

Maximal oxygen uptake and concentric isokinetic muscle strength in pubertal football trained and untrained boys of the same biological age

Athanasios Mandroukas*, Jan Heller

Faculty of Physical Education and Sport, Charles University, Prague, Czech Republic

*Corresponding author: thanmandrou@hotmail.com

ABSTRACT

The purpose of the present study was to examine the effects of long term (prolonged) football training on maximal oxygen uptake ($\dot{V}O_2$) and isokinetic muscle strength in young football players and untrained boys of the same biological age. Twenty football competitive boys (mean age 14 ± 0 yrs; height 165.5 ± 8.5 cm; weight 59.9 ± 9.5 kg; years of training 7 ± 3) and eighteen untrained school boys (mean age 14 ± 0 ; height 168.22 ± 10.46 cm; weight 59.3 ± 9.9 kg) of the same biological age volunteered to participate in the study. Sexual maturation classified according to Tanner's stage 3. The football players participated both in their school's physical education program and in their football team training program while the untrained group participated only in their school's physical education program (2–3 times per week for 40 min). All subjects were tested for maximal oxygen uptake ($\dot{V}O_2$) and respiratory exchange ratio (RER) on the treadmill using an open circuit spirometry. The isokinetic peak torque values of quadriceps (Q) and hamstrings (H) as well as the H:Q strength ratios were recorded. $H_{con}:Q_{con}$ was calculated as the ratio of the peak concentric torque of H to the peak concentric torque of the Q. Results showed that the trained group had significantly lower heart rate in rest ($p < 0.001$), higher RER ($p < 0.001$), maximal blood lactate (BL_{max}) ($p < 0.001$) and higher ($\dot{V}O_2$) max in both relative and absolute values ($p < 0.001$) compared to the untrained group. At angular velocities of $60^\circ s^{-1}$ and $180^\circ s^{-1}$ the relative peak torque of Q and H were significantly higher (Q = $p < 0.01$; H = $p < 0.01$). However, the absolute values of Q and H as well as the H:Q ratios at all angular velocities did not differ significantly between the two groups. The results suggest that systematic football training (intensity and duration) has a positive effect in metabolic capacity, cardiorespiratory system and neuromuscular function.

KEYWORDS

muscle strength; hamstrings; quadriceps; H:Q strength ratio; biological age; football players; puberty; maximal oxygen uptake

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INTRODUCTION

Today, children start serious athletic training at earlier ages than ever before. Both in young and adults, football is one of the most popular team sports in the world. It is commonly accepted that the physical activities of football have a positive impact in spiritual, psychological and bodily health (Hagger et al., 2001) and contributes to the maintenance of a physically active lifestyle (Krustrup et al., 2010). Regular football training, two to three times a week, caused significant cardiovascular and muscular adaptation (Nadeau et al., 2011; Krustrup et al., 2010). The aerobic capacity and the muscle strength in prepubertal and pubertal children have been a matter of long-lasting controversy (Vamvakoudis et al., 2007). Some studies demonstrated an improvement in $\dot{V}O_2$ (Eriksson & Koch, 1973; Máček et al., 1976; Lussier & Buskirk, 1977; Savage et al., 1986; Baxter-Jones et al., 1993), while other investigations (Kobayashi et al., 1978; Bar-Or, 1983; Mirwald & Bailey, 1984; Williams & Reilly, 2000) have shown little or no improvement. During puberty (13–16 years of age) occur difference in body size, aerobic power, muscle strength and performance between boys of contrasting maturity status, e.g. early versus late maturity of the same age (Malina et al., 2004). Complicating factors in this controversy has been mainly the different experimental design of the studies in this area as well as the chronological ages of the subjects (Armstrong, 1997). Most of these studies have been cross-sectional and therefore the effects of growth, development and heredity aspects may have been greater than those brought about by training (Mirwald et al., 1981; Vamvakoudis et al., 2001).

