AGE-RELATED DIFFERENCES IN FORCE-VELOCITY CHARACTERISTICS IN YOUTH SOCCER

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Original scientific paper
UDC: 796.012.11-796.012.13:796.332-053.6

Abstract:

Although the contribution of anaerobic power to soccer performance has been widely recognized, this parameter of physical fitness has not been well studied in young players. The aim of this study was to investigate the force-velocity (F-v) components of anaerobic power across adolescence. Male adolescent players (N=561; aged 10–22 years), classified into six two-year age groups, all members of competitive soccer clubs, performed the F-v test. The participants performed four sprints, each one lasting 7 seconds, against incremental braking force (2, 3, 4 and 5 kilograms) on a leg cycle ergometer (Ergomedics 874®, Monark, Sweden), interspersed by five-minute recovery periods. Positive correlation between age and theoretical maximal velocity (v_0, r=.57, p<.001), theoretical maximal force (F_0, r=.53, p<.001), maximal anaerobic power in absolute (P_{max}, r=.68, p<.001) and relative-to-body-mass values (rP_{max}, r=.47, p<.001) was found, while there was negative correlation between age and v_0/F_0 (r=-.37, p<.001). With regard to P_{max}, rP_{max}, v_0 and F_0, each age group had a higher score than its younger and a lower score than its older counterparts, while there was no difference between the age group under 18 years (U18), U20 and U22. The v_0 to F_0 ratio decreased with age, but there was no difference between U16, U18, U20 and U22 with regard to this trait. While our results about the development of anaerobic power across adolescence were in general agreement with previous studies, we identified different patterns of development of the F-v components of muscle power, which was a novel finding.

Key words: *adolescent, maximal anaerobic power, force, velocity, cycle ergometer, development*

Introduction

Among the physiological characteristics of elite soccer players, anaerobic power constitutes a main determinant of performance (Bangsbo, Mohr, & Krustrup, 2006). In adolescence, this parameter of physical fitness is important in the context of talent identification. For instance, the measures of anaerobic power in young players aged 13–16 years could partially determine if someone followed a career as an international, professional or amateur player in adulthood (Le Gall, Carling, Williams, & Reilly, 2010). In spite of the popularity of soccer among adolescents, only a few studies have been carried out regarding the physiological parameters of these athletes in a laboratory setting and no research has been ever conducted with regard to the force-velocity (F-v) characteristics of lower limbs in a large sample of young soccer players.

Recent studies have supported an association between F-v characteristics and performance (Bouhlel, Bouhlel, Chelly, & Tabka, 2006; Chelly, et al., 2010; Morin, Hintzy, Belli, & Grappe, 2002; Nikolaidis, 2010). For instance, maximal anaerobic power (P_{max}), theoretical maximal velocity (v_0) and theoretical maximal force (F_0) were significantly correlated with acceleration during the first step and with acceleration during a five-meter sprint in young soccer players (Chelly, et al., 2010). In a research on sprinters, P_{max} in W/kg was highly correlated with speed between five-meter to ten-meter sprints, and between zero- to ten-meter sprint (Morin, et al., 2002). In addition to its relevance to sprinting performance, P_{max} has been found moderately to highly correlated with the vertical jump and five-jump test (Bouhlel, et al., 2006). Moreover, in a comparison of force-velocity (F-v) characteristics between starters and substitutes of elite female soccer players, the starters had a higher v_0 than the substitutes (Nikolaidis, 2010).

Due to inherent ethical and methodological issues about the direct assessment of anaerobic metabolism in adolescents, the employment of alternative non-invasive methods targeting mechanical short-term power output has been suggested (Van Praagh & Dore, 2002). Detailed information about one's anaerobic power can be obtained by valid and reliable laboratory methods, such as

Wingate 30-second anaerobic test (Ayalon, Inbar, & Bar-Or, 1974), Bosco 60-second test (Bosco, Luhtanen, & Komi, 1983) and F-v test (Vandewalle, Peres, Heller, & Monod, 1985). With respect to the other aforementioned tests, F-v test has an advantage, because it provides information not only about P_{max}, but also about the constituents of power, i.e. force and velocity, descriptors of strength and speed, respectively.

