HUMAN MOVEMENT
2011, vol. 12 (4), 342–347

ANAEROBIC POWER ACROSS ADOLESCENCE IN SOCCER PLAYERS

doi: 10.2478/v10038-011-0039-1

PANTELIS THEO NIKOLAÏDIS
Hellenic Army Academy, Athens, Greece

ABSTRACT
Purpose. Although the contribution of anaerobic power in soccer performance is recognized, this component of physical fitness is not well-studied in adolescent players. The aim of this study is to investigate the development of anaerobic power across adolescence in a laboratory setting. **Methods.** Male adolescents (N = 217; aged 12.01–20.98 y), classified into nine one-year age-groups, and adult players (as the control group, N = 29; aged 21.01–31.59 y), who were all members of competitive soccer clubs, performed the 30-s Wingate anaerobic test (WAnT) against a braking force of 0.075 Kg · Kg^{-1} of body mass. **Results.** Compared with previous age-matched studies on the general population, the participants exhibited superior WAnT scores. The Pearson moment correlation coefficient between age and peak power (P_{peak}) was $r = 0.71$ ($p < 0.001$) and between age and mean power (P_{mean}) $r = 0.75$ ($p < 0.001$). Even when body mass or fat free mass was taken into account, the effect of age on these parameters remained ($0.51 < r < 0.55$, $p < 0.001$). One-way analysis of variance revealed differences in anaerobic power between the age groups across adolescence ($p < 0.001$), with the adult and age groups in the higher spectrum of adolescence performing better than those in the lower spectrum, supporting the aforementioned findings. **Conclusions.** We confirmed the importance of short-term power in adolescent soccer players, as well as the strong association between this sport-related physical fitness parameter and body mass and fat free mass ($0.89 < r < 0.94$, $p < 0.001$). However, what is novel is that we demonstrated that age effect on P_{peak} and P_{mean} remained even when body mass and fat free mass were factored out.

Key words: adolescent, physical fitness, exercise test, soccer, growth

Introduction

Performance in soccer results from a combination of physiological, psychological, social and environmental factors. Among the physiological factors, both physical fitness and the metabolic demands of game play have been well-studied in elite adult players, although recently there is an increased scientific interest in the physiological predisposition of young players for future excellence [1]. In spite of the popularity of soccer in adolescence and the foundation of several professional schools for young players, few studies have been published regarding physiological characteristics and, in particular, the anaerobic power of these athletes [2, 3]. Aerobic capacity is necessary to maintain performance during the 90 min of a soccer game, to undertake demanding training and to achieve optimal recovery; on the other hand, anaerobic metabolic pathways are utilized during very short bursts of moderate to intensive effort that can directly determine a match's outcome. When comparing the activity patterns during match play between adult and young players, not many differences can be found [4]. However, the physical and physiological characteristics of young athletes are influenced by body development and, consequently, they may be different from those of their adult counterparts [5, 6].

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 was suggested by Van Praagh and Doré [7]. Detailed information about one's anaerobic power can be obtained by valid and reliable laboratory methods, such as the Wingate 30-s anaerobic test (WAnT) [8], the Bosco 60-s test [9] and the Force-velocity (F-v) test [10]. Compared with the other tests, WAnT has the advantage in that it provides information about both the alactic and lactic anaerobic energy transfer system. The main indices of this test are: a) peak power (P_{peak}), the highest power elicited during the test taken as the average power of any 5-s period; b) mean power (P_{mean}), the average power during the 30-s test, minimal power; and c) fatigue index (FI), the difference between P_{peak} and minimal power (P_{min}), divided by P_{peak}. Regarding the taxation of the human energy transfer systems during the test, P_{peak} is considered as a descriptor of short-term power that relies mainly upon adenosine triphosphate-creatine phosphate (alactic anaerobic system), and P_{mean} as a descriptor of local muscular endurance capacity that relies mainly upon anaerobic glycolysis resulting in lactate production (lactic anaerobic system).