Training during childhood (prepubertal – pubertal) continues to be a subject of interest. However the results of training with children of different chronological age are difficult to separate the effects of training from these of growth. Although the isokinetic muscle strength as well as the aerobic power has been studied extensively there is no information on these variables throughout the same biological age in trained and in normal untrained children who had only the physical activities in the school. More specifically, little is known about the alteration that may occur in $\dot{V}O_{2\max}$ and muscle strength in trained and untrained children. To our knowledge the present study is the first to provide information about the aerobic power and concentric isokinetic strength of knee extensors and flexors in trained and untrained (non-athletic) boys of the same biological age. Thus, the purpose of this study was to examine and compare the difference in aerobic power and isokinetic concentric peak torque of the knee flexor and knee extensor muscles as well as the ratios between already trained and untrained pubertal boys of the same biological age.

MATERIALS AND METHODS

Participants

A total of thirty eight (mean \pm SD, $N = 38$, 20 football players and 18 untrained boys, age = 14 ± 0) subjects volunteered to participate in this study. The participants were divided into two groups: a) football players as trained group, b) untrained boys. The physical characteristics of the subjects are shown in Table 1. All subjects and their parents were informed of the nature, purpose, and the possible risks involved in the

study before giving their voluntary written consent for participation. All subjects completed a questionnaire that included their relevant medical and physical history. The exclusion criteria were: recent history of muscle injury of the lower limbs, present complaint of thigh and leg pain and any other medical problems contraindicated for experimental testing. Also, overweight boys were excluded from the untrained group. None of the subjects had been doing progressive resistive exercise 24 hours before the testing. All players in the study came from three football academies (clubs) which followed a specific training program, while the untrained came from four different schools of the same region (area). The untrained group participated only in their normal physical education program in their school and did not take part in any other sport activities. The trained group participated both in their schools physical education program and in the national championship competition games. They were a highly selective group with regard to skills, performance, size, anthropometric characteristics and physical condition. Boys of both groups were born on the first 6 months of the same year. Pubertal staging, by examination of pubic hair, penile and testicular development was performed by an experience paediatric physician, experienced in the assessment of secondary sex characteristics, state of pubic hair based on the criteria of Tanner (1962). So, the classification for the sexual maturity for both groups were in Tanner stage three. The participants visited the laboratory in order to be informed about the experimental procedures and familiarised with equipment. Leg dominance was determined by asking the boys the limb that they preferred to use when they kick the ball. The height and body weight were measured using an electronic digital scale (Seca 220e, Hamburg, Germany). Resting heart rate (HR) and resting systolic and diastolic blood pressures (sBP, dBP) were recorded before the testing. Tests were performed in a temperature – controlled laboratory (20 °C to 21 °C; ~ 50% relative humidity). The study was performed in accordance with the local university Ethics Committee guidelines and ethical standards of the Sports Medicine research.

Football training program

The football training protocol focused on the development of technical and tactical skills and on the improvement of game – related fitness. The duration of the training season was 41 weeks per year. They participated in 3 to 4 training sessions of 90 min each, per week for at least 7 years. Also, they competed in 1 game per week throughout the season. More specifically *football* training consisted of jogging, stretching, and calisthenics of approximately 45–50% of the maximal heart rate, followed by alternating 75–85% for 5–8 minutes and light 50–65% for 40–45 minutes. This period included running with and without the ball. Also, jumping and sprinting exercises were a regular part of their practice. The intensity of the session registered by telemetry (Sport Tester, Finland).

Untrained group

The school physical education program consisted of 2–3 training sessions per week and every session was lasted for 40 minutes. The content of this program consisted of ball games (e.g. football, basketball, volleyball, handball and some calisthenics). The intensity was estimated by telemetry (Sport Tester, Finland). Both the duration and the intensity of the training in this group were much less than the specific training

program of the football players. Subjects reported no musculoskeletal injuries of the lower limbs that would affect them from performing maximal isokinetic contraction.

