/min/kg in female subjects (Table 1).

Table 1. The mean (±S.E.M.) values and ranges for maximal work rate production capacity (Wmax), work rate at the anaerobic threshold (W_{AT}), percentage of anaerobic threshold to maximal work rate production capacity (%W_{AT}), maximal work rate production capacity for each kilogram body weight (Wmax/BW), aerobic work rate production capacity for each kilogram body weight (W_{AT}/BW) and estimated peak O_2 uptake (VO_2peak) for each kilogram body weight in male and female subjects

	Wmax (W)	**W_{AT} (W)**	**%W_{AT}**	**Wmax/BW (W/kg)**	**W_{AT}/BW (W/kg)**	**VO_2peak (ml/min/kg)**
Male	208±5	120±2	%58	2.845±0.11	1.649±0.06	36.60±1.2
Ranges	(140-260)	(85-150)	(51-76)	(1.102-3.769)	(0.669-2.192)	(21.99-46.19)
Female	121±3*	75±1*	%61	1.947±0.11*	1.209±0.06*	27.85±1.2*
Ranges	(60-165)	(55-100)	(51-71)	(0.636-3.139)	(0.748-2.093)†	(13.83-41.02)

* significantly different from the male subjects, † anaerobic threshold was not detected in a female subject

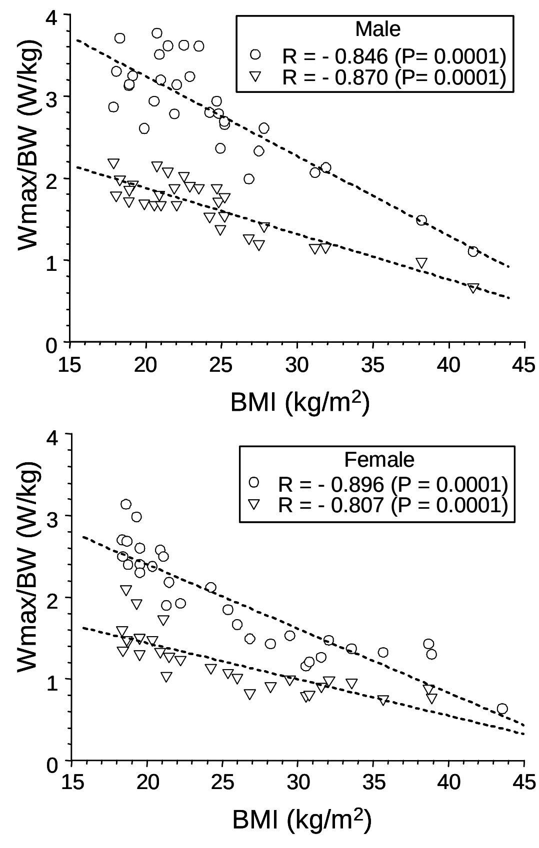

Fig. 1. The maximal work rate production capacity per kilogram body weight (Wmax/BW) (o) and aerobic capacity (∇) in relation to the body mass index (BMI) for male and female subjects.

As illustrated in Figure 1, there was a negative linear relationship between increased BMI and Wmax/BW and also increased BMI and W_{AT}/BW in both male and female subjects. Wmax/BW and W_{AT}/BW were found to be 2.845±0.11 W/kg and 1.649±0.06 W/kg in male subjects but 1.947±0.11 W/kg and 1.209±0.06 in female subjects (Table 1).

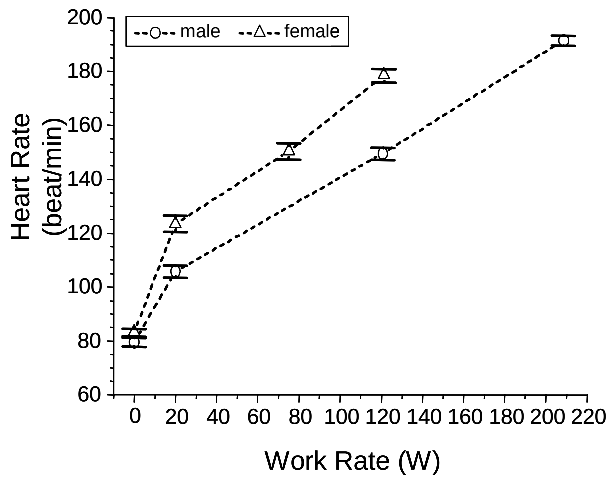

Fig. 2. The mean heart rate response to the progressively increasing work rate exercise tests: at rest, at the 20 W cycling, at the anaerobic threshold, and at maximal exercise performance, respectively: for the male (o) and female (Δ) subjects.

The heart rate responses to the incremental exercise test are shown in Figure 2. Females had higher heart rate values at the 20 W cycling compared to the males: 123.4±3.1 beat/min vs. 105.7±2.2 beat/min, and lower heart rate value at the Wmax 178.5±2.5 beat/min vs. 191.5±1.9 beat/min (Fig. 2).