A comprehensive sport-specific investigation of F-v characteristics helps to define more clearly the present levels of anaerobic power. Power is the work done in a unit of time or the product of force and velocity; thus, two athletes can possess similar levels of power, but different ratios of strength and speed. Consequently, knowledge about one's F-v characteristics can provide important information for optimal sport training, as the athlete can concentrate on the "weak" component of power. In addition, fitness specialists working with young soccer players should take the differences in these characteristics between adult and adolescent players into account, and a quantification of such differences would help in both talent identification and improvement in overall power.

The evolution of short-term power output throughout adolescence has already been investigated either in the male general population (Hertogh, Micallef, & Mercier, 1992) or in soccer players (Le Gall, Beillot, & Rochcongar, 2002) with the employment of field methods (vertical jump, 40-meter sprint) in large samples and cross-sectional study design. It has been also studied by laboratory methods (F-v and Wingate anaerobic tests) in the general population, in the lower spectrum of adolescence (Falgairette, Bedu, Fellmann, Van Praagh, & Couder, 1991; Martin, Doré, Hautier, Van Praagh, & Bedu, 2003) and on boys aged 8–18 years (Inbar, 1996). F-v test has been employed in prepubertal (N=20, aged 12-13 years) (Diallo, Doré, Duche, & Van Praagh, 2001) and older adolescent soccer players (N=23, aged 17.2±0.7 years) (Chelly, et al., 2010).

Certain studies have indicated a higher increase in muscular strength than in speed throughout adolescence (Hertogh, et al., 1992; Le Gall, et al., 2002; Mirkov, Kukolj, Ugarkovic, Koprivica, & Jaric, 2010; Ortega, et al., 2011; Ortega, et al., 2008). Particularly, muscular strength, estimated by the sum of right and left handgrip test scores, increased by 47.4% in adolescents from 13 to 18.5 years of age (Ortega, et al., 2008), and estimated by the average of right and left handgrip test scores, it increased by 67.8% in adolescents from 13 to 17 years of age (Ortega, et al., 2011). Strength, estimated by the countermovement vertical jump, increased by 20.6% in soccer players from 11 to 18 years (Le Gall, et al., 2002), while it increased by 46.8% in adolescents from 11 to 18 years (Hertogh, et al., 1992). In soccer players, speed, estimated by the 40-meter sprint, improved by 11.5% from 11 to 18 years (Le Gall, et al., 2002), while, estimated by the 5x10-meter sprint, it improved by 11.0% in children from 11 to 14 years (Mirkov, et al., 2010). In the general population's speed, estimated by the 4x10-meter sprint shuttle test, it improved by 9.1% in teenagers from 13 to 17 years (Ortega, et al., 2011) and by 5.7% in teenagers from 13 to 18 years (Ortega, et al., 2008).

Thus, we can reasonably assume that similar changes take place with regard to force, velocity and their ratio, although an important conceptual jump must be made when moving from strength and speed to force and velocity respectively. To the best of our knowledge, no study on F-v characteristics in a sample representative of the most part of adolescence in soccer has ever been conducted. Such a study could add valuable information not only with regard to the development of P_{max}, but also to the changes in muscular strength and speed, assessed by the same test.

To sum up what is known until now regarding the development of F-v characteristics during adolescence in soccer players based on the aforementioned studies, (a) P_{max}, in absolute or in relative-to-body-mass values, increases during adolescence, and b) muscular strength increases more than speed, thus suggesting alterations in F-v relationship. Therefore, the aim of the present study was to investigate the development of F-v characteristics throughout adolescence in soccer players in a laboratory setting, and to examine the research hypotheses that P_{max}, v_0 and F_0 increase, whereas the v_0 to F_0 ratio decreases.