Measurement of the isokinetic strength

Prior to testing, each subject underwent a 5-minute warm-up period on a bicycle ergometer (Monark, Varberg, Sweden) followed by 5 minute of stretching of the hamstrings and quadriceps as previous described by Mandroukas et al. (2014). The subject was then seated on the dynamometer in an adjustable chair; the upper body was stabilised with straps secured diagonally across the chest and the hips. Prior to maximal testing a series of submaximal concentric contractions were performed. Maximal isokinetic strength was recorded as the torque of the quadriceps and hamstrings muscles throughout the whole range of motion, at angular velocities of 60, 180, 300 ° s⁻¹. Peak torque was measured using a speed-controlled isokinetic dynamometer (Cybex II, Lumex Inc., Ronkonkoma, NY) with a specially designed program which included torque comparison adjusted to the weight of the leg. The knee to be tested was positioned at 90 ° of flexion, (0 ° = fully extended knee), in order to align the axis of the dynamometer lever arm with the distal point of the lateral femoral condyle. Gravity correction was performed for the tested leg. The length of the level arm was individually determined and the resistance pad placed proximal to the medial malleolus. The non-tested leg was hanging freely. Knee extension started when the knee positioned at 90 ° of the flexion while the knee flexion started when the knee was in full extension (0 °). Subjects were instructed to cross their arms over their chest and to kick the leg as hard and as fast they could through a complete range of motion. Three repetitions were carried out at each angular velocity and the best torque was used for the reanalysis. A 30 sec rest period was taken between each trial and a 60 sec rest period between each velocity measurement. During these procedures, subjects always performed maximal voluntary contractions, in which verbal encouragements was given to the subjects throughout the contractions. The concentric strength ratio between the knee flexors and the knee extensors (H : Q ratio) was expressed as the ratio between the peak values at each velocity. The conventional H : Q ratio determined as maximal hamstrings strength divided by maximal quadriceps strength.

Determination of maximum oxygen uptake

$\dot{V}O_{2max}$ was performed on a motorised treadmill (Jaeger LE 6000, Wurzburg, Germany) after a five-minute warm-up and stretching of the lower limbs. Subjects exercised to exhaustion according to a maximal incremental continuous exercise protocol consisting of ten 1-minute stages. The initial grade and speed were set at 0% at 8 and 10 km/h, respectively, and followed by an increase in speed of 1 km/h per stage with 2% stable grade. $\dot{V}O_{2max}$ values and cardiorespiratory indices were measured via an ergospirometric device based on breath by breath automated pulmonary/metabolic gas exchange system (Oxycon Pro-Jaeger, Wurzburg, Germany) using a fight face mask specially designed for children. The heart rate (HR) was recorded by means of a 12-lead electrocardiogram (Viasys) connected to the ergospirometric apparatus. Subsequently, the following additional cardiorespiratory indices were determined during the test: the exercise duration; the respiratory exchange ratio (RER); the maximal heart rate (HR_{max}). $\dot{V}O_{2max}$ was assumed when three of the four following criteria were met: a) the

HR during the last minute exceeded 95% of the expected maximal HR predicted 220-age; b) a respiratory exchange ratio ($\dot{V}CO_2/\dot{V}O_2$) at or higher than 1.1 was reached; c) $\dot{V}O_2$ reached a plateau and/or signs of subjective exhaustion were present and were no longer to run despite verbal encouragement; d) level of concentration of blood lactate higher than 6 mmol l⁻¹. Blood samples were obtained from a warmed fingertip and the concentration of blood lactate was determined in the 5th min of recovery using a lactate photometer analyser (Accusport, Boehringer Mannheim, Germany).

Statistical analysis

All data are expressed as mean \pm standard deviation (\pm SD). Independent sample T-test analysis was used to determine the differences among young football players and untrained boys. The statistical analysis was performed via the Statistical Package for Social Sciences (SPSS, version 22.0, Chicago, Illinois). The level of significance was set at $p < 0.05$.