The mean heart rate reserve was 111.8±2.6 beats in male and 95.3±2.3 beats in female subjects. There was a positive linear correlation between the heart rate reserve and Wmax/BW in male (r=0.593, P=0.0005) and in female (r=0.697, P=0.0001) subjects (Fig. 3). However, the heart rate reserve decreased linearly with increasing BMI in male (r=–0.699, P=0.0001) and female (r=–0.655, P=0.0001) subjects (Fig. 4).

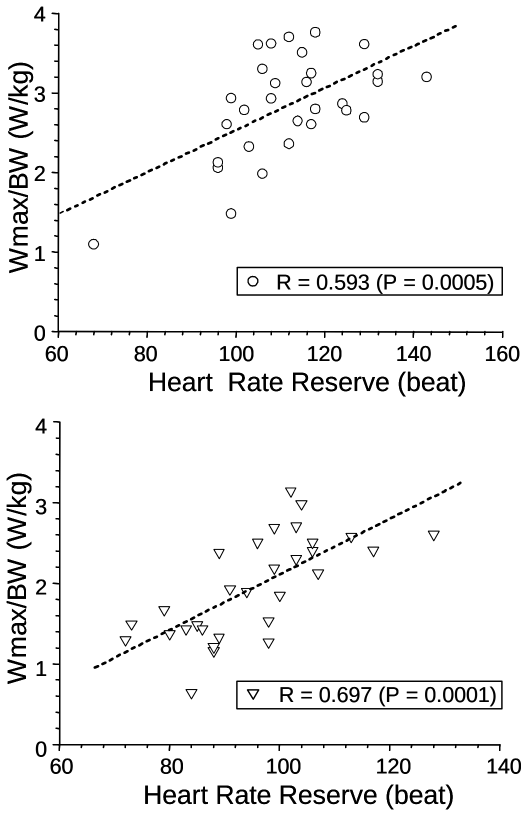

Fig. 3. The heart rate reserve and maximal work rate production capacity per kilogram body weight (Wmax/BW) for male (o) and female (∇) subjects.

While Wmax capacity was not affected by the body weight and height in the male group, we have found a negative correlation between body weight and Wmax capacity (r=–0.417, P=0.02) and a positive correlation (r=0.567, R=0.001) between height and Wmax capacity in the female group. Interestingly, age had a positive effect on Wmax capacity in the males (r=0.443, P=0.01) but a negative effect on Wmax capacity in the females (r=–0.431, P=0.01). However, W_{AT} showed no significant correlation with any of the variables in either males or females.

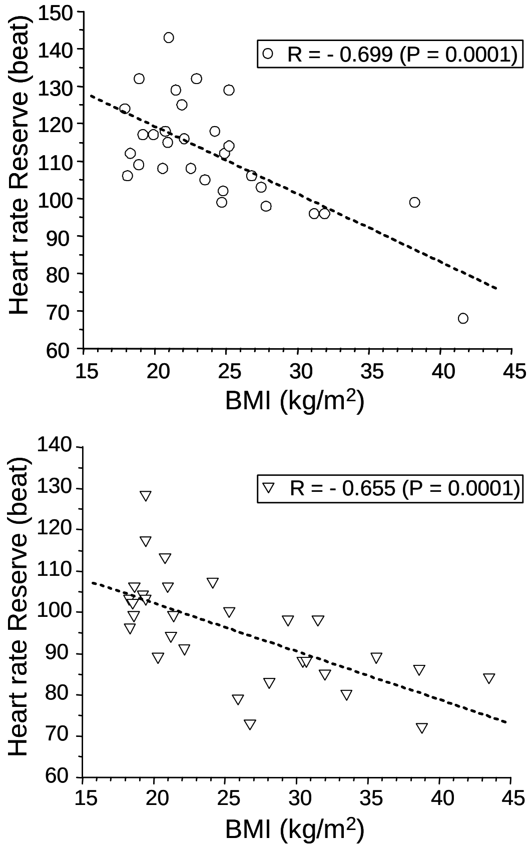

Fig. 4. The heart rate reserve and body mass index (BMI) for male (o) and female (∇) subjects.

Discussion

In the present study, it was found that aerobic power indicated by Wmax and W_{AT} production capacities per kilogram body weight negatively correlated with an increased BMI. Work capacity with regard to the body weight ratio can be useful in determination of work capacity and also aerobic fitness when measurement of VO_2 is not available (Gulmans *et al.* 1997, Rump *et al.* 2002).