Methods

Experimental approach to the problem and participants

In this investigation, a non-experimental descriptive-correlation design was used to examine the effect of age on F-v across adolescence. Testing procedures were performed at the beginning of the competitive period of seasons 2009/2010, 2010/2011 and 2011/2012. The study protocol was performed in accordance with the ethical standards laid down in the Declaration of Helsinki in 1975 and approved by the local Institutional Review Board. The team manager of each soccer club that participated in this study undertook to inform players or parents (in the case of underage participants) about the experimental design and the potential risks and received their oral informed consent. Although the period of adolescence is difficult to define in terms of chronological age due to its variation in time of onset and termination, it was suggested to range between 10 and 22 years of age in boys (Malina, Bouchard, & Bar-Or, 2004). For the purpose of this study, we followed this definition concerning the range of adolescence. Competitive soccer clubs in the region of Athens, Greece, were invited to participate in this research. Most of the participants competed in non-classified tournaments because there were no national tournaments for adolescent players, while those in the higher spectrum of adolescence competed in the A, B, C and D national league. Participants (N=561) were classified into six two-year age groups (under 12 years, U12, 10.1-12.0 years; U14, 12.1-14.0 years; U16, 14.1-16.0 years; U18, 16.1-18.0 years; U20, 18.1-20.0 years; U22, 20.1-22.0 years; Table 1). They visited the laboratory once; at first, anthropometric and body composition data were obtained, followed by a guided 15-minute warm-up. Then the F-v test was performed.

Procedures and equipment

Height and body mass were measured using respectively a stadiometer (SECA®, Leicester, UK) and an electronic scale (HD-351®, Tanita, Illinois, USA). The percentage of body fat was calculated from the sum of ten skinfolds using a skinfold calliper (Harpenden®, West Sussex, UK), based on the formula proposed by Parizkova (1978). The warm-up included two three-minute cycling stages against 1.0 W·kg^{-1} and 1.5 W·kg^{-1}, respectively, static stretching exercises concerning the whole body with emphasis on the lower limbs and a maximal 7-second sprint against a braking force of one kilogram.

The F-v test was employed to assess the maximal anaerobic power (P_{max}, expressed as W and as W·kg^{-1}, rP_{max}), theoretical maximal velocity (v_0) and force (F_0). This test employed various braking forces that elicit different pedaling velocities in order to derive P_{max} (Vandewalle, et al., 1985). The participants performed four sprints, each one lasting seven seconds, against an incremental braking force (2, 3, 4 and 5 kilograms) on a leg cycle ergometer (Ergomedics 874®, Monark, Sweden), interspersed by five-minute recovery periods. The seat height of the ergometer was adjusted to allow for a slight bend in the knee (approximately 175°) and in accordance with the participant's satisfaction. Each sprint began with a flying start, i.e. as soon as velocity reached 100 rpm (revolutions per minute), the weight basket was released and the braking force was applied.

For each participant an individual linear regression was determined between peak velocity and braking force for each of the four sprints (four data points for each F-v relationship; Figure 1). F_0 and v_0 corresponded to the intercepts with F and v axes in the F-v graph. P_{max} was calculated as $P_{max}=0.25 \cdot F_0 \cdot v_0$ (Vandewalle, et al., 1985). The duration of flywheel revolution was measured

Table 1. Anthropometric data, experience in soccer and training volume of the participants

	Age groups						
	U12 (n=24)	U14 (n=129)	U16 (n=201)	U18 (n=110)	U20 (n=52)	U22 (n=45)	ANOVA
Age (yr)	11.2±0.7	13.1±0.5	15.0±0.5	17.0±0.6	19.0±0.6	20.8±0.5	$F_{5,555}$=2152.01, p<.001
Body mass (kg)	42.4±9.1	52.0±9.4	63.0±8.9	68.7±8.7	71.0±6.3	74.4±7.8	$F_{5,555}$=100.43, p<.001
Height (m)	1.47±0.07	1.61±0.09	1.72±0.07	1.75±0.06	1.77±0.05	1.77±0.06	$F_{5,555}$=115.1, p<.001
BMI (kg·m^{-2})	19.4±2.8	19.9±2.3	21.4±2.4	22.3±2.4	22.7±1.8	23.7±2.0	$F_{5,555}$=30.18, p<.001
BF (%)	18.2±5.2	16.1±4.6	16.1±4.0	15.6±3.5	14.9±2.9	15.3±3.0	$F_{5,555}$=2.76, p=.018
Experience (years)	3.1±1.9	4.7±2.3	6.1±2.7	6.5±2.9	9.2±3.4	10.1±3.4	$F_{5,488}$=33.54, p<.001
Training (min·week^{-1})	243±67	285±86	332±99	387±126	425±167	464±170	$F_{5,493}$=24.94, p<.001

Legend: BMI body mass index, BF body fat.