RESULTS

The physical and anthropometric characteristics of the subjects are demonstrated in Table 1. No significant differences were found between the two groups regarding the age, height, weight, BSA and BMI. The results of the cardiorespiratory exercise testing are shown in Table 2. HR_{max}, resting systolic blood pressure (sBP_{rest}) and diastolic blood pressure (dBp_{rest}) showed no significant difference between the groups. However, the resting heart rate (HR_{rest}) was significantly lower in the trained group compared to untrained group ($p < 0.01$). Moreover, the trained group presented significantly higher RER ($p < 0.01$) and BL_{max} values ($p < 0.001$). The relative peak torque values of knee extensors and knee flexors were significantly different between the two groups as presented in Figure 1. At angular velocities of 60 ° s⁻¹ and 180 ° s⁻¹ the trained group had significantly higher peak torque value compared to untrained group ($p < 0.01$ and $p < 0.05$ respectively). However, no significant difference was found between groups in the fast angular velocity of 300 ° s⁻¹. Figure 2 shows no significant difference in absolute peak torque of the knee extensors and knee flexors between the two groups at all angular velocities (60, 180, 300 ° s⁻¹). Likewise, the H/Q peak torque ratio did

Table 1 Physical and anthropometric characteristics of the subjects (mean \pm SD)

	Trained group (n = 20)	Untrained group (n = 18)
Age (years)	14 \pm 0	14 \pm 0
Experience (years)	7 \pm 3	
Height (cm)	165.5 \pm 8.5	168.2 \pm 10.5
Weight (kg)	56.9 \pm 9.5	59.3 \pm 9.9
BMI (kg m ⁻²)	20.5 \pm 2.4	20.9 \pm 2.4
BSA (m ²)	1.6 \pm 0.2	1.7 \pm 0.2

BMI = Body Mass Index; BSA = Body Surface Area

not differ between the trained and the untrained group as presented in Figure 3. In figure 4 presented the $\dot{V}O_{2max}$ in absolute ($\text{ml O}_2 \text{ min}^{-1}$) and relative ($\text{ml O}_2 \text{ min}^{-1} \text{ kg}^{-1}$) values. The trained group showed significantly higher values in comparison with the untrained group ($p < 0.001$).

Table 2 Cardiorespiratory and metabolic values of the subjects

	Trained group (n = 20)	Untrained group (n = 18)
HR _{rest} (b min ⁻¹)	65 ± 3 **	73.1 ± 9
sBP _{rest} (mmHg)	112.9 ± 5	118.6 ± 6.8
dBp _{rest} (mmHg)	63.6 ± 5.4	62.2 ± 4.3
HR _{max} (b min ⁻¹)	197.8 ± 4.5	198 ± 5.6
Respiratory exchange ratio (RER)	1.2 ± 0.2 **	1.0 ± 0.1
BLa _{max} (mmol l ⁻¹)	8.7 ± 1.8 ***	6.4 ± 1.2

* $p < 0.05$, Trained groups vs Untrained group; ** $p < 0.01$, Trained groups vs Untrained group; *** $p < 0.001$, Trained groups vs Untrained group

