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COMPARISON OF AEROBIC AND ANAEROBIC POWER AND LEG STRENGTH BETWEEN YOUNG DISTANCE RUNNERS AND BASKETBALL/SOCCER PLAYERS

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Abstract. The purpose of the study was to compare aerobic power ($\dot{V}O_2max$), anaerobic power (Wingate test), isokinetic peak torque of knee flexor and extensor muscles and calcaneal bone density between young distance runners and soccer/basketball players to determine whether these sports activities were associated with physiological differences. The study groups were high school male distance runners (MDR, n=10) and soccer players (SO, n=10), and college female distance runners (FDR, n=12) and basketball players (BB, n=12). Mean $\dot{V}O_2max$ in $ml \cdot min^{-1} \cdot kg^{-1}$ of lean body mass was the same in both groups of runners, and significantly lower in BB, but not in SO. Absolute values of peak anaerobic power were significantly higher in BB and SO than in the respective runners' groups. However, when divided by body mass, the difference in peak and mean anaerobic power between SO and MDR was no longer significant. BB and SO had significantly greater flexor and extensor peak torque than the respective runner's group at all velocities, as well as greater bone density estimated from bone stiffness. When divided by body mass, peak torque of knee extensors was not significantly different between BB and FDR. Higher anaerobic power, isokinetic leg strength and bone density in BB and SO than in respective runners probably result from the specific dynamic movements such as sprinting, rapid directional changes, jumping and kicking inherent in these games.

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Key words: Aerobic power - Anaerobic power - Bone density - Isokinetic strength

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Introduction

Basketball and soccer are among the most popular sports internationally. Both are dynamic games with intermittent high intensity exercise, including frequent sprinting, sudden changes in direction and jumping. These actions require adequate leg muscle strength and anaerobic power that are frequently required during critical episodes of both games [15]. Many coaches and sports scientists also believe that a high level of aerobic fitness is a prerequisite for adequate repeated anaerobic performances during these sustained intermittent activities [25]. In intense soccer matches players may run 10 km at an average intensity close to their anaerobic threshold during a 90-min game [19].

The quadriceps muscles play an important role in jumping and kicking and body stabilization at landing, while the hamstring muscles are more involved in running and stabilizing knee rotations. The musculature around the knee is important for injury prevention, as well as knee function. Common measures of knee function include peak torque and hamstring to quadriceps torque ratio.

Differences in body composition, cardiorespiratory fitness and leg strength in these three sports reflect the unique responses to training and also the inherent prerequisite physical and physiological characteristics that are advantageous for a particular sport. Few comparisons have been made of these measures between young distance runners and players of soccer and basketball. Therefore, the purposes of this study were: (a) to compare the aerobic and anaerobic work capacity of young basketball and soccer players with those of young distance runners and (b) to compare the isokinetic quadriceps and hamstring muscle strength and bone density of young basketball and soccer players with those of young distance runners.

Materials and Methods

Subjects: Informed consent was obtained from all subjects, as approved by the Chukyo University Ethics Committee. Twelve female basketball players (BB) and 12 female distance runners (FDR); and 10 male soccer players (SO) and 10 male distance runners (MDR) were selected from volunteers from intercollegiate and high school teams, respectively, to be subjects in the study. They were selected based on availability for the testing schedule. All had trained for at least 3 years in their sports. They were thoroughly familiarized with all testing equipment and procedures before the study. Descriptive anthropometric measurements are shown in Table 1.

Table 1
Mean (SEM) anthropometric and body composition values of 4 groups

	Females			Males		
	BB (n=12)	FDR (n=12)	p diff.	SO (n=10)	MDR (n=10)	p diff.
Age (yr)	20.1 (0.4)	19.8 (0.3)	0.62	17.8 (0.1)	17.7 (0.2)	0.63
Mass (kg)	55.7 (1.7)	46.6 (0.8)	<0.001	61.8 (2.4)	56.5 (1.6)	0.09
Height (cm)	167 (2)	160 (2)	0.024	171 (2)	171 (1)	0.90
BMI ($kg \cdot m^{-2}$)	20.2 (0.4)	18.2 (0.4)	0.002	21.2 (0.8)	19.3 (0.4)	0.037
Body fat (%)	17.4 (1.1)	14.2 (0.7)	0.024	12.3 (0.7)	10.4 (0.6)	0.050
SI	113 (2)	101 (3)	0.002	121 (3)	112 (4)	0.09

BMI - body mass index; SI - stiffness (bone density) index by ultrasound;
BB - basketball; SO - soccer; FDR and MDR - female and male distance runners;
p diff. - probability of difference between groups being significant

Procedures: The subjects reported to the laboratory in the morning, at least 6 hr post-prandial. Each subject performed laboratory tests on two separate days, a week apart. The first day included measurements of height, weight, body fat (%fat), bone density and maximal oxygen uptake ($\dot{V}O_2max$) and on the second visit anaerobic power and isokinetic leg muscle strength were measured. All tests were given in the same order.