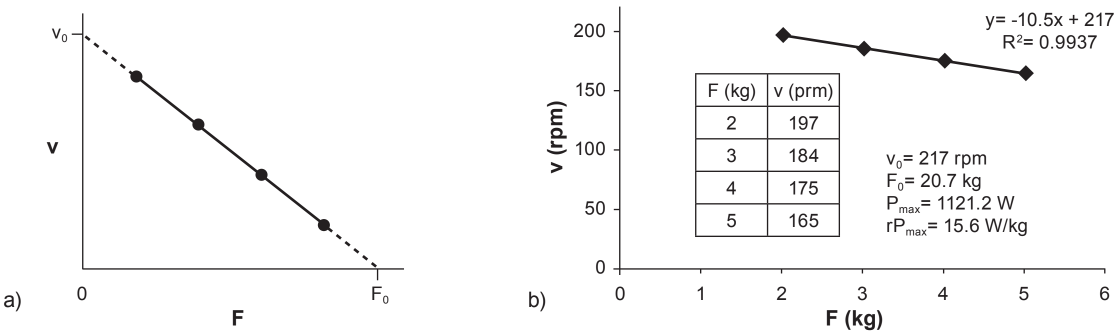

Figure 1. Force-velocity (F-v) relationship (a) and an example of a participant (b). v_0 denotes theoretical maximal velocity, F_0 theoretical maximal force, P_{max} maximal power and rP_{max} P_{max} expressed in relation to body mass values.

with an electronic sensor and peak velocity for each sprint was computed by specialized software (Papadopoulos, Kefala, & Nikolaidis, 2009).

Vandewalle, Peres, Heller, Panel and Monod (1987) highlighted the almost perfect inversely linear relationship between the braking force and velocity in male and female athletes of various sport disciplines (r=-.99, p<.001), i.e. the higher the braking force, the lower the velocity. Regarding the taxing of human energy transfer systems during the test, P_{max} was considered a descriptor of short-term power that relied mainly upon adenosine triphosphate-creatine phosphate (Ferry, 1999). The F-v test was suggested to be a reliable measure of the short-term power output of the children, adolescents and adults tested twice within a week (test-retest coefficient of variation 3%) (Doré, et al., 2003). With regard to its validity, in addition to its close relationship with running speed and jumping (Bouhlel, et al., 2006; Chelly, et al., 2010; Morin, et al., 2002), this test was also highly correlated with the Wingate anaerobic test (Vandewalle, Heller, Peres, Raveneau, & Monod, 1987).

Statistical analysis

Results were presented as mean±standard deviation. The age effect on F-v characteristics was examined by the Pearson's moment correlation coefficient (r), and partial correlations between the adjusted-for-anthropometric data (body mass, height and percentage of body fat) F-v characteristics and age were calculated. Differences between age groups were assessed using a one-way analysis of variance. Correction for multiple comparisons was undertaken using the Bonferroni method. Significance level was set at p≤.05. Statistical analyses were performed using IBM SPSS v.20.0® statistical software (SPSS Inc., Chicago, IL, USA).

Results

The scores of F-v characteristics for each age group are presented in Table 2. V_0 was significantly correlated with age (r=.57, p<.001) – the older the age-group through adolescence, the higher the v_0. The age groups differed with respect to this trait ($F_{5,555}$=63.54, p<.001). F_0 was linked with age too (r=0.53, p<.001) – the older the age-group through adolescence, the higher the F_0. The age groups differed with regard to this physiological characteristic ($F_{5,555}$=50.05, p<.001). P_{max} expressed either in absolute or in relative-to-body-mass values (rP_{max}) was related to age (r=.68, p<.001, and r=.47, p<.001, respectively). Thus, the older the age-group through adolescence, the higher both P_{max} and rP_{max}. Regarding P_{max} and rP_{max}, the age groups differed ($F_{5,555}$=107.33, p<.001, and $F_{5,555}$=39.15, p<.001, respectively). The v_0 to F_0 ratio (v_0/F_0) was significantly correlated with age (r=-.37, p<.001), hence, the higher the age-group through adolescence, the lower this ratio. The age groups differed with respect to this trait ($F_{5,555}$=22.80, p<.001). After adjusting the effect of anthropometric data and body composition (body mass, height and percentage of body fat), age was partially correlated with v_0 (r=.21, p<.001), P_{max} (r=.15, p<.001), rP_{max} (r=.14, p<.001), but not with F_0 (r=.04, p=.402) and v_0/F_0 (r=.02, p=.665).

