Journal of Physical Education and Sport ® (JPES), 13(1), Art 5, pp.27 - 32, 2013
online ISSN: 2247 - 806X; p-ISSN: 2247 – 8051; ISSN - L = 2247 - 8051 © JPES

Original Article

Physiological profile of elite Greek gymnasts

DALLAS GEORGE [1], ZACHAROGIANNIS ELIAS [1], PARADISIS GEORGE [1]
[1] Department of Physical Education and Sport Science,
National and Kapodistrian University of Athens

Published online: March 25, 2013
(Accepted for publication January 30, 2013)

DOI:**10.7752/jpes.2013.01005;**

Abstract:
The purpose of this study was to investigate physiological characteristics of female and male Greek international artistic gymnasts during pre-competition season. Nine female (mean ± sd: age 16.89 ± 3.62 years, height 150.17 ± 7.06 cm, body mass 46.07 ± 9.26 kg) and eleven male (mean ± sd: age 17.73 ± 1.55 years, height 161.18 ± 6.96 cm, body mass 58.09 ± 8.21 kg) international level artistic gymnasts recruited to participate in this study. They were evaluated for upper limps maximal muscular power, explosive strength of lower limp (vertical jump), maximal power of knee extensors and flexors, flexibility of hamstring and lower back, maximal oxygen consumption (VO_2max), running speed at VO_2max (vVO_2 max), running speed at ventilatory threshold (VT), HRmax, maximal blood lactate concentration, maximal alactic leg power (Wingate test) and maximal leg frequency. Females mean %body fat was significantly greater compared with the males ($p<0.01$). Flexibility and VO_2max was not different between females and males gymnasts ($p>0.05$). On the contrary there was significant difference for female and male gymnasts on mean maximal blood lactate concentration, anaerobic alactic maximal leg power, maximal leg frequency, maximal explosive leg power (vertical jump), knee extensors and flexors power, shoulders flexors and arm extensors (bench press) maximal power, arm pulls, vVO_2max, VT, and HRmax ($p<0.05$). The findings of the present study suggest that the physiological characteristics of international level gymnasts may play an important role during training. This provides coaches with valuable information on fitness parameters and helps to design individual training programs and evaluate responsiveness to training stimulus with the aim to maximize training adaptations and event specific performance.
Key words: Lactate threshold, anaerobic power, muscle power, artistic gymnastics

Introduction

Artistic gymnastics (AG) is a highly skilled sport where the physiological demands of gymnasts are continually increased as international standardization of competitive gymnastics takes place through International Federation of Gymnastics (FIG) via the Code of Points which is reviewed and updated every four years. The main physiological demands in AG centered on muscle power and strength without significantly mobilizing the aerobic processes. In terms of strength, gymnasts are amongst the strongest Olympic athletes when strength measured (relative strength) in relation to body weight (Kirby et al, 1981; Nelson et al, 1983). This has being demonstrated by their ability to support and move their body mass through various dynamic or static positions, mainly due to the support aspects of the sport (Nelson et al, 1983)**.** Especially, muscle strength of the lower limbs is very useful for rebounding from the floor and vaulting during various types of somersaults whereas muscle strength of upper limbs is very important for vaulting, pommel horse, parallel bars, and rings especially for static hold elements, e.g. iron cross, inverted cross and swallow.