Previous studies employing the WAnT, conducted on female soccer players, revealed that starters had better peak power than substitutes [11], indicating a link between this test and soccer performance. Knowledge about one's power characteristics can provide important information for optimal sports training, as the athlete can concentrate on their "weak" component of power, i.e. peak, mean or fatigue index. On the other hand, fitness specialists working with young soccer players should take the differences of these characteristics between adult and adolescent players into account, and the quantification of such differences could help either in talent identification or in improvement of overall power.

The development of maximal anaerobic power across adolescence has already been investigated either in the male general population (*N* = 184, aged 11–17 y) [12] or in soccer players (*N* = 328, aged 11–18 y) [2] with the employment of field methods (vertical jump, 40-m sprint) and cross-sectional studies. It has been also studied by laboratory methods (Force-velocity test and WAnT) in the general population, in the lower spectrum of adolescence (*N* = 81, aged 11–15 y) [13], on boys aged 8–18 y (*N* = 150) [14] and on males aged 10–45 y (*N* = 300) [15]. WAnT has been employed in research on adolescent soccer players to study the physiological profile of US Olympic youth soccer athletes [3], and to compare anaerobic fitness and repeated sprint tests [16]. However, a comprehensive, sport-specific investigation through the WAnT in a large sample would aid in more clearly defining the present levels of anaerobic power across adolescence.

To sum up, relevant previous studies were carried out either in large samples of the general population employing laboratory methods or in large samples of soccer players using field methods or in small samples of soccer players employing laboratory methods. Therefore, in the present study, we have examined the anaerobic power of young male soccer players with the WAnT. Our goal is to test two related hypotheses: 1) there are no differences with regard to WAnT indices between the age-groups of participants; and 2) there is no association between age and the WAnT indices.

Material and methods

In this investigation, a non-experimental, descriptive-correlation design was used to examine the effect of age on anaerobic power across adolescence. The testing procedures were performed during the competition season of 2009–2010. The local Institutional Review Board approved the study, and oral and written informed consent was received from all players or parents after verbal explanation of the experimental design and potential risks of the study. Exclusion criteria included any history of chronic medical conditions and the use of any medication. The male adolescents (*N* = 217; aged 12.01–20.98 y), classified into nine one-year age-groups (those under thirteen were classified as U13 as well as aged 12.01–13 y; U14: 13.01–14 y, U15: 14.01–15 y, U16: 15.01–16 y, U17: 16.01–17 y, U18: 17.01–18 y, U19: 18.01–19 y, U20: 19.01–20 y, U21: 20.01–21 y) and adult players (classified as a control group, *N* = 29; aged 21.01–31.59 y) who volunteered to participate in this study were all members of competitive soccer clubs (Tab. 1). Although the adolescence period is difficult to define in terms of chronological age due to its variation in onset time and termination, it is suggested to range between 10 and 22 y in boys [17] and is considered to be the cornerstone for future athletic excellence. The players were familiarized with the testing procedures used in this study through pre-investigation familiarization sessions. The study participants visited our laboratory once, where anthropometric and body composition data were obtained, followed by a guided 15-min warm-up and then the WAnT was performed.

Table 1. Anthropometric characteristics and the body composition of the study participants

	Age groups									
	U13	U14	U15	U16	U17	U18	U19	U20	U21	Control
N	15	28	43	35	25	29	12	17	13	29
Age (y)	12.67 (0.27)	13.5 (0.24)	14.53 (0.27)	15.51 (0.29)	16.51 (0.29)	17.44 (0.26)	18.29 (0.21)	19.49 (0.35)	20.59 (0.26)	25.28 (3.11)
Body mass (kg)	47.6 (10.4)	58.3 (7.2)	61 (8.8)	66.3 (9.5)	73.2 (14.1)	68.5 (9.6)	69.9 (5.6)	73.8 (6.3)	75.6 (6.8)	76.3 (6.5)
Stature (m)	1.561 (0.112)	1.666 (0.074)	1.702 (0.08)	1.734 (0.057)	1.759 (0.061)	1.748 (0.053)	1.752 (0.056)	1.773 (0.062)	1.78 (0.065)	1.795 (0.059)
BMI (kg · m^{-2})	19.27 (1.89)	20.97 (1.98)	21.04 (2.49)	22.01 (2.68)	23.67 (4.63)	22.35 (2.56)	22.76 (0.99)	23.5 (1.78)	23.84 (1.46)	23.66 (1.25)
Body fat (%)	14.6 (3.6)	16.4 (3.6)	16 (4)	16.4 (4.2)	16.4 (4.7)	15.4 (3.2)	14.7 (3)	14.9 (3.2)	14.4 (2)	14.9 (3)
Fat-free mass (kg)	40.5 (8.2)	48.6 (5.7)	51.1 (6.6)	55.1 (6.1)	60.7 (8.5)	57.7 (6.8)	59.7 (5.3)	62.7 (4.1)	64.6 (5.5)	64.9 (5)