Physiological tests: %fat: This was estimated from body impedance (Weight Manager 2.05, RJL Systems, Clinton, MI).

Calcaneal bone stiffness: Bone stiffness in the os calcis of the dominant foot was measured by an Achilles ultrasound bone densitometer (Lunar Corp., Madison, WI). The “stiffness index” (SI) was calculated by a computer program from the combined data of the speed of sound and the broadband ultrasound attenuation. A high correlation exists between ultrasound measurements of bone stiffness and bone density in vitro [18] and in vivo [21]. Ultrasound measurements also contain characteristics of bone architecture and elasticity [9].

$\dot{V}O_2max$: This was measured using a continuous running test on a Quinton 65 treadmill (Quinton Instrument Co., Seattle, WA). Metabolic and respiratory measurements were obtained using a MetaMax system (Cortex Biophysik GmbH, Leipzig, Germany). Following a 6-min warm up at zero% grade at 8 $km \cdot hr^{-1}$ and 9 $km \cdot hr^{-1}$ for female and male subjects, respectively, the grade was increased 2.5% every 2 min until exhaustion. $\dot{V}O_2max$ was the highest 10 s value, provided that a $\dot{V}O_2$ plateau occurred at the last work level.

Wingate anaerobic test: Anaerobic performance was measured using a friction-loaded cycle ergometer (Lode Excalibur, Groningen, The Netherlands), interfaced with a microcomputer. The braking load was set at 75 $g \cdot kg^{-1}$ of body mass [11]. The test was preceded by a 4-min warm up at 60 rpm against a resistance of 50 W with a brief (3-5 s) all-out sprint at the end of the warm-up period. The test was started after the subject reached a pedal rate of 80 rpm, where the resistance was applied. The subjects then performed a standard 30 s supramaximal Wingate cycle test, wherein they were told to maintain pedaling, while seated, at a maximal rate for the duration of the test. Verbal encouragement was given to assist subjects to reach their peak power and maintain it for 30 s. The highest Watt (W) value during the 30 s was defined as peak power, and the mean power was calculated as the average W value during the 30 s. The difference between the peak power value and the lowest value occurring at the end of the 30 s, divided by the peak value and multiplied by 100 was taken as a fatigue index (%).

Leg muscle strength test: Knee flexor and extensor muscle strength was measured with a Cybex isokinetic dynamometer (Lumex Inc., NY). Measurements were made with the subjects seated with arms folded over the chest. The pelvis and thorax were firmly strapped to avoid movement. The thigh of the dominant leg was strapped in place above the knee and a strap was placed just above the ankle. The axis of the knee was placed in line with the axis of rotation of the dynamometer. Muscle strength was measured at velocities of 30, 180 and 300 deg/s, beginning at the lowest velocity. While given verbal encouragement, the subject performed 5 maximal voluntary repetitions of alternating knee extension and flexion, with a fixed rest period of 90 s between trials. The highest peak torque value (in Newton·meters, N·m) of these 5 repetitions was recorded at each angular velocity. The hamstring/quadriceps (H/Q) ratio was calculated as a percentage at each velocity.

Data analysis: All data are given as means and SEM. One-way analysis of variance (ANOVA) was used to test for the significance of differences ($p<0.05$) of measurements between the four study groups.

Results

The physical characteristics of the four groups are summarized in Table 1. In the females, BB was significantly taller and heavier than FDR, while among the males, SO tended to be heavier than MDR, but not significantly. The %fat and BMI were lower in both FDR and MDR than in BB and SO, respectively.

Bone stiffness: Table 1 shows that SI, reflecting bone density, was higher by 12 and 8%, respectively, in BB and SO than in the respective running groups, but the difference was not significant between SO and MDR (p=0.09).