Duration of gymnastics exercises in all competitive apparatus for both sexes (men and women) is small (4 to 70 s), intensity is not maximal and may be described as a combination of static and dynamic exercises. The anaerobic system has been considered as the main energy supplier during gymnastics (Astrand and Rodahl, 1976) as maximal effort and sort duration categorizes gymnastics as a high-intensity, anaerobic sport (Goswami and Gupta, 1998). The anaerobic threshold (lactate or ventilatory) also is another approach that determines the level of aerobic endurance (Allen et al, 1985). Previous research suggests that physiological data during actual gymnastics performances due to the nature of the activity and the relatively short duration of the performances required elevated (179 b.p.m.) heart rate (Jemmi et al, 2000; Viana nd Lebre, 2005). In addition, fhe flexibility demands of gymnastics are the most significant and unique aspects of gymnastics that serve to separate it from other sports. The emphasis of flexibility is due to the need of gymnasts to adopt body positions in order to fulfill technical aspects of various skills during performance as well as to reduce the possibility of injuring by preventing gymnasts from forcing limbs into overstretching during extreme ranges of motion (Hubley-Kozey and Stanish, 1990). Although, previous studies have also evaluated the physiological characteristics of gymnasts during gymnastics routines from different competitive level (Goswami and Gupta, 1998; Jemmi et al, 2000; Grantham, 2000) research is sparse regarding the physiological characteristics of gymnasts during pre-competition period, where gymnasts increase the level of fitness physiological parameters in order to taper for

Corresponding Author: DALLAS GEORGE, Email: gdallas@phed.uoa.gr

the upcoming competition. Therefore the purpose of this study was: a) to investigate the physiological characteristics of elite male and female Greek gymnasts during pre competition period.

Material and methods
Subjects

Nine female (mean ± sd: age 16.89 ± 3.62 years, height 150.17 ± 7.06 cm, body mass 46.07 ± 9.26 kg) and eleven male gymnasts (mean ± sd: age 17.73 ± 1.55 years, height 161.18 ± 6.96 cm, body mass 58.09 ± 8,.21kg) recruited to participate in this study. They were informed of the purpose, benefits and risks of the study and gave their written consent to serve as subjects. Study design was also accepted by the local ethical committee. A buttery of tests included a) anthropometrical characteristics: body mass, height, %fat-skinfold, b) strength and power of lower and upper limbs: explosive strength of lower limb (vertical jump), leg knee flexors and extensors maximal power, shoulder flexors and arm extensors maximal power (bench press), maximal alactic leg power (Wingate test) and maximal leg frequency, c) cardiorespiratory parameters: peak oxygen consumption (peakVO_2), running speed at VO_2 max, (vVO_2max), running speed at ventilatory threshold (vVT), HRmax (bpm), post test maximal blood lactate concentration (mmol/l)), and d) flexibility.

Measurements

Data collection performed one month before subjects' participation in the European championship. A rest period of 10 min was used between each test except the final treadmill trial where subjects were rested for 20 minutes. To avoid diurnal variation, all testing sessions were conducted at the same time of day (13:00 to 15:00). Verbal encouragement was given throughout testing trials.

Anthropometrical characteristics

Body mass (kg) was measured to the nearest 0.01 kg (Seca 770 UK), height (cm) was measured to the nearest 0.1cm using a stadiometer (Seca Leicester, U.K.). Skinfolds thicknesses were measured at the biceps, triceps, subscapular, and suprailiac sites, using Harpenden skinfold caliper (UK). The Durnin and Womersley (1974) equation used to estimate % body fat.

Flexibility

The hamstring flexibility was tested by using a standard sit-and-reach box (Cranlea, UK). The subjects were asked to remove their shoes and sit with their legs extended in front of them against the box. The subjects then placed one hand over the other and stretched forward along the top of the box until they could stretch no further, holding this position for 3 seconds. The best trial of the three allowed was recorded to the nearest 1.0cm (Nieman, 1990) for further analysis

Upper and lower body strength and power

Maximal power of knee leg extensors and flexors, shoulder flexors and arm extensors was measured under isotonic ballistic condition (Bosco et al, 1995). A device Ergopower (Ergotest Technology A.S. Langensub, Norway) was used based on precise measurement of the load displacement. The vertical displacements of the loads were measured with a sensor which was interfaced to an electronic device. The electronic device with the software calculated velocity, acceleration, force, power and work corresponded to the load displacement (Bosco et al, 1995). The subjects performed 3 maximal knee leg extensions and flexions, bench press for shoulder flexors and arm extensors and arm pulls with a submaximal load with 20 seconds recovery between trials. The highest power value was used for statistical analysis.