Decreased physical work capacity is a common finding in patients with obesity which describes the condition of BMI greater than 30 kg/m^2 due to excess body fat mass (Rowland 1991, Reybrouck *et al.* 1997). In addition, a markedly low work production capacity has also been reported in underweight subjects (i.e. BMI lower than 17 kg/m^2) (Satanarayana *et al.* 1977, Desai *et al.* 1984).

During exercise, skeletal muscles, the heart and the O_2-carrying capacity of the blood have significant effects on work production capacity. The systematically reduced exercise capacity could be linked with a reduced O_2 supply to the active muscles. In patients with obesity, increase in type II muscle fibers decrease in type I muscle fibers (Kissebah and Krakower 1994) may also have an important effect on reduced work capacity. Furthermore, work capacity has been shown to be affected by various factors, including age (Sallis 1993, Yang *et al*. 1999), genes and environment (Bouchard and Shephard 1994) and height (Farazdaghi and Wohlfart 2001).

During exercise, it is generally accepted that heart rate increases in an almost linear manner with increasing work rate. A progressively decline in maximal heart rate in relation to the age is reported and this is suggested to be independent of gender or training status (Wiebe *et al*. 1999). However, this was not the case in our study groups in which the age of subjects varied between 18 to 25 years. There was a progressive decrease in heart rate reserve with increasing BMI in male and female subjects. A reduced cardiac performance during progressive work rate exercise in obese subjects has been reported (Salvadori *et al*. 1999). Left ventricular dimensions are enlarged in obese subjects (Nakajima *et al*. 1989, Alaud-din *et al*. 1990), which results in a reduced ventricular contractility at rest and during exercise in obese patients. In addition, elevated myocardial oxidative stress has been reported in patients with obesity (Vincent *et al*. 1999).

As expected, both Wmax capacity and W_{AT} were systematically low in female subjects compared to male subjects. It has been well established that women have a smaller blood volume and heart size than men when expressed relative to body mass or fat-free mass (Mitchell *et al*. 1992). Furthermore, women have lower hemoglobin concentration and arterial O_2 content (Mitchell *et al*. 1992) and this has an important effect on aerobic power (Howley *et al*. 1995). However, the metabolic transition point (indicating aerobic power) was present on average in 58 % of male and in 61 % of female Wmax capacities which was not significantly different between the groups. These values are in accordance with the results of other investigations in which it was found that the mean anaerobic threshold for normal subjects ranged between 35 % to 80 % of Wmax capacity (Hansen *et al*. 1984, Whipp 1994).

As a result, Wmax and aerobic work production capacities with regard to the body weight are inversely correlated with BMI and also with heart rate reserve. Thus, it may be useful to consider a strategy to increase aerobic fitness in subjects with high BMI to prevent further increases in body weight and reduction of cardiopulmonary fitness.

References

ALAUD-DIN A, METERISSIAN S, LISBONA R, MACLEAN LD, FORSE RA: Assessment of cardiac function in patients who were morbidly obese. *Surgery* **108**: 809-818, 1990.

BOUCHARD C, SHEPARD RJ: Physical activity, fitness and health: the model and key concepts. Human Kinetic Publisher: Champaign; 1994, pp 77-88.

DESAI ID, WADDELL C, DUTRA S, DE OLIVEIRA SD, DUARTE E, ROBAZZI ML, ROMERO LSC, DESAI MI, VICHI FL, BRADFIELD RB, DE OLIVEIRA JED: Marginal malnutrition and reduced physical work capacity of migrant adolescent boys in southern Brazil. *Am J Clin Nutr* **40**: 135-145, 1984.

DESPRES J-P, BOUCHARD C, MALINA RM: Physical activity and coronary heart disease risk factors during childhood and adolescence. *Exerc Sports Sci Rev* **18**: 243-260, 1990.

FARAZDAGHI GR, WOHLFART B: Reference values for the physical work capacity on a bicycle ergometer for women between 20 and 80 years of age. *Clin Physiol* **21**: 682-687, 2001.

GULMANS VA, DE MEER K, BINKHORST RA, HELDERS PJ, SARIS WH: Reference values for maximum work capacity in relation to body composition in healthy Dutch children. *Eur Respir J* **10**: 94-97, 1997.

HANSEN JE, SUE DY, WASSERMAN K: Predicted values for clinical exercise testing. *Am Rev Respir Dis* **129**: 49-55, 1984.

HOLLMANN W: Historical remarks on the development of the anaerobic threshold up to 1966. *Int J Sports Med* **6**: 109-116, 1985.

HOWLEY ET, BASSETT DR Jr, WELCH HG: Criteria for maximal oxygen uptake: review and commentary. *Med Sci Sports Exerc* **27**: 1292-1301, 1995.

JOHNSON, MS, FIGUEROA-COLON R, HERD SL, FIELDS DA, SUN M, HUNTER GR, GORAN MI: Aerobic fitness, not energy expenditure, influences subsequent increase in adiposity in black and white children. *Pediatrics* **106**: E50, 2000**.**

KISSEBAH AH, KRAKOWER GR: Regional adiposity and morbidity. *Physiol Rev* **74**: 761-811, 1994.