Table 2
Mean (SEM) cardiorespiratory responses to treadmill exercise in 4 groups

	Females			Males		
	BB (n=12)	FDR (n=12)	p diff.	SO (n=10)	MDR (n=10)	p diff.
HR_R (bpm)	54 (1)	54 (1)	0.92	57 (2)	53 (2)	0.10
Max HR (bpm)	187 (2)	188 (2)	0.75	174 (2)	174 (5)	0.94
$\dot{V}O_2max$ ($L \cdot min^{-1}$)	2.88 (0.07)	2.78 (0.04)	0.24	3.57 (0.15)	3.54 (0.13)	0.88
$\dot{V}O_2max$/mass ($ml \cdot min^{-1} \cdot kg^{-1}$)	52.1 (1.3)	59.7 (0.9)	<0.001	57.8 (1.3)	62.7 (2.0)	0.06
$\dot{V}O_2$ max/LBM ($ml \cdot min^{-1} \cdot kg^{-1}$)	63.1 (1.6)	69.7 (1.4)	0.005	66.0 (1.6)	70.1 (2.5)	0.19
Max O_2 pulse ($ml \cdot b^{-1}$)	15.4 (0.4)	14.8 (0.3)	0.23	20.5 (0.8)	20.4 (0.6)	0.93
Max $\dot{V}_E$ ($L \cdot min^{-1}$)	113.6 (4.3)	95.7 (5.9)	0.022	126.1 (6.2)	127.9 (5.9)	0.84
Max $\dot{V}_E/\dot{V}O_2$	39.7 (1.8)	34.4 (2.0)	0.06	35.6 (1.5)	36.3 (1.4)	0.72
Max RER	1.18 (0.02)	1.20 (0.03)	0.67	1.12 (0.01)	1.13 (0.02)	0.69

RER – respiratory exchange ratio; LMB – lean body mass; BB – basketball; SO – soccer; FDR and MDR – female and male distance runners; p diff – probability of difference between groups being significant

Aerobic power: Results of the aerobic exercise capacity tests are shown in Table 2. $\dot{V}O_2max$, expressed in L/min, was not significantly different between BB and FDR or between SO and MDR. However, a significant higher $\dot{V}O_2max$ value was observed in FDR vs. BB, when expressed relative to total or lean body mass. The values per total or lean body mass were also higher for MDR than SO, but not significantly. The max HR and max O_2 pulse were similar in the two groups of each gender, indicating that the arteriovenous O_2 difference (O_2 extraction) was also similar. Maximal pulmonary ventilation (max $\dot{V}E$) was significantly higher in BB than FDR (114 vs. 96 $L \cdot min^{-1}$), but in the male groups the values were similar and consequently max $\dot{V}E/\dot{V}O_2$ was lower in FDR than BB (p=0.06). The maximal respiratory exchange ratio (RER) was not significantly different between female or male groups and neither was resting HR, with all groups showing lower resting HRs than the untrained norm.

Table 3
Mean (SEM) anaerobic power measurements (Watt) in 4 groups

		Females			Males		
		BB (n=12)	FDR (n=12)	p diff.	SO (n=10)	MDR (n=10)	p diff.
Peak power	W	532 (27)	379 (7)	<0.001	647 (27)	568 (24)	0.040
	W/kg	9.6 (0.4)	8.1 (0.1)	0.002	10.5 (0.3)	10.0 (0.3)	0.27
Mean power	W	447 (20)	334 (8)	<0.001	567 (26)	520 (20)	0.17
	W/kg	8.0 (0.3)	7.2 (0.1)	0.017	9.2 (0.1)	9.2 (0.2)	0.92
Fatigue index	(%)	24.4 (1.9)	16.4 (1.6)	0.004	21.7 (1.0)	16.3 (1.9)	0.024

BB – basketball; SO – soccer; FDR and MDR – female and male distance runners; p diff. – probability of difference between groups being significant

Anaerobic power: The Wingate anaerobic test results are shown in Table 3. Peak power outputs were significantly higher in the basketball and soccer players than in the respective runner's groups, but mean power was only significantly higher in BB than FDR. When expressed relative to body mass, significant differences were still apparent in the females, but not in the males. The fatigue index was significantly lower in both groups of runners than in the respective BB and SO groups.