Vertical jump performance

Vertical jump tests were conducted on a switch mat (Bosco et al, 1983) connected to a digital timer (accuracy±0.001s, Ergojump, Psion XP, MA.GI.CA. Rome, Italy), which recorded the flight time (t_f) of each single jump. In order to avoid upper body work and to minimize horizontal and lateral displacements the hands were kept on the hips through the tests. The rise of the center of gravity above the ground (h in m) was measured (Bosco et al, 1998) from flight time (t_f in seconds) applying ballistic laws: $h=t_f{}^2 \cdot g \cdot 8^{-1}$ (m) where g is the acceleration of gravity (9.81 $m \cdot s^{-2}$). The subjects were jumping from a semi-squatting position without counter movement (SJ). Three trials were performed, the best result was considered for statistical analysis.

Maximal anaerobic alactic leg power

A modified wingate anaerobic test (WAnT) was used to measure maximal anaerobic alactic power. The WAnT was performed on a cycle ergometer (Monark 894E, Sweden). The seat was adjusted to a predetermined height to allow for complete knee extension with the ankle flexed at 90^o. Toe clips were used and the subject was required to remain seated for the duration of the test. The subjects warmed up for 5 minutes at a pedaling rate of 50-60 rpm against a resistance of 1 kgr. Two unloaded 5-second sprints were performed at the end of the third and fifth minutes of the warm-up period. The maximal pedaling rate (LFmax) attained during the sprints was recorded. Following a 2-minute rest, the subjects performed the 6 second WAnT against a resistance of 0.075 kg.kg body mass^{-1}. The subjects were instructed to increase pedal frequency progressively until they reach 80-100 revolutions.min^{-1} and then as fast as possible for the duration of the test while the resistance was also applied. The subjects were verbally encouraged to maintain as high the pedaling rate as possible throughout the 6-second test duration. Pedal revolutions were monitored at a resolution of 0.025 revolutions and recorded at 1-

second intervals. Subjects' peak power (PP) determined as the highest value over the first 5-second period of testing.

Cardiorespiratory parameters

Subjects performed an incremental test for the determination of VO2max, vVO2max and the ventilatory threshold (VT). Subjects fasted for four hours prior to testing. Following a 5-min warm-up, treadmill (Techogym runrace 1200, Italy) velocity was increased by 1km.h-1 every two minutes until volitional fatigue. This protocol has been validated from other studies for the determination of VO2max, VT and vVO2max simultaneously (Scott and Houmard, 1994; Noakes et al, 1990; Hill and Rowell, 1996). Gas collection was made during the last 30 s period of each 2min stage in order to allow the subject to attain steady state VO2 (LaFontaine et al, 1981). VO2 was measured by the open circuit Douglas Bag method. The subject breathed through a low resistance 2-way Hans-Rudolph 2700 B valve. The expired gases passed through a 90cm length of 340mm diameter flexible tubing in to 150-liter capacity Douglas Bags. The concentration of CO2 and O2 in the expired air were measured by using the 17630 CO2 and 17620 O2 (Vacumed, USA) Carbon Dioxide and Oxygen Analyzers. The gas analyzers were calibrated continuously against standardized gases (15,88% O2, 3.95% CO2 and 100% N2). Expired volume was measured by means of a dry gas meter (Harvard) previously calibrated against standard air flow with a 3 liter syringe. Barometric pressure and gas temperature were recorded and respiratory gas exchange data for each work load (i.e. VO2, VCO2, VE and R) were determined on a locally developed computer program based on the computations described by McArdle, Katch and Katch (Mc Ardle et al, 1991) when VEatps, FECO2 and FEO2 are known. The highest VO2 value obtained during an incremental exercise test was recorded as the subject's VO2max which also elicited a heart rate within ±10bpm of age predicted HRmax, a Respiratory Exchange Ratio (RER) greater than 1.05, and finally a score on the completion of the test equal or greater than 19 in the 15 grade Borg scale (Borg and Ottoson, 1986).