Discussion and conclusions

The aim of the study was to investigate the effect of age on P_{max} and its components in adolescent soccer players. First, we examined the changes in short-term power output. P_{max} increased by 173.8% between the U12 and U18 group (362 W and 991 W accordingly). This finding was in agreement with previous studies, which, employing various assessment methods, indicated a significant change in power output during this period. For instance, P_{max}, estimated by the combination of 40-meter sprint time and body mass, increased by 152.5% in soccer players from 11 to 18 years (1046 W and 2641 W), and, estimated by the combination of countermovement vertical jump and body mass, increased by 127.0% (448 W and 1017 W) (Le Gall, et al., 2002). In the general population an increase by 100.2% (462 W and 924 W) was reported (Hertogh, et al., 1992). Peak power, the index of Wingate anaerobic test, increased by 120.3% in

Table 2. Force-velocity characteristics of the participants

	Age groups						
	U12 (n=24)	U14 (n=129)	U16 (n=201)	U18 (n=110)	U20 (n=52)	U22 (n=45)	ANOVA
P_{max} (W)	362±95	602±172	846±194	991±238	1059±183	1093±211	$F_{5,555}$=107.33, p<.001
rP_{max} (W·kg^{-1})	8.6±1.9	11.6±2.5	13.5±2.6	14.4±2.8	14.9±2.2	14.7±2.3	$F_{5,555}$=100.43, p<.001
v_0 (rpm)	162±15	188±19	205±20	218±20	219±22	222±21	$F_{5,555}$=39.15, p<.001
F_0 (kg)	8.9±2.2	12.9±3.7	16.6±4.0	18.4±5.2	19.6±4.5	20.0±4.9	$F_{5,555}$=50.05, p<.001
v_0/F_0 (rpm·kg^{-1})	19.5±5.6	15.8±4.8	13.1±3.7	12.8±3.8	12.0±3.8	11.8±3.2	$F_{5,555}$=22.80, p<.001

Legend: P_{max} maximal power, rP_{max} relative maximal power, v_0 theoretical maximal velocity, rpm revolutions per minute, F_0 theoretical maximal force.

young people from 12.2 to 17 years of age (321 W and 707 W) (Armstrong, Welsman, & Chia, 2001). The comparison of these findings with regard to short-term power output with previous studies that employed different methodology revealed similar findings; soccer players in the higher spectrum of adolescence present almost double P_{max} than those in the lower spectrum. P_{max} was highly correlated with body mass (*r*=.76, *p*<.001) and fat-free mass (*r*=.82, *p*<.001). Therefore, considering the corresponding increase in fat-free mass from U12 to U18 (34.3 kg and 57.8 kg, respectively), differences in P_{max} among these groups should be partially attributed to changes in fat-free mass.

Second, we examined changes in the components of P_{max} (F_0 and v_0). F_0, the indicator of muscular strength, increased by 106.7% from U12 to U18 (8.9 kg and 18.4 kg). However, this improvement was smaller than the corresponding value of P_{max}, which agreed with the existing data. V_0, the indicator of speed, revealed an even smaller improvement than P_{max} and F_0; it developed by 34.6% from U12 to U18 (162 rpm and 218 rpm). P_{max} (991 W), rP_{max} (14.4 W·kg^{-1}), v_0 (218 rpm) and F_0 (18.4 kg) values of U18 were close to soccer players' data of comparable age (907 W, 14.1 W·kg^{-1}, 201 rpm and 18.0 kg) (Chelly, et al., 2010).

