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Physiological and Neuromuscular changes between young soccer players and untrained adolescents.

A comparison study

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Abstract

Aim. The purpose of this study was to examine the effects of soccer training on maximal oxygen uptake, isokinetic muscle strength and anthropometric characteristics in different ages of soccer players and untrained adolescents of the same biological age.

Subjects. A total of one hundred and twenty six (n=126) young soccer players and untrained boys throughout the developmental ages of 12 (soccer players n=22; untrained boys= 22) 14 (soccer players n=20; untrained boys= 18) and 16 (soccer players n=22; untrained boys= 22) volunteered to participate in the study. Sexual maturation was classified according to Tanner's stages. Soccer players participated both in their school's physical education program and in a soccer training program, while the untrained participated only in their school's physical education program.

Methods. All participants underwent anthropometric measurements and performed a maximal exercise testing on a motor driven treadmill to determine maximal oxygen uptake ($\dot{V}O_{2\max}$) and cardiorespiratory indices. The isokinetic concentric peak torque values of the hamstrings (H) and quadriceps (Q), as well as the conventional strength ratios of H:Q, were measured on an isokinetic dynamometer (CSMI, Humac Norm, Cybex II) at angular velocities of 60,180, and 300°·s⁻¹.

Results. The trained group showed significantly higher $\dot{V}O_{2\max}$, in absolute and relative values (p<0.001), BL_{\max} (p<0.05) and RER_{\max} (p<0.05) compared to the untrained group. Resting HR and systolic blood pressure were significantly lower (p<0.05) for the trained compared to untrained. The isokinetic muscle strength (absolute and relative) was significantly higher (p<0.001) in the 12 and 16 years old trained group, compared to untrained, for the knee extensors and knee flexors. However, no significant differences were found between the 14 years old trained and untrained, for the muscle groups of Q and H.

Conclusion. The results showed that systematic soccer training (intensity and duration) has a positive effect in the central cardiovascular system expressed as $\dot{V}O_{2\max}$, HR and blood pressure, as well as in the peripheral system, expressed as an increase lower limb muscle strength; specifically, agonist - antagonist (Q and H). The results provide important information and knowledge for more effective training programs not only for soccer but also for any other sport training.

Key words: isokinetic muscle strength; hamstrings; quadriceps; H:Q strength ratio; maximal oxygen uptake; biological age; youth soccer players; exercise testing; developmental ages, untrained adolescents

1. Introduction

Physical activity constitutes one of the most important factors for the normal growth of children and adolescents, as it influences positively the physical and psychological health and it is also very important for all the stages of the level in health and life quality. Regular soccer training, two to three times a week, caused significant cardiovascular and muscular adaptation (Nadeau et al., 2011; Krstrup et al., 2010).

Training during childhood (prepubertal – pubertal) continues to be a subject of interest. However, reviewing the results of training with children of different chronological age (CA), it is difficult to separate the effects of training from those of growth. Although the isokinetic muscle strength as well as the aerobic power have been studied extensively, little is the information on these variables throughout the same biological age in trained and untrained boys, who undertook only the physical activities in school. To the best of our knowledge, little is known about the effects of soccer training on aerobic power and concentric isokinetic strength of knee extensors and flexors in trained and untrained (non-athletic) adolescents of the same biological age. Many studies of young soccer players have not considered maturity status as a factor, influencing functional capacity (Chin et al., 1994).

Soccer is a sport that demands power and strength, and therefore, the players need to gain strength through routine exercise. Such is essential to accumulate strength in most of the large muscle groups on the body. Soccer demands a specific type of physical activity classified as high-intensity intermittent exercise. Resultantly, the athlete's body has to undergo both anaerobic and aerobic processes for the purpose of energy release. The present study was designed to examine and compare: a) the anthropometric characteristics; b) the maximal aerobic power; c) the absolute and relative muscle strength of the knee extensors and knee flexors, as well as the H:Q strength ratio between young soccer players and untrained adolescents of the same biological age.

2. Literature Review

2.1 Maturity

Growth spurt among the young adolescents varies, but it mostly occurs between the ages of 9 and 15 years for both males and females. The rapid growth spurt in weight and height influences soccer training, because it elicits a positive impact on training intensity and endurance. Trainers should those recognise adolescent participants who have attained the peak height velocity (PHV) and utilise it to improve soccer performance and enhance training.