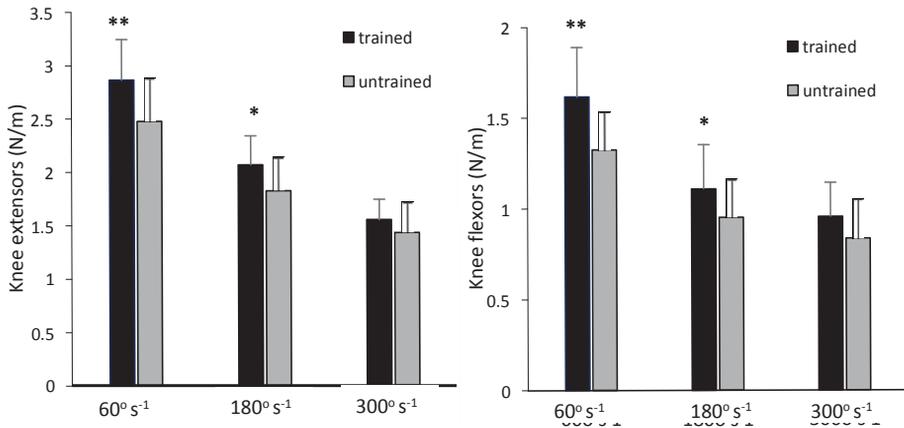


Figure 1

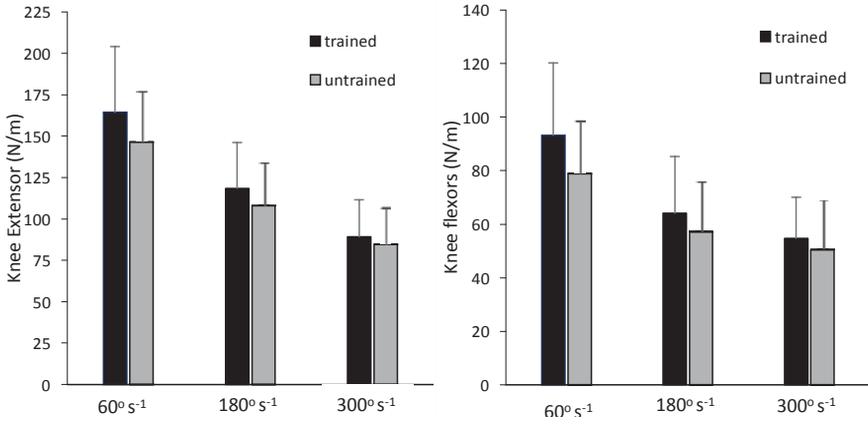


Figure 2

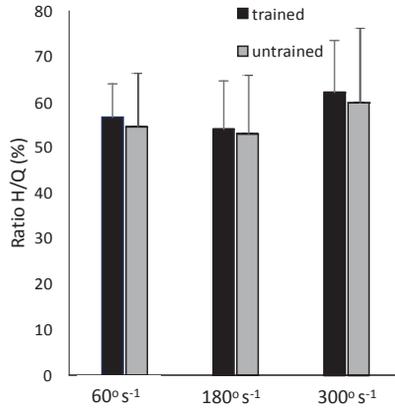


Figure 3

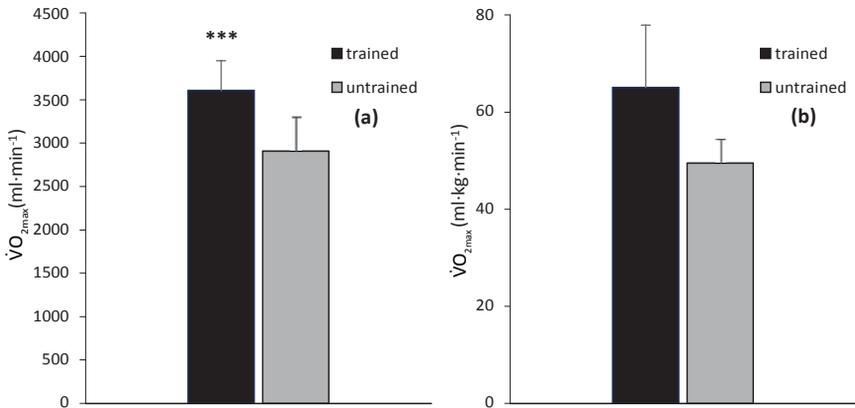


Figure 4

DISCUSSION

The purpose of this study was to examine and compare the aerobic power and the concentric isokinetic muscle strength between trained and untrained boys of the same biological age. The results of the present study showed that the $\dot{V}O_{2\max}$ both in absolute and relative values were higher in the trained group compared to untrained group. Football training during previous years has showed to have effects in aerobic power. The higher aerobic capacity that was found in the trained group may be attributed not to training only, but to hereditary endowment. In football as in all sport, young athletes constitute a highly select group chosen on the basis of size and technical skills. Football training improve the running economy, the neuromuscular function and the adaptations resulting from the higher training intensity. While significant difference were found in relative muscle peak torque, no significant difference were observed across absolute muscle strength between the two groups. The torque – velocity relationship in both groups showed a similar, adult-like pattern, namely as angular velocity increased peak torque decreased. Quadriceps strength is greater than hamstrings strength at all angular velocities. However, it is interesting to note that the absolute strength of quadriceps and hamstrings was similar in the two groups. Our results are in agreement with other studies for young football players (Berg et al., 1985; Capranica et al., 1992) who have documented no difference in isokinetic strength of the lower limbs in preadolescent boys compared to no athletes and in disagreement with all previous studies that have investigated the quadriceps and hamstrings strength in isokinetic dynamometer between groups with various chronological age. The differences in relative muscle strength were observed in slow (60°s^{-1}) and moderate (180°s^{-1}) angular velocities. The non-significant difference that was found at fast angular velocity of 300°s^{-1} may be due to the fact that boys in this age are insufficient to develop maximum torque in relation to time. It is known that in normal children the aerobic power, eccentric and concentric peak torque of the knee joint increase during growth and development. Blimkie (1989) suggested that a complex interaction of factors may contribute to the development of isokinetic leg strength during growth and maturation. Cross-sectional studies have indicated strong relationships between stature, body mass and isokinetic leg strength (De Ste Croix et al., 1999; Housh et al., 1995). Some studies (Alexander & Molnar, 1973, Kanehisa