Velocity at VO_2max (vVO_2max)

The lower running speed that elicits a VO_2 equivalent with VO_2max during the VO_2max test was defined as vVO_2max (Billat et al, 1994).

Ventilatory threshold assessment

Criteria described by others were used for the VT detection (Davis, 1985; Wasserman et al, 1973). The VT was primarily determined as the VO2 or work load as which VE began to increase nonlinearly. To check the onset of hyperventilation other subsidiary criteria were used such as: 1) a systematic increase of VE/VO2, 2) a nonlinear increase of VCO2 and 3) a systematic decrease of FECO2. The highest test-retest reproducibility (r=0.93) and the closest correlation (r=0.96) with LT have been reported by Sucec (1982) when ventilatory transients such as FEO2, VE/VO2 and FECO2, VE/VCO2 are used for the VT detection. The workload before systematic increase of either VE/VO2, or VE/VCO2 with a concomitant decrease of FECO2, when a two-minute incremental protocol has been employed can be easily defined. Yoshida et al (Yoshida et al, 1981) examined the use of the Douglas Bag technique for VT assessment and found it a valid non-invasive measure of onset of metabolic acidosis (OMA).

Blood lactate analysis

Finger tip blood samples were taken 5 minutes after the completion of VO_2max test. The concentration of lactate was measured enzymatically (Dr Lange Cuvette Test LKM 140) using miniphotometer LP 20 Plus (Dr Lange, Germany). Blood was taken using 10 ml end-to-end capillaries and placed in a reagent solution hemolyzing the blood. Lactate was processed in a reaction producing quinonimin in proportion to the amount of lactate in the sample, and the concentration of quinonimin was read off in an LP 20 Plus apparatus at 540 nm (576 THz) after a 3 min reaction time.

Heart rate - Heart rates were continuously recorded throughout the tests by a Polar heart rate monitor (S 710, Finland).

Data analysis - Data were analyzed using the SPSS PC program for windows (v.15). Means and standard deviations were calculated. Independent student -test was applied to examine groups effect differences. Statistical significance was set at $p<0.05$.

Results

Statistical analysis revealed main effect for Body mass, height and % body fat (Table 1). Body mass and height were significant higher in males (58.09 & 161.18) compared to female gymnasts (46.07 & 150.17 respectively) whereas % body fat was lower (8.37±1.96 & 15.34±3.28 respectively) (table 1). The means and standard deviations of anthropometric characteristics of the gymnasts are shown in table 1.

Table 1: Anthropometrical characteristics of elite female and male gymnasts (means ±SD)

	Female (n=9)	Male (n=11)
Age (years)	16.89±3.62	17.73±1.55
Height (cm)	150.17±7.06*	161.18±6.96
Body mass (kg)	46.07±9.26*	58.09±8.21
Body fat (%)	15.34±3.28*	8.34±1.96
Flexibility test (sit & reach) (cm)	36.44±4.24	34.18±3.40

$^{*}p<0.05$, $^{+}p<0.01$

Main effect was revealed for the majority of cardiarespiratory parameters. The vVO_2 max and ventilatory threshold of male gymnasts (12.45±0.76 & 9.13±0.81 respectively) were significant higher ($p< 0.05$) compared to females (11.27±1.03 & 8.16±0.93 respectively). In addition, male gymnasts presented significant higher Lactate and HR (7.97±2.02 & 194.64±4.69 respectively) compared to females (5.84±1.81 & 189.44±17.74 respectively) (Table 2).

Also, a main effect was revealed for all muscles strengths' parameters, as male gymnasts produced significant higher values than those of females (Table 2). It has to be mentioned that shoulders flexors- arm extensors as well arm pulls in male gymnasts (243.55±70.00 & 480.22±121.30 respectively) were twice compared to those of female gymnasts (114.11±34.05 & 270.78±61.87 respectively) (table 2).