While these results with regard to P_{max} development throughout adolescence were in general agreement with previous studies, we identified different patterns of development of the F-v components of muscle power, which was a novel finding. The differences in F-v characteristics are illustrated in Figure 2. We observed similar trends in P_{max}, rP_{max}, v_0 and F_0. Each age group had a higher score than its younger and a lower score than its older groups, while there was no difference between U18, U20 and U22. The v_0 to F_0 ratio decreased with age, but there was no difference between U16, U18, U20 and U22 with regard to this trait.

Age explained 32.4% of the variance of v_0, 28.4% of F_0, 46.2% of P_{max} and 13.5% of v_0/F_0. However, when F-v characteristics were adjusted for anthropometric data (body mass, height and body fat percent), the corresponding percentage of variance accounted for by age was close to zero (4.5%, 0.1%, 2.2% and 0%). Based on these observations it was implied that age exerted a significant influence on all F-v parameters, which were explained chiefly by the developmental changes in body dimensions and body composition during adolescence. The smaller muscle mass per body mass, lower glycolytic capability and deficient neuromuscular coordination pointed to the possible reasons for a low anaerobic

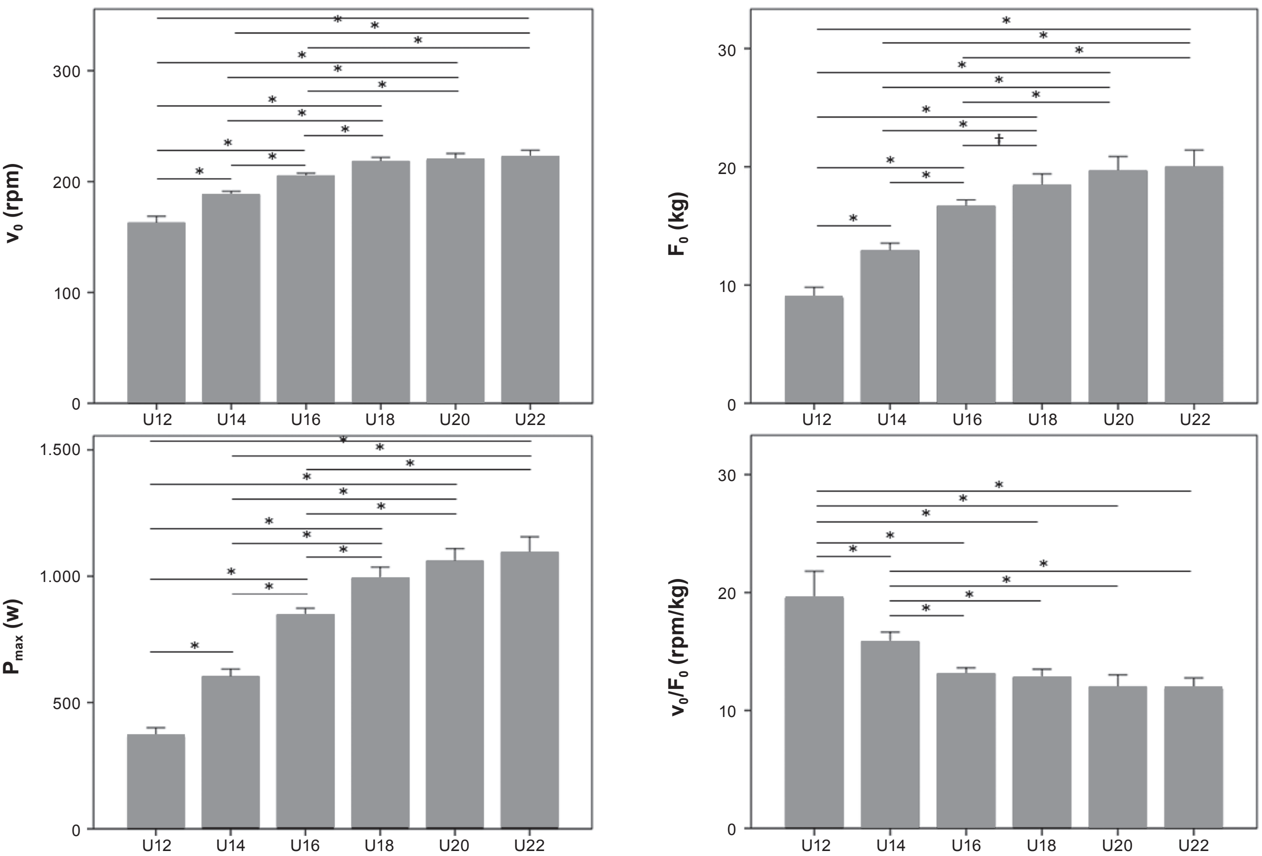

*Figure 2. Differences between age groups of soccer players (U12, U14, U16, U18, U20 and U22) with regard to theoretical maximal velocity (v_0, up on the left), force (F_0, up on the right), maximal power (P_{max}, down on the left) and v_0 to F_0 ratio (down on the right). Error bars represent standard error. *p<.001, †p<.01.*

performance in children (Bar-Or & Rowland, 2004; Ratel & Martin, 2011). These conditions seem to be weak during adolescence and to be annihilated until adulthood. In addition to these conditions, three biomechanical factors were also proposed as determinants of anaerobic power: a) increase of the length of the lower limbs' levers, b) increase of muscular groups' power, and c) technique (Le Gall, et al., 2002).