The strength of the lower limbs among players is of great concern. Specifically, the quadriceps (Q), hamstrings (H), and triceps surae group must produce high forces useful for jumping, tackling, kicking,

turning, changing pace and direction. The necessity of muscular strength in soccer is measured by putting together the measurements of muscular strength as well as the determinations of strength dependent skills in soccer such as kicking. Research posit that the combination of strength training and normal soccer training improves muscular strength and enhances kick performance (De Proft et al., 1988).

2.2 Muscle Characteristics

H is a spindle (fusiform) muscle, which has a complex anatomy and functions four individual muscle portions, three of which span both the knee and hip joints (Askling et al., 2003). The H muscle group work by extending the hip joint and flexing the knee joint. They are also useful in different types of movement and equally in decelerating activities that involve eccentric contractions (Chumanov et al., 2007). Functionally, the co-activation of H, during concentric Q actions, significantly increased, however during concentric H muscle actions the co-activation of the Q did not significantly change (Wright et al., 2009).

2.2.1 Imbalances in strength between H and Q muscles

Lower limb isokinetic muscle strength tests have mainly focused on the assessment of the knee joint. One primary goal in the assessment of muscular strength and power is to identify gross muscle weakness or functional imbalances, between legs and also between agonistic and antagonistic muscle groups of the same leg (i.e. between knee flexor and knee extensor muscle groups). Previous reports in adults suggested that conventional H:Q strength ratio should be at least 0.6, namely H are 60% as strong as the Q (Coombs et al. 2002; Holcomb et al. 2007), for preventing H and/or knee related injuries (Sangnier and Tourny-Chollet, 2007; Yeung et al., 2009; Coombs et al., 2002). Q and H are two muscle groups with different function. It has been reported that co-activation of H muscles significantly increases during concentric Q muscles contractions. However, this is not the case for the opposite, as co-activation of Q muscles does not change during concentric H muscle contractions (Wright et al., 2009).

2.3. Limitations of previous research and Rationale for current study

To the best of our knowledge, most of the studies have investigated the effects of training during childhood (prepubertal and pubertal) on the isokinetic muscle strength and aerobic power between children of the same CA. Hence, the results reported raise concerns regarding the effects of training, because they are difficult to separate from the effects of growth. For these reasons, it is essential to make a thorough investigation considering the biological age, comprising a range of angular velocities, in order to examine and analyze the differences in absolute peak torque (APT) as well as the anthropometric and physiological parameters between adolescents.

2.6 Purpose of the study

The purpose of the present study was to examine and compare the physical and physiological characteristics and muscle strength between young soccer players and untrained adolescents, who participated only at the physical activities in school, of the same biological age (12, 14 and 16 years). More specifically, the aims of this study were:

- To evaluate the absolute and relative $\dot{V}O_{2\max}$, HR_{rest} , HR_{\max} , BLa_{\max} and BP_{rest} .
- To measure and investigate the concentric isokinetic muscle strength of knee extensors and knee flexors at a range of angular velocities along with:
 - The APT values of the H and Q and H:Q strength ratio across angular velocities and age groups for trained and untrained adolescents.

3. Materials and Methods

3.1 Participants

A total of one hundred and twenty six (n=126) young boys throughout the developmental ages of 12 (n=44), 14 (n=38) and 16 (n=44) volunteered to participate in this study. The study was performed in accordance with the local university Ethics Committee guidelines and ethical standards of the Sports Medicine research. The participants were divided according to their biological age in three age groups and each group was divided into two sub-groups: a) soccer players as trained group (12 years, n=22, training experience= 4.9 ± 2.2 years; 14 years, n=20, training experience= 6.2 ± 1.8 years; 16 years, n=22, training experience= 8.7 ± 1.6 years), b) untrained boys (12 years, n=22; 14 years, n=18; 16 years, n=22). The physical characteristics of the adolescents are shown in Table 1. All participants and their parents were informed of the nature, purpose, procedures, potential discomfort, risks and benefits involved in the study before giving their voluntary written consent for participation. All participants 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. 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. Pubertal staging, by examination of pubic hair, penile and testicular development was performed by an experienced paediatric physician, experienced in the assessment of secondary sex characteristics, state of pubic hair based on the criteria of Tanner (1962). All measurements were undertaken by the same investigator (Athanasios Mandroukas) in order to prevent intertester variability.

The training protocol was based on the normal technical-tactical and physiological elements of soccer indicated for improvement according to developmental age. The school Physical Education program consisted of 2-3 training sessions per week for all age groups and every session lasted 40 minutes. Both the duration and the intensity of the training in this group were much less than the specific training program of the soccer players.