Table 2: Physiological characteristics of elite female and male gymnasts (means±SD)

Cardiarespiratory parameters	**Female (n=9)**	**Male (n=11)**
VO_2 max ($ml.kg^{-1}.min^{-1}$)	48.73±8.46	50.59±4.81
vVO2 amx ($kg.h^{-1}$)	11.27±1.03	12.45±0.76*
Ventilatory Threshold ($km.h^{-1}$)	8.16±0.93	9.13±0.81*
HR max (b.p.m.)	189.44±17.74	194.64±4.69*
Lactate ($mmol.lit^{-1}$)	5.84±1.81	7.97±2.02*
Muscle power-strengh		
Maximal anaerobic power (watt)	9.07±0.89	11.71±1.23*
Maximal leg frequency (r.p.m.)	149.33±15.29	$183.45±9.71^{+*}$
Vertical jump (cm)	22.77±1.86	$36.01±5.91^{+}$
Right knee extension (watt)	85.75±23.36	$153.09±38.33^{+}$
Left knee extension (watt)	82.78±24.35	$149.63±41.89^{+}$
Right knee flexion (watt)	64.33±19.65	$114.54±19.35^{+}$
Left knee flexion (watt)	51.00±21.65	$108.45±25.90^{+}$
Shoulder flexors and arm extensors (watt)	114.11±34.05	$243.55±70.00^{+}$
Arm pulls (watt)	270.78±61.87	$480.22±121.30^{+}$

Discussion

The present study focuses on the anthropometrical and physiological characteristics of elite female and male gymnasts that are members of Greek National team in artistic gymnastics. Comparing biometrical characteristics of our male gymnasts to those of same level in a similar age group (Jemmi et al, 2000; Grantham, 2000), they reported lower values for body height and body mass. Percentage of body fat though was comparable with the data published by Jemni et al (2000) and lower with the group studied by Grantham (2000). On the contrary, our female gymnasts were taller and heavier, with lower percentage of body fat compared with those of Grantham (2000). Regarding body height and body mass, gymnastics provides competitive opportunities for performers who are amongst the smallest and lightest of all athletes (Malina et al, 1976). In fact, it has been found that smallness is actually beneficial for gymnasts regarding competition performance (Bale and Goodway, 1990). Such a physique, with the centre of gravity near to the axis of rotation, facilitates the performance of gymnastic rotational movement, arm hang and support elements.

Values of peak oxygen consumption ($peakVO_2$) of our male gymnasts are in agreement with previous published values of 49.6 ± 4.9 $ml.kg^{-1}.min^{-1}$ measured by Goswami and Gupta (1998) after gymnastic routines. Comparable values (52.62 ± 1.29 ml $kg^{-1}.min^{-1}$) also published by Jemni and his colleagues (2000). Montpetit (1976) measured range of $peakVO_2$ values between 46-60 $ml.kg^{-1}.min^{-1}$. On the contrary, the values of our study (50.59±4.81 and 48.73±8.46 $ml.kg^{-1}.min^{-1}$) are slightly higher from those of Grantham [9] that showed values of 48.2 ± 4.9 and 42.7 ± 3.0 $ml.kg^{-1}.min^{-1}$ for male and female gymnasts respectively. It is obvious that international level gymnasts present compared with other elite athletes lower VO_2max values since the contribution of the oxidative system to the energy demands of artistic gymnastics during training and competition seems to be not important (Jemmi et al, 2000; Noble, 1975). Mean HRmax values (189.44 ± 17.74 and 194.64 ± 4.69 bpm) for females and males gymnasts respectively are higher compared with the values reported (range 162-172 bpm) by Montgomery and Beaudin (1982) for club and elite level gymnasts during performance of gymnastics routines. That might be explained by the fact that during gymnastics routines which last 50-70 sec gymnasts can't reach HR max values. Noble (1975) found a range of 160-181 bpm on three skilled women gymnasts during performance of floor exercises. Jemni and his colleagues (2000) reported also a range of HR values between 114-185 bpm during training. HR fluctuations during gymnastics performance are probably due to the intermittent nature of the events, vigorous movements and quick changes in posture (Mc Ardle et al, 1991), as well by the difficulty of gymnastics routines in these apparatus. The only study (Goswami and Gupta, 1998) which have measured HRmax during a gradient exercise test (cycle ergometer) for a male (university level) group of gymnasts reported similar (198.6 ± 5.7 bpm) values. The use of different testing device (treadmill v cycle ergometer) and the performance level of the subjects may explain differences of HRmax values at the end of an exhaustive test.