Leg muscle strength: Fig. 1 shows the peak torque for knee flexors and extensors at three angular velocities for the groups. The hamstring and quadriceps muscles achieved significantly higher torque values at all three velocities in BB and SO than in the respective runner's groups. When the peak torque values were expressed relative to body mass the statistical differences were diminished. The torque in the extensors was no longer significantly greater in BB than FDR and the value for flexors for SO was no longer significantly higher than MDR at 30 deg/s.

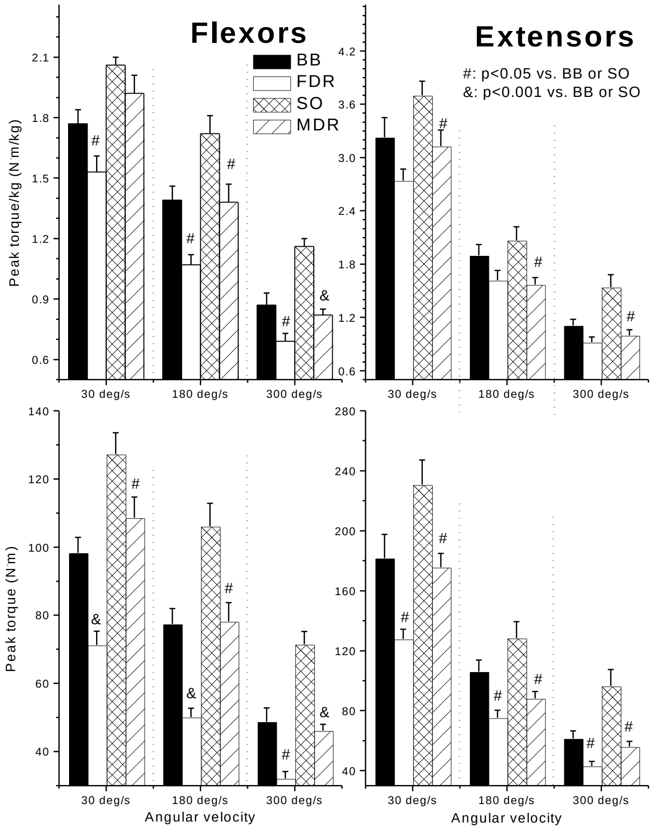

Fig. 1

Isokinetic measurements of maximal knee flexion and extension at angular velocities of 30, 180 and 300 deg/s in groups of basketball players (BB), female distance runners (FDR), soccer players (SO) and male distance runners (MDR). Lower panel shows peak torque (N·m) and upper panel shows peak torque relative to body mass (N·m/kg). Values are mean ± SEM

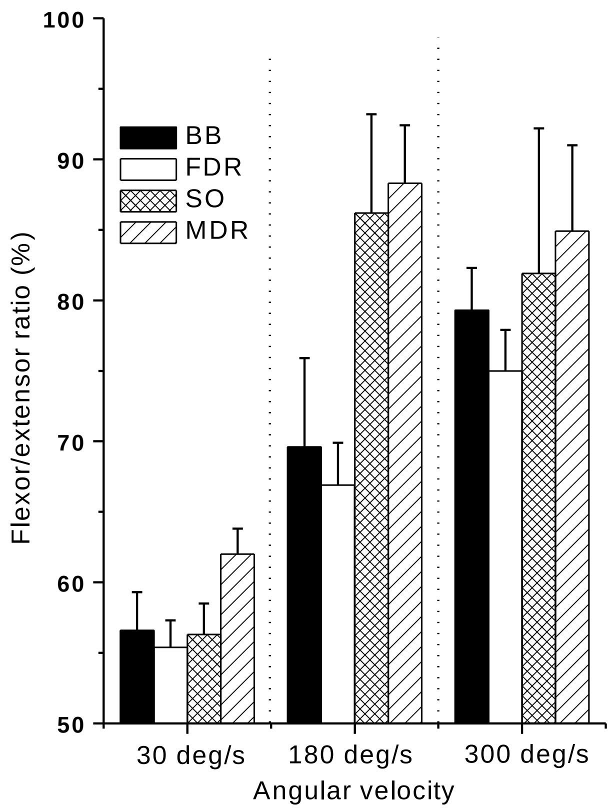

Fig. 2
Knee flexion (hamstrings)/extension (quadriceps) peak torque ratios in four subject groups. Values are ratio ± SEM. No differences were significant between BB and FDR or between SO and MDR

Fig. 2 shows the flexor/extensor or hamstring/quadriceps (H/Q) ratio in the groups, demonstrating that there was no significant difference between runners and their respective groups of basketball or soccer athletes of the same gender. The H/Q ratio was always lower for SO and higher for BB compared with runners, but not significantly.