3.2 Measurements

3.2.1 Anthropometric measurements

The standing height was measured to the nearest 0.5 cm using a stadiometer, and the body weight was measured using an electronic digital scale (Seca 220e, Hamburg, Germany). All participants underwent anthropometric examinations, including BSA, LBM and BMI.

3.2.3 Isokinetic Strength Testing

The strength of knee flexors and extensors in the dominant leg were measured using an isokinetic dynamometer Cybex II (CSMI, Humac Norm, Cybex II). The participant was then seated on the dynamometer in an adjustable chair; the upper body was stabilized with straps secured diagonally across the chest, around the hips and thighs, to prevent any extraneous joint movement. The knee tested, was positioned at 90° of flexion (0° corresponding to fully extended knee) to align the axis of the dynamometer lever arm with the distal point of the lateral femoral condyle. The length of the lever arm was individually determined, and the resistance pad placed at 5 cm above the malleoli. Knee extension started when the knee was positioned at 90° of 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 as they could through a complete ROM. Three repetitions were carried out at each angular velocity and the best peak torque (PT) value of the three trials was used. A 30-second rest period was taken between each trial and a 60-second rest period was taken between each velocity measurement. During these procedures participants always performed maximal voluntary contractions, in which verbal encouragement was given to the participants throughout the contractions. Maximal isokinetic strength was recorded as the torque of the H and Q muscles throughout the whole ROM at angular velocities of 60, 180 and 300°·sec⁻¹. The conventional H:Q ratio was calculated by dividing each participant's highest concentric PT leg flexion by the highest concentric PT leg extension.

3.2.4 Determination of maximum oxygen uptake

Maximal oxygen uptake ($\dot{V}O_{2\max}$) was performed on a motorised treadmill (Pulsar, H/P Cosmos, Germany) after a five-minute warm-up and stretching of the lower limbs. $\dot{V}O_{2\max}$ was determined using an uphill incremental continuous treadmill running test to exhaustion. The initial grade and speed were set at 0%

at 6 km/h for the 12 years old and at 8 km/h for the 14 and 16 years old, for 4 minutes, and followed by stepwise increase in speed of 1 km/h every minute per stage with 2% stable grade until exhaustion. The oxygen uptake, determined by means of absolute ($\text{ml}\cdot\text{min}^{-1}$) and relative values adjusted to body weight ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$), as well as the cardiorespiratory indices were measured via an ergospirometric device based on breath by breath automated pulmonary/metabolic gas exchange system (Oxycon Pro-Jaeger, Würzburg, Germany) using a tight face mask specially designed for children. The HR was recorded continuously using a Polar HR monitor (Polar Electro, Oy, Kempele, Finland) connected to the ergospirometric device. Subsequently, the following additional cardiorespiratory indices were determined during the test: the exercise duration; the respiratory exchange ratio (RER); and the maximal heart rate (HR_{max}). $\dot{V}\text{O}_{2\text{max}}$ 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 RER ($\text{VCO}_2/\dot{V}\text{O}_2$) at or higher than 1.1 was reached; c) $\dot{V}\text{O}_2$ reached a plateau and/or signs of subjective exhaustion were present and the subject was unable to continue running, despite verbal encouragement; d) level of concentration of blood lactate higher than $6\text{mmol}\cdot\text{l}^{-1}$ (Chamari et al., 2004, 2005). Blood samples were obtained from the hand warmed fingertip and the concentration of blood lactate was determined in the 5th minute of recovery using a lactate photometer analyser (Accusport, Boehringer Mannheim, Germany).

3.3 Data / Statistical Analysis

Statistical analysis was undertaken using SPSS V.22.0 (SPSS Inc., Chicago, Illinois, USA) and Microsoft Excel 2013 (Microsoft Corp., Redmont, Washington, USA). Initially, descriptive statistics were used to calculate means and standard deviations for the testing sessions, for all groups. A two-way analysis of variance (ANOVA) was used to compare the effect of two categorical independent variables. Multiple comparisons with Bonferroni Post-hoc tests were used to determine which groups in the ANOVA differ from each other, particular whether there were significant differences between trained and untrained adolescents and between age groups. Level of significance was set at $p<0.05$.

4. Results

The physical and anthropometric characteristics between trained and untrained adolescents in different age groups are shown in Table 1.