Values are presented as mean with standard deviation in brackets. BMI – body mass index

Stature, body mass and ten skinfold sites were measured and the body mass index was calculated as well as the percentage of body fat was estimated from the sum of the skinfold measurements [18]. Fat free mass was calculated as the difference between body mass and the product of body mass by the percentage of body fat. Skinfold measurements were taken on the dominant side of each athlete. An electronic weight scale (HD-351, Tanita, USA) was employed for body mass measurement (to the nearest 0.1 kg), a portable stadiometer (SECA, UK) for stature (0.001 m) and a caliper (Harpenden, UK) for skinfolds (0.0005 m). After the taking to the above anthropometric measurements and a short warm-up, all of the athletes completed the WAnT for the lower limbs on a cycle ergometer (Ergomedic 874, Monark, Sweden). Braking force for the 30-sec WAnT was determined by the product of body mass in kg by 0.075. Seat height was adjusted to each participant's satisfaction and toe clips with straps were used to prevent the feet from slipping off the pedals. The participants were instructed before the tests that they should pedal as fast as possible and were vigorously encouraged during the test.

The duration of every flywheel revolution in the Wingate anaerobic test was measured with the help of an electronic sensor while the power output of every revolution was computed by specialized software [19]. The results are presented as mean ± *SD* (standard deviation). Data sets were checked for normality using the Shapiro-Wilks normality test and visual inspection. The effect of body mass, fat free mass and age on anaerobic power was examined by the Pearson product moment correlation coefficient (r) and then the coefficient of determination (R^2) was calculated. Differences between the age-groups were assessed using one-way analysis of variance. Correction for multiple comparisons was undertaken using the Bonferroni method. The significance level was set at alpha = 0.05. All statistical analyses were performed using NCSS 2007 computer software (NCSS, USA).

Results

One-way analysis of variance revealed differences between the age-groups regarding P_{peak} in absolute ($F_{9,228} = 26.81$, $p < 0.001$) and relative (to body mass) values ($F_{9,228} = 12.68$, $p < 0.001$), P_{mean} in absolute ($F_{9,224} = 33.82$, $p < 0.001$) and relative values ($F_{9,224} = 10.7$, $p < 0.001$), and minimal power in absolute ($F_{9,224} = 23.8$, $p < 0.001$) and relative values ($F_{9,224} = 4$, $p < 0.001$), while there was no difference in the fatigue index ($F_{9,223} = 4$, *n.s.*). The employment of the Bonferroni method for multiple comparisons revealed particular differences (Tab. 2). Changes in the absolute and rela-