LEE CD, BLAIR SN, JACKSON AS: Cardiorespiratory fitness, body composition, and all-cause and cardiovascular disease mortality in men. *Am J Clin Nutr* **69**: 373-380, 1999.

MITCHELL JH, TATE C, RAVEN P, COBB F, KRAUS W, MOREADITH R, O'TOOLE M, SALTIN B, WENGER: Acute response and chronic adaptation to exercise in women. *Med Sci Sports Exerc* **24** (6 Suppl): S258-S265, 1992.

NAKAJIMA T, FUJIOKA S, TOKUNAGA K, MATSUZAWA Y, TARUI S: Correlation of intraabdominal fat accumulation and left ventricular performance in obesity. *Am J Cardiol* **64**: 369-373, 1989.

REYBROUCK T, MERTENS L, SCHEPERS D, VINCKX J, GEWILLIG M: Assessment of cardiorespiratory exercise function in obese children and adolescents by body mass-independent parameters. *Eur J Appl Physiol Occup Physiol* **75**: 478-483, 1997.

ROWLAND T: Effects of obesity on aerobic fitness in adolescent females. *Am J Dis Child* **145**: 764-768, 1991.

RUMP P, VERSTAPPEN F, GERVER WJ, HORNSTRA G: Body composition and cardiorespiratory fitness indicators in prepubescent boys and girls. *Int J Sports Med* **23**: 50-54, 2002.

SALLIS JF: Epidemiology of physical activity and fitness in children and adolescents. *Crit Rev Food Sci Nutr* **33**: 403-408, 1993.

SALVADORI A, FANARI P, FONTANA M, BUONTEMPI L, SAEZZA A, BAUDO S, MISEROCCHI G, LONGHINI E: Oxygen uptake and cardiac performance in obese and normal subjects during exercise. *Respiration* **66**: 25-33, 1999.

SATANARAYANA K, NAIDU AN, CHATTERJEE B, RAO SM: Body size and work output. *Am J Clin Nutr* **30**: 322-325, 1977.

UTTER, AC, NIEMAN DC, WARD AN, BUTTERWORTH DE: Use of the leg-to-leg bioelectrical impedance method in assessing body-composition change in obese women. *Am J Clin Nutr* **69**: 603-607, 1999.

VINCENT HK, POWERS SK, STEWART DJ, SHANELY RA, DEMIREL H, NAITO H: Obesity is associated with increased myocardial oxidative stress. *Int J Obes Relat Metab Disord* **23**: 67-74, 1999.

WASSERMAN K, WHIPP BJ: Exercise physiology in health and disease. *Am Rev Respir Dis* **112**: 219-249, 1975.

WASSERMAN K, HANSEN JE, SUE DY, WHIPP BJ: *Principles of Exercise Testing and Interpretation.* JM HARRIS (ed), Lea & Febiger, Philadelphia, 1994, pp: 18-72.

WEI M, KAMPERT JB, BARLOW CE, NICHAMAN MZ, GIBBONS LW, PAFFENBARGER RS JR, BLAIR SN: Relationship between low cardiorespiratory fitness and mortality in normal-weight, overweight, and obese men. *JAMA* **282**:1547-1553, 1999.

WIEBE CG, GLEDHILL N, JAMNIK VK, FERGUSON S: Exercise cardiac function in young through elderly endurance trained women. *Med Sci Sports Exerc* **31**: 684-691, 1999.

WHIPP BJ: The bioenergetic and gas-exchange of basis of exercise testing. *Clin Chest Med* **15**: 173-192, 1994.

WHIPP BJ, DAVIS JA, TORRES F, WASSERMAN K: A test to determine parameters of aerobic function during exercise. *J Appl Physiol* **50**: 217-221, 1981.

WHIPP BJ, WAGNER PD, AGUSTI A: Factors determining the response to exercise in healthy subjects. In: *Clinical Exercise Testing.* J ROCA, BJ WHIPP (eds), ERS Journals Ltd, Sheffield, 1997, pp 3-31.

YANG X, TELAMA R, LEINO M, VIIKARI J: Factors explaining the physical activity of young adults: the importance of early socialization. *Scand J Med Sci Sports* **9**: 120-127, 1999.

YOUNG DR, SHARP DS, CURB JD: Associations among baseline physical activity and subsequent cardiovascular risk factors. *Med Sci Sports Exerc* **27**: 1646-1654, 1995.

Reprint requests

Dr. O. Ozcelik, Department of Physiology, Faculty of Medicine (TIP), Firat University 23119, Elazig TURKEY. Fax: +90 424 233 37 70. E-mail: oozcelik@excite.com or oozcelik@firat.edu.tr