Table 1. Physical and anthropometric characteristics between trained and untrained adolescents in different age groups (mean±SD)

| | Age (years) | | | | | |
|-----------------------------|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|
| | 12 years (n=44) | | 14 years (n=38) | | 16 years (n=44) | |
| | Trained (n=22) | Untrained (n=22) | Trained (n=20) | Untrained (n=18) | Trained (n=22) | Untrained (n=22) |
| Training age (yrs) | 4.9±2.2 | | 6.2±1.8 | | 8.7±1.6 | |
| Height (cm) | 161.4 ±12.8 | 152.4 ±7.4*** | 166.5 ±8.5 | 168.2 ±10.5 | 176.6 ±5.8 | 173.2 ±6.2 |
| Weight (kg) | 52.5 ±13.4 | 52.0 ±13.0 | 56.9 ±9.5 | 59.3 ±9.9 | 67.3 ±6.4 | 67.6 ±4.5 |
| BSA (m ²) | 1.5 ±0.3 | 1.5 ±0.2 | 1.6 ±0.2 | 1.7 ±0.2 | 1.8 ±0.1 | 1.8 ±0.1 |
| LBM (kg) | 44.1 ±9.8 | 42.0 ±7.7 | 47.6 ±6.8 | 49.1 ±7.1 | 55.5 ±4.4 | 54.8 ±3.4 |
| BMI (kg/m ²) | 19.8 ±2.5 | 22.1 ±3.7 ** | 20.5 ±2.4 | 20.9 ±2.4 | 21.6 ±1.5 | 22.6 ±1.6 |

*** U12 trained vs U12 untrained, p<0.001; ** U12 trained vs U12 untrained, p<0.01 (Multiple comparisons: Bonferroni Post-hoc).

Table 2. Physical and physiological characteristics between trained and untrained adolescents in different age groups (mean±SD).

| | Age (years) | | | | | | |
|------------------------------------------------------------------|-------------------------------|---------------------|--------------------|---------------------|--------------------|---------------------|-------------------|
| | 12 years (n=44) | | 14 years (n=38) | | 16 years (n=44) | | |
| | Trained (n=22) | Untrained (n=22) | Trained (n=20) | Untrained (n=18) | Trained (n=22) | Untrained (n=22) | |
| HR _{rest} (b·min ⁻¹) | 69.9 ± 9.6 *** | 78.2 ± 7.3 | 65.0 ± 3.0 ### | 73.1 ± 9.0 | 61.2 ± 4.8 | 63.8 ± 4.8 | |
| Blood Pressure rest | sBP _{rest} (mmHg) | 118.4 ± 7.1* | 122.7 ± 5.7 | 112.9 ± 5.0 #,¥ | 118.6 ± 6.8 | 119.5 ± 9.4 \$ | 120.2 ± 8.2 |
| | dBP _{rest} (mmHg) | 63.0 ± 7.4 *** | 69.5 ± 6.7 | 63.6 ± 5.4 | 62.2 ± 4.3†† | 61.4 ± 6.4 | 62.5 ± 6.6 !!! |
| V̇O _{2max} (ml·min ⁻¹) | 2978.4 ± | 2112.3 ± | 3607.7 ± | 2908.3 ± | 3891.5 ± | 2949.7 ± | |
| | 803.1 *** | 337.6 | 343.9 ### | 393.5 | 548.8 \$\$\$ | 192.1 | |
| V̇O _{2max} (ml·kg ⁻¹ ·min ⁻¹) | 57.0 ± | 41.4 ± | 65.1 ± | 49.5 ± | 57.9 ± | 43.9 ± | |
| | 5.9 *** | 3.9 | 12.8 ### | 4.9 | 7.1 \$\$\$ | 5.0 | |
| HR _{max} (b·min ⁻¹) | 198.3 ± 6.9 | 195.0 ± 4.3 | 197.8 ± 4.5 | 198.0 ± 5.6 | 190.8 ± 6.9 \$ | 194.3 ± 5.4 | |

| | | | | | | |
|----------------------------------------|-----------------|---------------|-------------------|---------------|------------------|---------------|
| BLa_{max} ($mmol \cdot l^{-1}$) | 8.4 ± 0.7 | 8.5 ± 0.6 | 8.7 ± 1.8 ### | 6.4 ± 1.2 | 9.4 ± 1.3 \$ | 8.7 ± 0.7 |
| Respiratory exchange ratio (RER) | 1.1 ± 0.0 * | 1.2 ± 0.1 | 1.2 ± 0.2 ### | 1.0 ± 0.1 | 1.1 ± 0.1 | 1.2 ± 0.1 |

*** U12 trained vs U12 untrained, $p < 0.001$; * U12 trained vs U12 untrained, $p < 0.05$ ### U14 trained vs U14 untrained, $p < 0.001$; # U14 trained vs U14 untrained, $p < 0.05$; \$\$\$ U16 trained vs U16 untrained, $p < 0.001$; \$ U16 trained vs U16 untrained, $p < 0.05$; ¥ U12 trained vs U14 trained, $p < 0.05$; § U14 trained vs U16 trained, $p < 0.05$; †† U12 untrained vs U14 untrained, $p < 0.01$; !!! U12 untrained vs U16 untrained, $p < 0.001$ (Multiple comparisons: Bonferroni Post-hoc).