Table 2. Anaerobic power of the study participants

	Age groups									
	U13	U14	U15	U16	U17	U18	U19	U20	U21	Control
P_{peak} (W)	452.36 (114.85) < U15	566.16 (111.41) < U16	626.4 (115.09) < U17	714.27 (122.72) < U20	769.48 (142.35)	774.21 (149.69)	769.66 (94.31)	839.36 (75.35)	852.92 (80.57)	867.86 (89.07)
rP_{peak} ($W \cdot kg^{-1}$)	9.56 (0.68) < U16	9.64 (1.15) < U16	10.31 (0.92) < U18	10.91 (0.83)	10.63 (1.05)	11.23 (0.97)	10.99 (0.81)	11.52 (0.6)	11.21 (0.94)	11.37 (0.66)
P_{mean} (W)	356.7 (82.58) < U14	450.9 (91.99) < U16	490.6 (92.36) < U16	564.5 (90.94) < U20	601.1 (91.14) < Control	614.3 (89.94) < Control	605.6 (58.92)	662 (75.37)	686.4 (55.98)	697.8 (62.07)
rP_{mean} ($W \cdot kg^{-1}$)	7.6 (0.75) < U16	7.73 (0.96) < U16	8.07 (0.88) < U18	8.61 (0.89)	8.56 (1)	8.97 (0.58)	8.66 (0.46)	9.03 (0.78)	9.13 (0.89)	9.16 (0.54)
P_{min} (W)	264.1 (51.01) < U15	338.3 (70.15) < U16	359.6 (87.97) < U17	408.5 (80.55) < U21	427.4 (70.59) < U21	442.9 (57.58) < Control	427.6 (73.65) < Control	468.5 (87.34)	513 (59.74)	521.8 (54.18)
rP_{min} ($W \cdot kg^{-1}$)	5.68 (0.73) < Control	5.83 (0.87) < Control	5.93 (1.07) < Control	6.26 (1.1)	6.11 (0.98)	6.51 (0.68)	6.1 (0.83)	6.39 (1.09)	6.83 (0.95)	6.86 (0.69)
Fatigue index (%)	40.45 (7.69)	39.35 (8.72)	42.26 (10.84)	42.53 (9.1)	42.27 (8.71)	41.76 (7.86)	44.36 (7.91)	44.22 (9.26)	39.55 (7.52)	39.56 (6.12)

Values are presented as mean with standard deviation in brackets. BMI – body mass index; P_{peak} – peak power; P_{mean} – mean power; P_{min} – minimal power; rP_{peak} – relative peak power; rP_{mean} – relative mean power; rP_{min} – relative minimal power. < indicates significant difference between age groups based on Bonferroni post-hoc analysis

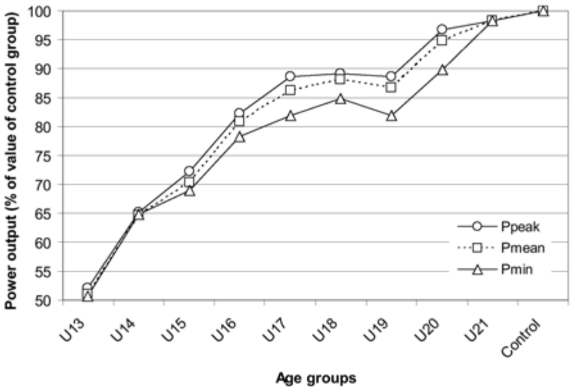

Figure 1. Age-related differences in absolute anaerobic power, presented as a percentage of value of the control group. P_{peak} – peak power; P_{mean} – mean power; P_{min} – minimal power

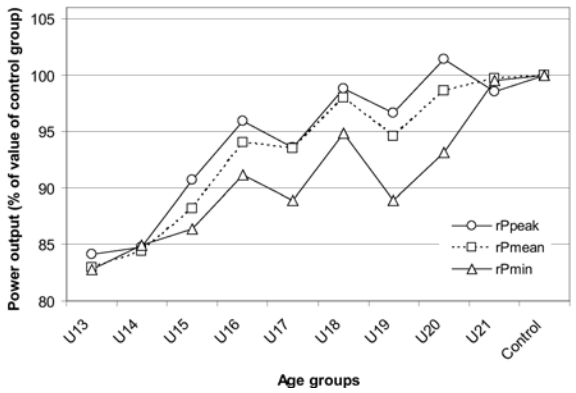

Figure 2. Age-related differences in relative (to body mass) anaerobic power, presented as a percentage of value of the control group. rP_{peak} – relative peak power; rP_{mean} – relative mean power; rP_{min} – relative minimal power

tive (to body mass) anaerobic power indices are illustrated in Figure 1 and Figure 2, respectively. According to Inbar [14], in order to allow for intra- and inter-study comparisons despite differences in the testing procedures, protocols and populations, a common scale is used where values are shown as a percentage when taking the value of control group as 100%.