Explosive leg power is an essential factor to perform rebounding from the floor or the springboard on vaulting horse (Bosco and Komi, 1980). Mean value of our male gymnasts (36.01 ± 5.91 cm) is similar (35.3 ± 5.6) with the data of Grantham [9] for international level gymnasts. Female gymnasts presented slightly lower (27.77 ± 1.86 cm) mean value compared with the value (30.0 ± 5.4 cm) reported by the same study (Grantham, 2000). Comparing with other sports gymnasts' explosive leg power is surprisingly significantly lower. Range of values (41-68 cm) for soccer players (Douglas, 1993), track college (41-45 cm) level sprinters (Weber et al, 2008), beach volley players (Riggs and Sheppard, 2009), fencers (Tsolakis et al, 2010) have been measured. Testing procedure, the nature of training and anthropometrical characteristics of the athletes may partly explain this difference.

Flexibility (sit and reach)

Gymnastics performance depends on flexibility (Sands, 1994) due to the need to adopt certain body positions in order to perform gymnastics movements with an extreme range of motion. The flexibility demands are probably the most essential aspects of gymnastics that serve to separate gymnastics from other sports (Sands, 1994). The major joint that needs to present an increased range of motion in both sexes is hip joint where, in most cases, lower limps act during gymnastics skills with straight leg. Our results showed similar values between female and male gymnasts (36.44±4.24 vs 34.18±3.40cm) which mean that flexibility is a very important performance aspect for both sexes. Compared with other athletes, gymnasts' flexibility values are significantly higher than soccer players (Ostojic and Stojanovic, 2007) and volleyball players (Duncan et al, 2006).

Maximal blood lactate concentration

Maximal post exercise lactate accumulation value of 7.97±2.02 $mmol/l^{-1}$ for our male gymnasts is comparable with the values reported after maximal exercise to fatigue on treadmill (8.40 ± 2.50 $mmol/l^{-1}$) and cycle ergometer (8.7 $mmol/l^{-1}$) but lower after arm crank ergometry (12.1 ± 2.9 $mmol/l^{-1}$) in trained subjects (Dassonville et al, 1998). Range of 6-8 $mmol/l^{-1}$ maximal lactate values have also been reported in well trained mountain climbers on cycle ergometer (Grassi et al, 1999). The relative low blood lactate values might be the result of the nature of the incremental test to exhaustion as lactate removal and consumption balance its accumulation in muscle tissue level and blood (Brooks, 2007). Although there are no reports for gymnasts in the literature for lactate values after incremental exercise tests some studies examined the lactate response during training and competition. Goswami and Gupta (1998) reported values between 5.18 – 10.54 $mmol/l^{-1}$ for male gymnasts while performing compulsory routines three times in each apparatus in different days with an interval of 3-3½ min between subsequent repetitions. Jemni et al (2000) also reported a range of values of 2.2-11.6 $mmol.l^{-1}$lactate values for 12 male gymnasts while performing routines on six Olympic events. From these data is evident that energy demands during sort lasting gymnastics routines are mainly supported by anaerobic metabolism.