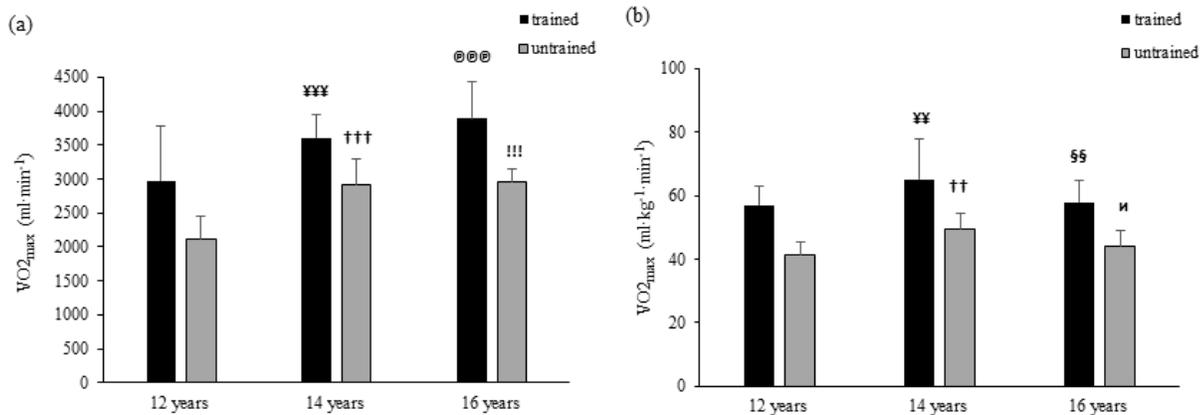


Figure 1. Absolute (a) and Relative (b) maximal aerobic power among different age groups of trained and untrained adolescents during the maximal running test. Values represent mean \pm SD.

†† U12 untrained vs U14 untrained, $p < 0.01$; ††† U12 untrained vs U14 untrained, $p < 0.001$; !!! U12 untrained vs U16 untrained, $p < 0.001$; ⁿ U14 untrained vs U16 untrained, $p < 0.05$; \$\$\$ U12 trained vs U14 trained, $p < 0.001$; ¥¥ U12 trained vs U14 trained, $p < 0.01$; @@@ U12 trained vs U16 trained, $p < 0.001$; §§ U14 trained vs U16 trained, $p < 0.01$.