Figure 3 depicts values of F-v parameters as a percentage taking the value of an adult group as 100%. The employment of F-v test had the advantage not only of studying the development of anaerobic power, but also to investigate the components of power. An important finding was that although force and velocity increased through adolescence, the ratio v_0/F_0 decreased significantly (e.g. from 19.5 rpm·kg^{-1} in U12 to 11.8 rpm·kg^{-1} in U18), indicating changes in the force-velocity profile of soccer players. While in childhood and the early age of adolescence a dominance of velocity was remarkable, the development resulted in a swift of the F-v curve to the right, as well as in the rotation of the curve on the left (Figure 4). These changes should be attributed to the disproportionate increases of force and velocity.

A main limitation of any study conducted on current fitness scores in the context of talent identification is that the attribution of a physical ability, whether to talent or previous training, remains questionable. In this study, the participants were interviewed about their current training load (weekly time) and previous experience (years engaged in soccer). However, the possibility remained that the physiological characteristics of better players were due to a systematic approach to training prior to their induction to the team or due to current out-of-sport physical activity levels. With regard to the estimation of power output, in order for the data to be comparable with previous research, the values obtained from the F-v test did not take into account the effect of flywheel inertia. Corrected values for the effect of inertia can be obtained with a simple *post hoc* method with an error of 1.3% (Morin & Belli, 2004).

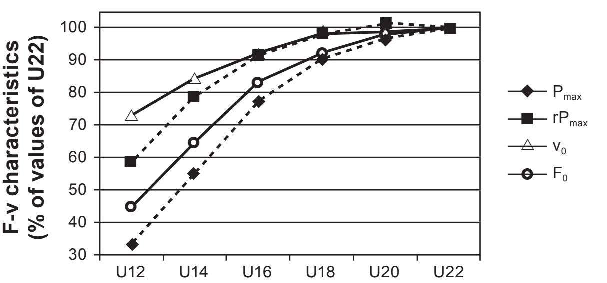

Figure 3. Age-related differences in absolute (P_{max}) and relative-to-body-mass maximal power (rP_{max}), theoretical maximal velocity (v_0) and theoretical maximal force (F_0).

Maximal anaerobic power was significantly less for the soccer players in the lower spectrum of adolescence than for their older counterparts, even after the adjustment for body mass. However, there was a disproportionate increase in the F-v characteristics, which resulted in changes in the v_0 to F_0 ratio through adolescence. The differences between age groups tended to be annihilated towards adulthood. Thus, these findings confirmed the pattern of anaerobic power development through adolescence that had already been investigated in the general population. However, what was novel was the quantification of such a pattern in soccer players and the identification of the changes in F-v characteristics (decrease of v_0/F_0), a finding that could be implemented in a training process targeting optimal sport-related fitness or talent identification.