The Pearson moment correlation coefficient was $r = 0.71$ ($p < 0.001$) between age and P_{peak}, $r = 0.76$ ($p < 0.001$) between age and P_{mean} and $r = 0.70$ ($p < 0.001$) between age and minimal power. When these parameters were expressed in relative (to body mass) values, the respective correlation coefficients were $r = 0.55$ ($p < 0.001$), $r = 0.53$ ($p < 0.001$) and $r = 0.35$ ($p < 0.001$) and when expressed in relative to fat free mass values, the correlation coefficients were $r = 0.51$ ($p < 0.001$), $r = 0.54$ ($p < 0.001$) and $r = 0.35$ ($p < 0.001$), accordingly. P_{peak} was highly correlated to body mass ($r = 0.93$, $p < 0.001$, $R^2 = 0.86$) and fat free mass ($r = 0.94$, $p < 0.001$, $R^2 = 0.88$), as well as P_{mean} ($r = 0.89$, $p < 0.001$, $R^2 = 0.80$; $r = 0.93$, $p < 0.001$, $R^2 = 0.86$, respectively) and minimal power ($r = 0.76$, $p < 0.001$, $R^2 = 0.57$; $r = 0.81$, $p < 0.001$, $R^2 = 0.65$, respectively).

Discussion

Although it is clearly recognized that anaerobic power is linked to performance in soccer, little is known about the short-term power output of those who practice this sport. This is the first study to examine the relationship between age and the main indicies of the WAnT (P_{peak}, P_{mean} and FI) in a large sample of young male soccer players. First, we examined the level of the participants' anaerobic power in light of the previous studies. Overall, the participants exhibited high levels of anaerobic power. The anaerobic power of our study sample was comparable to that of the US Olympic team [3] and superior to that of the general population [20, 21]. Compared with 12.2 y boys [20], the U13 age group (12.37 y) had higher P_{peak} (417.13 W vs. 321 W), rP_{peak} (8.88 W · kg^{-1} vs. 7.89 W · kg^{-1}), P_{mean} (318.7 W vs. 269 W) and rP_{mean} (6.84 W · kg^{-1} vs. 6.61 W · kg^{-1}). Compared with normative data of the general population [21], the adult players received a score of "excellent" on a 7-degree scale (from "very poor" to "excellent") in P_{peak} and P_{mean}, and they were classified higher than the 95th percentile. These findings confirmed anaerobic power as an important sport-related physical fitness parameter in soccer.

Second, we demonstrated that P_{peak} and P_{mean} significantly differed between the age groups of the young players, i.e., the older the group, the higher the short-term power output, whereas there was no difference with regard to FI. Correspondingly, there was a direct relationship between age and P_{peak} and P_{mean} either in absolute or relative to both body mass or fat free mass values. Our findings were scrutinized in light of the previous data on the general population [13] and on soccer players [3, 16]. In these studies, P_{peak} was 9.3 ± 0.2 W · kg^{-1} in U14, 10 ± 0.3 W · kg^{-1} in the U15 and 10.5 W · kg^{-1} in U16 group, P_{mean} 8 ± 0.2 W · kg^{-1}, 8.1 ± 0.2 W · kg^{-1} and 8.7 ± 0.2 W · kg^{-1}, and FI 27.1 ± 1.9%, 36.8 ± 1.9% and 35 ± 1.9%, respectively [3], while the corresponding values in older adults were 10.6 ± 0.9 W · kg^{-1}, 8.7 ± 0.4 W · kg^{-1} and 36.3 ± 7.4% [16]. In research on the general population, mean power was increased from 6.3 ± 1.1 W · kg^{-1} (11–12 y) to 6.7 ± 1.2 W · kg^{-1} (13 y) and 7.6 ± 1 W · kg^{-1} (14–15 y) [13].

The increase of anaerobic power across adolescence in soccer players (from U13 to U19, +70% in P_{peak}) was lower than what was reported in previous studies [2, 12, 20]. In particular, maximal power, estimated by a combination of 40 m sprint time and body mass, increased by 152% in soccer players from 11 y to 18 y (1046 ± 122 W and 2641 ± 384 W), and, when estimated by a combination of countermovement vertical jump displacement and body mass, increased by 127% (448 ± 51 W and 1017 ± 92 W; [2]), while in the general population an increase of 100% (461.5 ± 80.4 W and 923.8 ± 179.8 W) was reported [12]. P_{peak}, an index of WAnT, increased by 120% from 12.2 y to 17 y (321 ± 83 W and 707 ± 114 W; [20]). This discrepancy should be attributed to differences in the assessment methods and in the training levels, as it is expected that in a more homogeneous sample a smaller variability of the physiological parameters can be identified.