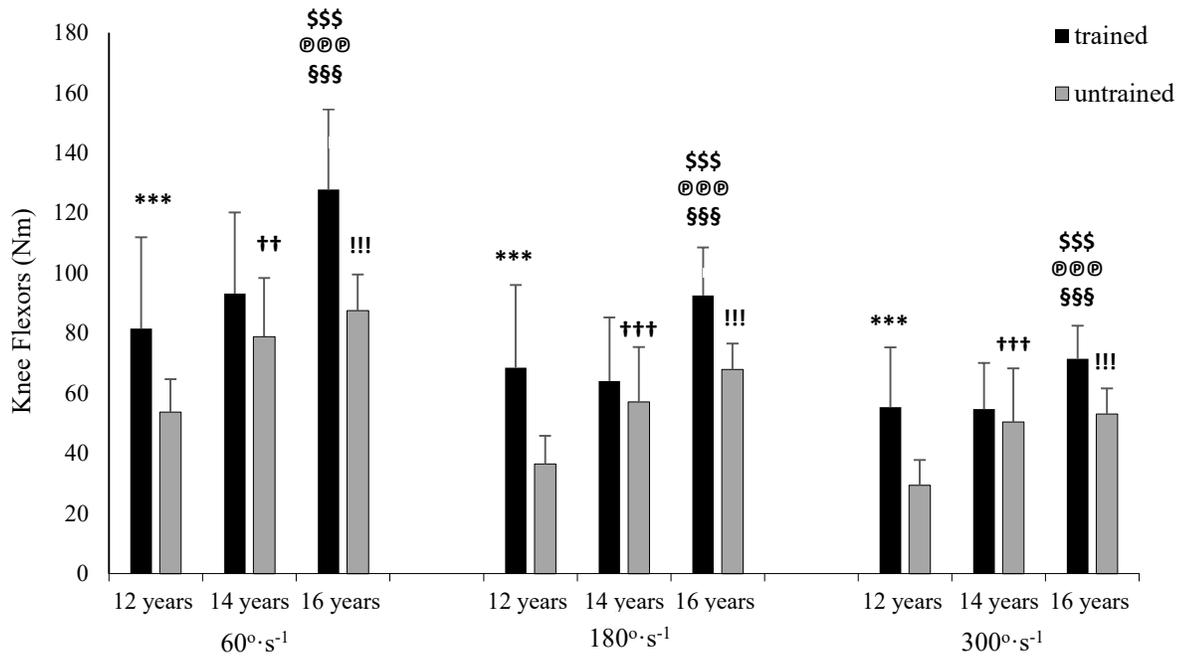


Figure 2. Absolute isokinetic muscle strength of knee flexors between trained and untrained subjects in different age groups at different angular velocities. The values are expressed as means ± SD.

*** U12 trained vs U12 untrained, $p < 0.001$; \$\$\$ U16 trained vs U16 untrained, $p < 0.001$; †† U12 untrained vs U14 untrained, $p < 0.01$; ††† U12 untrained vs U14 untrained, $p < 0.001$; !!! U12 untrained vs U16 untrained, $p < 0.001$; ⓈⓈⓈ U12 trained vs U16 trained, $p < 0.001$; ⓈⓈⓈ U14 trained vs U16 trained, $p < 0.001$.

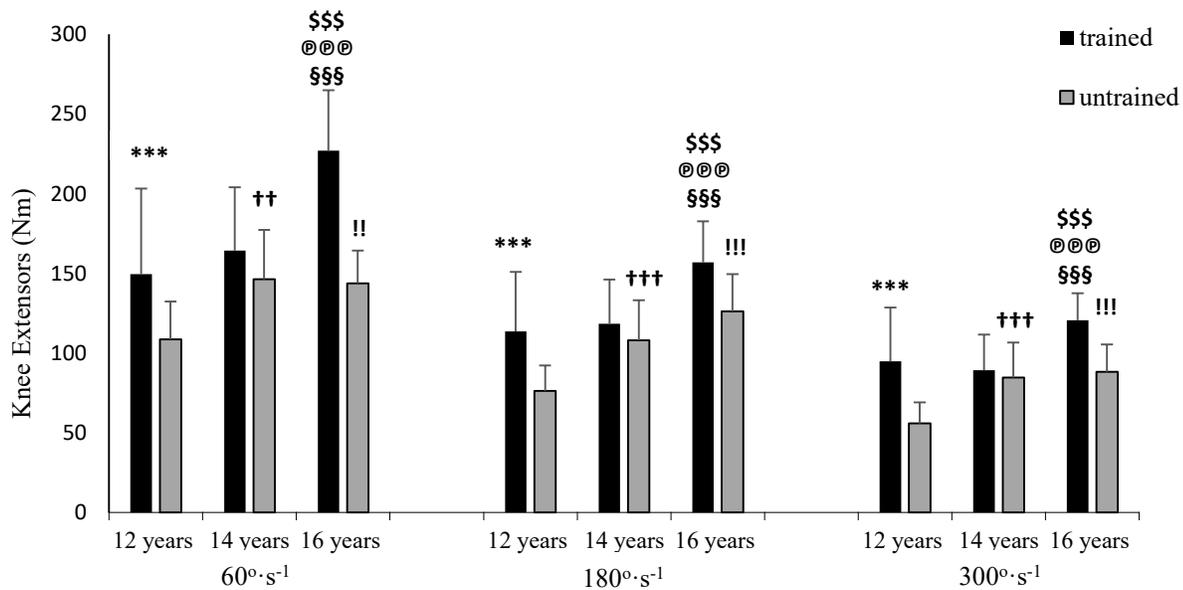


Figure 3. Absolute isokinetic muscle strength of knee extensors between trained and untrained subjects in different age groups at different angular velocities. The values are expressed as means ± SD.

*** U12 trained vs U12 untrained, $p < 0.001$; \$\$\$ U16 trained vs U16 untrained, $p < 0.001$; ++ U12 untrained vs U14 untrained, $p < 0.01$; +++ U12 untrained vs U14 untrained, $p < 0.001$; !! U12 untrained vs U16 untrained, $p < 0.01$; !!! U12 untrained vs U16 untrained, $p < 0.001$; @@@ U12 trained vs U16 trained, $p < 0.001$; \$\$\$ U14 trained vs U16 trained, $p < 0.001$.