Conclusions

In summary, this study revealed the physiological characteristics in artistic gymnastics. The findings of the present study suggest that the physiological characteristics of high level gymnasts may play an important role during training. This may help athletes and coaches to design individual training programs and evaluate responsiveness to training stimulus and maximize training adaptations.

The testing methods described in this study evaluate physiological variables that may influence gymnastics performance, for the purposes of developing a physiological profile of elite Greek male and female gymnasts and establishing a database that will allow for comparison of the performance of the developmental gymnasts with international gymnasts of other countries.

References

Allen WK, Seals DR, Hurley BF, Hurley EF, Ehsanim AA, Hagbergm JM. Lactate threshold and distance running performance in young and older endurance athletes. J ApplPhysiol. 1985; 58: 1281-1284.

Astrand PO, Rodahl K. (1976). *Textbook of work physiology*. New York: McGraw Hill.

Bale P, Goodway J. Performance variables associated with the competitive gymnast. Sports Med. 1990; 10 (3) : 139-145.

Billat V, Renoux JC, Pinoteau J, Petit B, Koralsztein JP. Times to exhaustion at 100% of velocity at VO2 max and modelling of the time-limit/velocity relationship in elite long-distance runners. Eur J Appl Physiol. 1994; 69: 271-273.

Borg G, Ottoson D. *The perception of exertion in physical work.* London: McMillan Press, 1986; (Wenner-Gren Center international symposium series; vol 46.)

Bosco C, Belli A, Astrua M, Tihanyi J, Pozzo R, Kellis S, Tsarpela O, Foti C, Manno R, Tranquilli C. Dynamometer for evaluation of dynamic muscle work. Eur J Appl Physiol. 1995; 70: 379-386.

Bosco C, Cardinale M, Colli R, Tihanyi J, von Duvillard SP, Viru A. The influence of whole body vibration on jumping ability. Biol Sport. 1998; 15: 157-164.

Bosco C, Komi V. Influence of aging on the mechanical behavior of leg extensor muscles. Eur J Appl Physiol O. 1980; 45: 209-219.

Bosco C, Luhtanen P, Komi PV. A simple method for measurement of mechanical power in jumping. Eur J Appl Physiol. 1983; 50: 273-282.

Brooks GA. Lactate link between glycolytic and oxi dative metabolism. Sports Med. 2007; 37: 341-343.

Dassonville P, Lewis SM, Zhu X-H, Ugurbil K, Kim S-G, Ashe J. Effects of movement predictability on cortical motor activation. Neuroscience Res. 1998; 32: 65-74.

Davis JA. Anaerobic threshold: review of the concept and directions for future research. Med Sci Sports Exer. 1985; 17: 6–21.

Douglas T. Physiological characteristics of elite soccer players. Sports Med. 1993; 16: 80-96.

Duncan MJ, Woodfield L, Nakeeb Y. Anthropometric and physiological characteristics of junior elite volleyball players. Br J Sports Med. 2006; 40: 649-651.

Durnin V, Womersley J. Body fat assessed from total body density and its estimation from skinfold thickness: Measurements on 481 men and women aged from 16 to 72 y. Brit J Nutr. 1974; 32: 77–97.

Goswami A, Gupta S. Cardiovascular stress and lactate formation during gymnastic routines. J Sports Med Phys Fit. 1998; 38: 317-322.

Grantham NJ. Body composition and physiological characteristics of male and female national and international high performance gymnasts, J Sport Sci. 2000; 18 (1): 24-25.

Grassi B, Quaresima V, Marconi C, Ferrari M, Cerretelli P. Blood lactate accumulation and muscle deoxygenation during incremental exercise. J Appl Physiol. 1999; 87: 348-355.

Hill W, Rowell AL. Running velocity at VO_{2max}. Med Sci Sports Exer. 1996; 28: 114-119.

Hubley-Kozey CL, Stanish WD Can stretching prevent athletic injuries? J Musculoskelet Med. 1990;7 (3):21-31.