These findings could be integrated in either a short-term or a long-term training plan targeting optimal sport-related fitness or talent identification, respectively. The recent suggestions about the association between F-v characteristics and soccer performance (Bouhlel, et al., 2006; Chelly, et al., 2010; Morin, et al., 2002; Nikolaïdis, 2010) implied that F-v test could be useful as a fitness assessment tool in this sport. The practical significance of this test is impressive, because, in addition to anaerobic power, it provides information about strength and speed, too. The challenge for soccer trainers is to act upon these components of anaerobic power. Using information derived from F-v test, trainers would do well to ensure that players have sufficiently developed both constituents of anaerobic power and can focus on a specific component of anaerobic power. Since most of the contemporary research in soccer has been carried out with adults, the coach or fitness trainer for the determination of optimal training load could employ data about the development of anaerobic power and mechanical characteristics from childhood to adulthood, too.

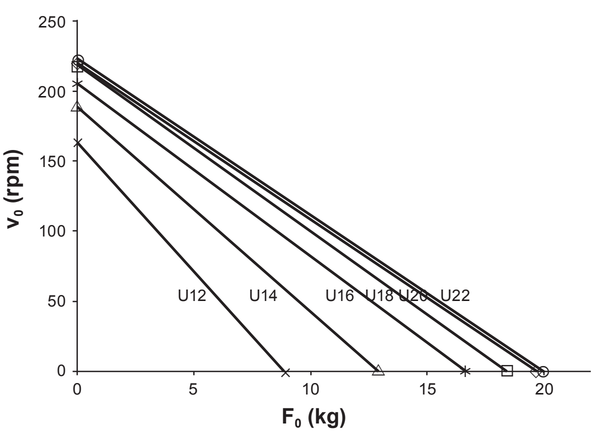

Figure 4. Differences in the inversely proportional relationship between velocity (v) and force (F) across youth soccer.

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Submitted: February 27, 2012
Accepted: November 20, 2012

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S DOBI POVEZANE RAZLIKE U KARAKTERISTIKAMA SILE-BRZINE U MLADIH NOGOMETAŠA

Iako je općeprihvaćena činjenica kako je anaerobna snaga važna za uspjeh u nogometu, ovaj parametar kondicijske pripremljenosti nije se dovoljno proučavao na populaciji mladih nogometaša. Cilj je ovog istraživanja bio utvrditi odnos anaerobnih komponenata sile-brzine kroz razdoblje adolescencije. Muški adolescenti (N=561; u dobi od 10–22 godine), klasificirani su u šest dvogodišnjih kategorija. Svi ispitanici, članovi nogometnih klubova koji se natječu, izveli su test sila-brzina. Ispitanici su izveli četiri sprinta, svaki u trajanju od sedam sekunda, pri čemu su svladavali progresivnu silu otpora (2, 3, 4 i 5 kilograma) na nožnom bicikl-ergometru (Ergomedics 874, Monark, Sweden). Odmori između sprintova trajali su 5 minuta. Utvrđena je pozitivna korelacija između dobi i teoretske maksimalne brzine (v_0, r=0,57, p<0.001), teoretske maksimalne sile (F_0, r=.53, p<0.001), apsolutne maksimalne anaerobne snage (P_{max}, r=0.68, p<0.001) i relativne maksimalne anaerobne snage (rP_{max}, r=0.47, p<0.001), dok je negativna korelacija utvrđena između dobi i v_0/F_0 (r=-0.37, p<0.001). U parametrima P_{max}, rP_{max}, v_0 i F_0 u svakoj je dobnoj grupi zabilježen veći rezultat nego u grupi mlađih ispitanika te niži rezultat nego u grupi starijih ispitanika, dok nije zabilježena značajna razlika između dobnih grupa do 18 godina (U18), U20 i U22. Odnos v_0 i F_0 smanjivao se s godinama, ali nije bilo značajne razlike između U16, U18, U20 i U22 u navedenom odnosu. Iako su rezultati ovog istraživanja o razvoju anaerobne snage tijekom adolescencije bili u suglasju s dosadašnjim znanstvenim istraživanjima, utvrdili smo različite obrasce razvoja komponenatai sile-brzine mišićne snage, što predstavlja novu znanstvenu spoznaju.

Ključne riječi: *adolescenti, maksimalna anaerobna snaga, sila, brzina, bicikl-ergometar, razvoj*