5. Discussion

The present study examined two major sections that are the most important factors in physical performance. These are the cardiorespiratory and neuromuscular function (strength) of Q and H, between trained young soccer players and untrained young boys with the same biological age (12, 14 and 16 years). The research hypotheses for the current study were confirmed and the outcomes verify that $\dot{V}O_2$, both in absolute and relative values, was higher in the trained group than in the untrained group. Such elevation of the $\dot{V}O_{2\max}$ in the trained group was likely caused by a) an increase in metabolic capacity, b) low running economy or c) the combination of previous training and hereditary endowment. The significant difference that was found in height between the 12 years old trained and untrained adolescents, was not due to adjustments from training, but maybe due to the fact that in soccer, as in all sports, the young athletes constitute a highly select group chosen on the basis of size and technical skills.

A few studies of young soccer players who took the biological age into consideration found varying results. Baxter – Jones et al. (1995) as well as Cacciari et al. (1990) recorded no significant difference between trained and controls in prepubertal boys (10 years old). Conversely, Metaxas et al. (2014) found that $\dot{V}O_{2\max}$, expressed in $\text{ml} \cdot \text{min}^{-1}$, was significantly higher in 13 years old soccer players in comparison with the 11 year-olds. They concluded that the absolute $\dot{V}O_{2\max}$ is highly related with age. However, the relative $\dot{V}O_{2\max}$ ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) did not significantly differ between the ages examined (11, 13, 15 years). Nevertheless, the results of the present study showed that there were significant differences between the 12 and 14 years old soccer players both in absolute and relative $\dot{V}O_{2\max}$ values ($p < 0.01$). In addition, significant differences were observed between the 14 and 16 years old trained boys, only in the relative $\dot{V}O_{2\max}$ values. The lower HR_{rest} and BP_{rest} values that were found in the trained group, compared to the untrained, is a phenomenon due to the adjustments from training. The difference in HR_{\max} that was found between the trained and untrained boys at the age group of 16 year-olds may be due to a) genetic factors, or b) the fact that the untrained could not continue to exercise during maximal workload for a long time period, because of rapid fatigue. It must be noted that the HR_{\max} do not change with and by training.

The events put pressure on the lower limbs, showing the need for the development of muscle strength in soccer players. For this purpose, maximal muscular strength is a fundamental quality that influences power performance (Hoff and Helgerud, 2004). To be specific, the H strength is crucial in soccer players for joint

stabilization during tasks and especially in eccentric actions (Cometti et al., 2001). When the muscle strength of a pre-pubertal is examined on the isokinetic dynamometer, it is necessary to emphasize whether the muscle strength will be expressed in absolute values, as the examinee is seated and the body weight is isolated; or in relative values, considering the body mass and height of the examinee. It should be also clarified if the values of H:Q strength ratios are expressed from the conventional or from the functional (eccentric-concentric) H:Q ratio.

Generally, the torque – velocity relationship in young populations indicates a similar, adult-like pattern, namely as angular velocity increased PT decreased. In this study, Q muscle strength was greater than H at all angular velocities and in all ages.

The results obtained in this study showed that the absolute and the relative isokinetic muscle strength of knee extensors and knee flexors were significantly higher in the 12 and 16 years old trained boys, in comparison with the untrained of the same age at all angular velocities. However, it is noteworthy that there were no significant differences in the APT values of the 14 year-olds group, between trained and untrained, for both Q and H at all angular velocities. Our results are in agreement with other studies for young soccer players (Capranica et al., 1992) who have documented no difference in isokinetic strength of the lower limbs in prepubertal trained boys, compared to non-athletes and in disagreement with all previous studies that have investigated the Q and H strength in isokinetic dynamometer, between groups with a varying CA. Boys in biological age of 14 years are in a transition period 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 results of the current study clearly showed that there is a positive increase in H and Q absolute muscle strength with the increase of age across all measured angular velocities. It should be noted that this positive increase occurs despite the increase in body weight and height. In all angular velocities (60, 180, 300°·s⁻¹) the absolute muscle strength for the Q muscle in the 12 year-olds group has almost twice the strength of the H muscles (the ipsilateral H muscles). With increasing age, this difference between Q and H in muscle strength slightly decreases. The absolute muscle strength of Q and H increases linearly with biological age. The H:Q strength ratio changes with angular velocity. As angular velocity increases, the strength percent increase is greater in the H muscle than the Q muscle. The Q is a pennate muscle, meaning all of its muscle fibers are attached to a central tendon and it contracts on a linear axis. The fibers of the Q muscle have a greater pennation angle, which translates that this muscle group produces higher strength but implies lower speed. When the knee is extended from a seated position on the dynamometer, the Q muscle is in a favourable position. Conversely, the contraction of H from the same position, places the knee in a disadvantageous state