Jemmi M, Friemel FC, Lechevalier J-M, Origas M. Heart rate and blood lactate concetration analysis during a high-level men's gymnastics competition. J Strength Cond Assoc. 2000; 14 (4): 389-394.

Kirby RL, Simms FC, Symington VJ, Garner JB. Flexibility and musculoskeletal symptomatology in female gymnasts and age-matched controls. Am J Sports Med. 1981; 9(3): 160-164.

LaFontaine T, Londeree B, Spath W. The maximum steady state versus selected running events. Med Sci Sports Exer. 1981; 13: 190-192.

Malina RM, Bouchard C, Shoup .F, Demirjian A, Lariviere G. Age at menarche, family size and birth order in athletes at the Montreal Olympic Games. Med Sci Sports Exer. 1976; 11: 354-358.

Mc Ardle, WD, Katch FI, Katch VL. *Exercise physiology, energy nutrition and performance.* 1991; Philadelphia: Lea & Febiger.

Montgomery DL, Beaudin A. Blood lactate and heart rate response of young female gymnasts during gymnastics routines. J Sports Med Phys Fitness. 1982; 22: 358-365.

Montpetit R. *Physiology of gymnastics.* In JH Salmela (Ed.).The Advanced Study of Gymnastics, 1976; 183-193.

Nelson JK, Johnson BL, Con Smith G. Physical characteristics, hip flexibility and arm strength of female gymnasts classified by intensity of training across age. J Sports Med Phys Fit. 1983; 23: 95-101.

Nieman DC *Fitness and Sport Medicine.An Introduction.*Palo Alto,CA:Bull Publishing Company.1990;150-151.

Noakes TD, Norman RJ, Buck RH, Godlonton J, Stevenson K, Pittaway D. The incidence of hyponatremia during prolonged ultraendurance exercise. Med Sci Sports Exer. 1990; 22: 165–170.

Noble L. Heart rate and predicted VO_2 during women's competitive gymnastic routines. J Sports Med. 1975; 15: 151-157.

Ostojic SM, and Stojanovic MD. Range of motion in the lower extremity elite vs non-elite soccer players. Serbian J Sports Sci. 2007; 1(2): 74-78.

Riggs MP, Sheppard JM.The relative importance of strength and power qualities to vertical jump height of elite beach volleyball players during the counter movement and squat jump.J Hum Sport Exe.2009;(4)3:221-236.

Sands WA. Physical abilities profile National TOPs testing, Technique. 1994; 14(8): 15-20.

Scott BK, Houmard JA. Peak running velocity is highly related to distance running performance. Int J Sports Med. 1994; 15(8): 504-507.

Sucec, A, et al. The reproducibility of the AT by venous blood lactate and gas exchange measurements. Med Sci Sports Exer. 1982; 14(2): 127.

Tsolakis Ch, Douvis A, Tsigganos G, Zacharogiannis E, Smirniotou A. Acute Effects of Stretching on Flexibility, Power and Sport Specific Performance in Fencers. J Hum Kinet. 2010; 26: 105-114.

Viana J, Lebre E. Heart rate analysis during men's and women's artistic gymnastics routines. In M. Jemmi; J.F. Robi (Eds.), 5th International Conference of the FRAGA. 2005; (pp. 81-83). France: Association Française de Recherche en Activities Gymnastiques et Acrobatiques.

Wasserman K, Whipp B, Koyal S, Beaver W. Anaerobic threshold and respiratory gas exchange during exercise. J Appl Physiol. 1973; 35: 236-243.

Weber, K.R., Brown, L.E., Coburn, J.W., Zinder, S.M. Acute effects of heavy-load squats on consecutive squat jump performance. J Strength Cond Res. 2008; 22 (3): 726 – 730.

Yoshida S, Satake T, Mackill DS. *High temperature stress in rice.* IRRI Research Paper Series. 1981; Vol. 67.