et al., 1995; Pääsuke et al., 2001) showed an increase in muscle strength of quadriceps and hamstrings in untrained children during growth and developments. Children in biological age of 14 years occur during a period of transition to adolescent (adulthood) that is often viewed within the context of sexual maturation and stature growth. The biological events that occur are complex and include changes to the nervous and endocrine system (Beunen & Malina, 1988). The trained group undergo a more systematic strength and endurance training with high frequency, intensity and durations. Despite not measuring serum testosterone in our study, our results would agree with Hansen et al. (1999) and Zakas et al. (1994) who indicated that training and age lead to hormonal and metabolic adaptations. Zakas et al. (1994) showed that training can be a stimulus for increased growth hormone and testosterone in pubertal but not in prepubertal (10 years) boys. The term muscular imbalance usually refers to the strength relationship between hamstrings to quadriceps muscles. The kinetic characteristics in football such as starting, jumping,

feints and directional and speed changes place greater stress of the lower limbs. Our results showed no significant differences in H:Q strength ratio between the groups in all angular velocities. The strength of quadriceps and hamstrings in this age seems to have a parallel increase. The data of H:Q strength ratio produced in the present study may be useful but, at least at young ages, it is doubtful whether these data can provide a definitive answer on how to develop a tool for preventing hamstrings or quadriceps muscle injuries. It must be pointed out that the relationship of function between hamstrings and quadriceps muscles in terms of the strength and muscle balance in practice plays a key role in the movement of the knee joint, which is why it is of great interest and is given special attention both in sport medicine as well as in the rehabilitation settings. The results of the present study indicate that football training has a positive effect in metabolic capacity, cardiorespiratory system and muscle strength of the lower limbs. In summary, the results suggest that football training improved $\dot{V}O_2$ max and muscle strength of knee extensor and flexor muscles more than the expected increases which were attributed to age and corresponding physical growth and maturation. Our findings may have been influenced by genetic factors, the selection of young subjects for specific sport and adaptations caused by training. However, the current study could indicate further research regarding the effects of age, training and their combination on muscle strength and performance in pubertal trained and untrained boys.

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