Discussion

The basketball players were taller and heavier than the distance runners, as would be expected because of that sport's pre-selection of height. However, male soccer players were the same height as the runners and somewhat heavier (p=0.09). The %fat and BMI in both male and female runners' group were significantly lower than the male SO and the female BB. The %fat for SO (12.3%) was identical to that reported for elite soccer players in Saudi Arabia, having a mean age of 24 yr [2] and not much different from the 11% value reported for elite soccer players in England [8]. The mean %fat of 17.4% in BB (Table 1) is higher than the 15.8% reported for Canadian Intercollegiate female basketball players [20], but lower than the 20.8% reported for American College players [24].

The average bone density estimate of 112 for the four groups was higher than the 89 reported for 94 non-athletic college women (age=20 yr) and the 94 for 62 men (age=19) that were previously measured in our laboratory [13]. The force imposed on the calcaneus is highly correlated with the magnitude of the ground reaction force. Activities such as sprinting and landing from jumps generate greater external loads on the calcaneus and the greater SI in BB and SO than distance runners can be attributed to these repetitious movements.

Aerobic power: $\dot{V}O_2max$ in both groups of runners was higher than the respective groups of BB and SO when expressed relative to total or lean body mass, however only the differences in the females were significant, suggesting that soccer is associated with a greater aerobic capacity than basketball. The $\dot{V}O_2max$ in BB of 52.1 $ml \cdot min^{-1} \cdot kg^{-1}$ is higher than the 50 reported for elite Canadian [20] and American [24] college players and closer to the 51.3 reported for the Canadian National team [22]. The slightly higher $\dot{V}O_2max$ in BB in this study is likely due to the athletes' smaller body size (55.7 kg) because of their youth and also their year-round strenuous conditioning and skills training. A direct relationship between $\dot{V}O_2max$ values and basketball success has been suggested [3]. The specific intermittent and intense exercise required in successful basketball games requires both anaerobic and aerobic energy production in combination with a large muscle mass and neuromuscular precision in passing and shooting.

The $\dot{V}O_2max$ value for SO of 57.8 in Table 2 falls within the 55-68 $ml \cdot min^{-1} \cdot kg^{-1}$ range reported for male International level soccer players, 22-26 yr of age [2,19,25,26]. It is also very similar to the 58.6 reported for elite junior Asian players [7] and the ~58.3 for Norwegian players [10]. However, these $\dot{V}O_2max$ values are all below the 62.7 value in MDR. However, in a soccer match a larger body mass is an important advantage, provided that aerobic capacity is not compromised, and this will lower the $\dot{V}O_2max$ value per mass. The aerobic energy system plays a primary role in replenishment of phosphocreatine stores and lactate removal during high intensity intermittent exercises in the competitive training cycle [12]. Accumulation of blood lactate forces players to reduce not only their work rates, but also the quality of technical and tactical game elements [23]. Therefore, players with higher $\dot{V}O_2max$, having a faster exercise recovery, have the advantage of being able to participate in more competitive and critical situations. In addition, $\dot{V}O_2max$ is positively correlated with the distance covered during a game [4]. Wisloff *et al.* [25] stated that it would be reasonable to expect about 70 $ml \cdot min^{-1} \cdot kg^{-1}$ for $\dot{V}O_2max$ in a 75 kg male elite or professional players.

The 35% higher O_2 pulse in males (Table 2) must reflect the correspondingly greater stroke volume in males than female athletes in this study; it is not likely that the O_2 extraction differed between the male and female runners during maximal exercise.

Anaerobic power: Peak power output was significantly higher in BB and SO than in the respective female and male distance runners (Table 3), as expected. Since basketball is an intermittent sport incorporating sprinting, rapid and repeated changes in direction and jumping for two 20-min periods, anaerobic energy production is required, but the aerobic requirements are less than in soccer because in basketball there are interruptions in play every few minutes and substitutions occur more frequently. The mean power output was also higher in BB and SO, but by a lesser magnitude. The two 45-min continuous work bouts in a soccer match can be considered as aerobic exercise bouts of varying intensity with frequent intermittent intense anaerobic exercise superimposed during the most decisive and competitive situations. Relative to body mass, differences between SO and MDR in peak and mean power became even less apparent. The relatively similar anaerobic power/mass in distance runners relative to soccer players may have resulted from years of strenuous interval training by runners.