of rapid flexion. The question that arises is whether the greater strength of Q, compared to H muscles, can only be attributed to Q's greater muscle mass; or whether it can also be attributed to the position of the body at the measuring point, where the Q muscles, due to functional anatomical position is able to make advantageous biomechanics contractions; or even whether the soccer training of the H muscle is inadequate, perhaps it is unwittingly overlooked in practice and so is not exercised to the same extent as the Q muscles.

It is well known that there is a significant difference in muscle strength between children and adults, even when it is normalized to body size. Regarding maximum effort, either for the determination of $\dot{V}O_{2\max}$ or muscle strength, the children recruit a smaller percentage of their motor-unit pool than adults (Grosset et al., 2008). The untrained young boys in everyday life, as well as in schools' Physical Education, are deprived from maximum physical activity, resulting in reduced coordination and rapid fatigue.

All the components for the increase of muscle strength and $\dot{V}O_{2\max}$ may be due to neural adaptations and metabolic capacity. More specifically, Behm and Sale (1993) described a number of factors that characterized the trained adolescents, such as selective activation of muscles, synchronization, increased reflex potential, increased recruitment of motor units and increased co-contractions of antagonists.

The strength assessment of these muscles is usually performed on an isokinetic dynamometer during an open kinetic chain movement. There are no ground reaction forces on the foot and shank, but only on the thigh and trunk. However, because the isokinetic dynamometer does not generate a natural movement, the values of the H:Q strength ratio, despite the useful information they provide, must be interpreted carefully. In practice, the H:Q strength ratio is tested at completely different joint angles with different speeds, using the weight of the body, which may possibly increase the burden on the knee joint approximately tenfold, over that exerted on the joint by the isokinetic dynamometer.

From the analysis of the training performed by the soccer players who participated in this study, it was observed that the H muscles are not routinely stimulated. The H muscle group received no specific training with eccentric exercise. In movements with additional weights, players mostly follow a flexion – extension exercise of the knee, without particular emphasis on training H muscles. Focused exertion of Q muscles can easily be performed from a seated position, as well as from many alternative positions, whereas the corresponding training of the H muscle is more complex and depends, not only on the position of the isokinetic dynamometer, but also on a starting position, limited to that which places the maximum burden on the muscle group in question. Despite the emphasis during training, which stresses the fact that knee flexor strength is extremely important in soccer players for joint stabilization during various tasks, it seems that strength training of H muscles remains inadequate.

6. Conclusions

The results of the present study can be used as normative data for young soccer players, as well as for the general population of young boys, throughout the developmental ages (12, 14, 16) with regards to the cardiorespiratory system and to the H and Q muscle strength. This knowledge can be used as a springboard to more efficient strengthening of the involved muscles. The findings of the present study will be a useful tool for training purposes and will provide important information for more effective training programs, accompanied by additional exercises on the field.

This study assessed children of developmental ages of 12, 14 and 16 years old. It has to be noted, that the results of the laboratory measurements will have to be accompanied by practical tests on the field. Additionally, the laboratory measurements, as well as the tests on the field, show certain peculiarities. It is often made clear, that children are not a proportional diminution of adults, but a completely separate category. This means that extensive attention needs to be applied to the methodology followed during the assessment. The trained young individuals, who are familiar with physical exercise, are responding satisfactorily, in regards to the requirements and the scope of this exercise. The difficulties in maximum performance are emerging in younger children and more evidently in the untrained ones. In this study, for the determination of $\dot{V}O_{2\max}$, the treadmill was used, as it is a realistic way of running for children. At the same time, this apparatus offers the possibility of altering the inclination (grade) for maximum loading of the central cardiovascular system. In the treadmill however, great balance and coordination of movement is needed, elements with which, the untrained need familiarisation, motivation and stimulation, with many repetitions. Despite the cost, the tests in the laboratory provide results of high accuracy. Deciphering those results correctly and providing tailored advice and training plans, can offer a great incentive for the maintenance and improvement of the physical condition and overall well-being of any individual.

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