Third, the association between short-term power output and body mass and body composition was investigated. Body mass and fat free mass were as high as 86% and 88%, respectively, to the variance in P_{peak}. The respective values for P_{mean} were 80% and 86%, while for P_{min} they were 57% and 65%.These findings came to terms with previous observations on the anaerobic power of the general male population across adolescence [12, 14], in which a large proportion of the variance in anaerobic power was accounted for by body mass. Moreover, pubescent male soccer players (e.g. U13) exhibited about 50% of their adult counterparts absolute anaerobic power, while the corresponding percentage on relative to body mass values was close to 85%, highlighting the role of body mass and fat free mass as the main determinants of anaerobic power. This influence of body mass is also indicated by the much slower rate of increase in relative rather than absolute anaerobic power (Fig. 1 and Fig. 2).

Consequently, there still remains a small proportion of variance that needs to be explained by other factors. Bar-Or and Rowland [22] pointed out possible reasons for low anaerobic performance in children, such as smaller muscle mass per body mass, lower glycolytic capability and deficient neuromuscular coordination. These conditions seem to be attenuated during adolescence and eradicated in adulthood. In addition to these conditions, three biomechanical factors were also identified as determinants of anaerobic power [14]: the increase of the length of lower limbs' levers, the increase of muscular groups' power, and technique.

Physical fitness has a strong interrelationship with physical activity (PA), i.e. higher PA levels result in higher fitness scores, while people with higher fitness scores achieve higher PA levels. A main limitation of any study based on current fitness scores, in the context of talent identification, is whether the attribution of a physical ability can be made to talent or previous training and remains questionable. In our study, the participants were interviewed about their current training load (weekly time basis) and previous experience (years engaged in soccer). However, the possibility still remains that the physiological characteristics of better players are due to a systematic approach to training prior to their induction to the team [1] or due to current non-sport physical activity levels.

This study was carried out on Greek soccer players. Consequently, its results could also be generalized to similar populations of other countries, on the assumption that these countries are found on a similar or lower level than Greece (10th FIFA world ranking as of February 2011; [23]). It is presumed that at a higher international level, considering the contribution of physical fitness on soccer performance, players have better anaerobic power among the other parameters of physical fitness and, therefore, differences between age groups may be attenuated or even be considered null.

These findings could be integrated in either a short-term or long-term training plan for sport-related fitness improvement or talent identification, respectively. However, identifying talent for soccer at an early age is far from being a mechanistic process [24], i.e., it is more complex in team sports than in individual sports where there are discrete objective measures of performance. Since most of the contemporary research in soccer has been carried out on adults, data about the evolution of anaerobic power from childhood to adulthood could also be employed by a coach or fitness trainer towards determining optimal training load. For instance, the findings in the present study can be employed as normative data and the differences of both absolute and relative to body mass values of anaerobic power should be taken into account in the training process.

Conclusion

Considering the importance of short-term high-intensity activities in soccer performance and the lack of information about the anaerobic profile of adolescent players, the short-term power output across adolescence, as assessed by WAnT, was investigated in this paper. The anaerobic profile of the participants was found to be superior with regard to the general population. P_{peak} and P_{mean} were significantly less in those soccer players at the lower spectrum of adolescence than for their older counterparts, even after adjustment for body mass or fat free mass, and there was a direct relationship between these WAnT indices and age. Thus, our findings confirmed the pattern of anaerobic power development across adolescence that was already investigated in the general population. However, what is novel is the quantification of such a pattern in soccer players, where such findings could be implemented in the training process for sport-related fitness improvement or talent identification.

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Paper received by the Editors: August 5, 2010
Paper accepted for publication: July 12, 2011

Correspondence address
Pantelis Theo Nikolaïdis
Thermopylon 7
Nikaia 184 50, Athens, Greece
e-mail: pn@ergometriko.gr