Both female and male runners had a significantly lower fatigue index than the corresponding basketball and soccer players, indicating that runners can better sustain power over 30 s. This may be the result of anaerobic endurance obtained by current distance training regimes that emphasize repeated speed (interval) training. Also, the higher peak power produced by the basketball and soccer players may deplete phosphagen stores faster and consequently curtail the duration that power is applied.

Strength characteristics: As commonly reported, torque decreased with increasing velocity in all groups (Fig. 1) and the quadriceps could supply greater torque than the hamstrings at all velocities (Fig. 2). Both soccer and basketball players generated significantly greater peak torque at all angular velocities for both quadriceps and hamstring muscles than did the respective runners. The quadriceps muscles are most important for jumping (basketball) and kicking (soccer). Cabri *et al.* [6] showed that isokinetic leg strength was correlated with the maximal ball-kicking distance. The hamstring muscles play a prime role in controlling the running activities and stabilizing the knee during turns or tackles. Furthermore, the knee flexor muscles act mainly to brake the leg by eccentric contraction during this movement, hence limiting the forward motion of the leg after the foot has struck the ball. Soccer and basketball games require similar kinetic requirements, such as sprinting, jumping and direction changes, with the quadriceps playing a specific and vital role in jumping in basketball and kicking in soccer. The soccer players demonstrated higher peak torques of knee extensors at every angular velocity than those for distance runners in absolute values and also relative to body mass. This higher peak torque of knee extensors in SO than MDR can be partially explained by the fact that the soccer players had systematic strength training for extensor muscles. High knee extension strength, particularly at high speeds, is required for a game that places a more frequent demand on kicking than the jumping in basketball. Absolute strength in soccer is beneficial when attempting to move an external object such as the ball or an opponent.

The torque values of knee extensors for SO in the present study were lower than those of young (17 yr) Italian National level soccer players weighing 69 kg [16], but the values were similar when equated by body mass at 180 and 300 deg/s (2.1 and 1.5 N·m/kg, respectively). For BB the mass-corrected values interpolated at 60 and 120 deg/s for flexors and extensors in Fig. 1 are very similar to the means for the Canadian National Women’s Basketball Team (22 yr, 75 kg) [22]. Greater leg strength in BB than FDR would be expected because of the frequent sprinting, jumping, stopping and changing direction required in basketball. These differences were clear in peak torque for both muscle groups, but not for extensors when standardized for mass. The higher values for hamstring muscles in FDR may be related to the specific running motion and longer time spent at this activity.

Reports of the H/Q ratio have been frequent, but inconsistent. In this study no difference in H/Q ratio was shown at any angular velocity between the groups of the same gender. At 30 deg/s the male distance runners tended to have a higher H/Q ratio than soccer players (Fig. 2, p=0.06) due to a smaller extensor torque (15%) than flexor torque (7%) relative to SO. This may result from the lack of extensor use in running vs. playing soccer. As in previous studies, the ratio increased with increasing angular velocity. Moore and Wade [17] have suggested that the target H/Q ratio in basketball players should be 70 and 83% at 60 and 180 deg/s, which are about 12% higher than values in Fig. 2. Conversely, higher ratios at 180 deg/s were found for males in the present study for soccer players (86%) and distance runners (88%) than the 77% value reported by Magalhaes *et al.* [14] in high school football players and the 57% at 90 deg/s in elite professional soccer players. Sports medicine specialists [5] feel that low H/Q ratios may indicate a susceptibility to injury, e.g., Aagaard *et al.* [1] suggested that H/Q ratios be above 60% at low angular velocities.

In summary, $\dot{V}O_2max$ per lean body mass was the same in the male and female distance runners, but significantly lower in basketball players and only slightly lower in soccer players. Anaerobic power was higher in the basketball and soccer players than in respective runners, but relative to body mass the difference was attenuated, especially in soccer players. The relatively high anaerobic power and lower fatigue index in distance runners are probably related to their interval training emphasizing speed. Higher isokinetic peak torque per body weight was found for leg flexors and extensors in male soccer players, but only for flexors in female basketball players than runners. This probably indicates the relative lack in basketball and running of the quadriceps training specific to kicking in soccer.

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