SECTION – SPORT SCIENCES

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RELATIONSHIPS BETWEEN ANTHROPOMETRIC TRAITS, BODY COMPOSITION AND AEROBIC CAPACITY IN MALE SOCCER PLAYERS AGED 13–15 YEARS

Authors' contribution:
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Key words: physical development, aerobic capacity, soccer training

Abstract

Purpose. This study describes the relationships between body dimensions, body composition and aerobic capacity in young soccer players at a targeted stage of their sports training.

Basic procedures. A group of 27 soccer players (13.6–15.6 years of age) was examined during a 2-year training period. Anthropometry, body composition and aerobic capacity were assessed.

Main findings. Positive correlations were found between body mass (BM), fat free mass (FFM), skeletal muscle mass (SMM), and absolute maximal oxygen uptake (VO_{2max}) and physical working capacity (PWC_{170}) values ($p < 0.05$). By contrast, there were unexpected negative correlations between BM, FFM, SMM, and relative VO_{2max} values ($p < 0.01$). Additionally, negative correlations between BMI and relative VO_{2max} values ($p < 0.05$) were noted.

Conclusions. The negative relationships between BM, FFM, SMM and relative VO_{2max} demonstrated the ineffectiveness of the soccer training process in terms of players' aerobic capacity development. At the same time, decreasing relative aerobic capacity indices in consecutive years clearly point to the inadequate implementation of the training program or misconceptions in shaping aerobic capacity. Therefore, it is necessary to verify the implementation of this program in order to improve players' aerobic capacity.

Introduction

Successful soccer performance is the result of multiple, complex and interdependent factors, which include, inter alia, players' body build (anthropometric traits and body tissue components) and aerobic and anaerobic capacity [1, 2, 3, 4].

Studies show that significant differences in body height, body mass and body mass index (BMI) [5, 6] exist between professional soccer players playing different positions. Such variability was also noted in body build [7, 8] and body fat [9] for elite soccer players from different age categories.

Modern soccer requires from players not only top physical condition, but also adequate motor preparation, including high levels of aerobic capacity. This has been confirmed by descriptive studies [10], cross-sectional studies [11] and training-based studies [2]. With regard to matches, the energy demand in soccer players is mainly associated with the oxidative (aerobic) metabolic pathway [4]. Available data, however, point to different percentage contributions of the aerobic pathway during a match: Bangsbo [1] – 70%, Ekblom [12] – 80% and Helgerud et al. [2] even over 90%. At the same time, the mean intensity of the match effort remains around the anaerobic threshold (80–90% of maximal heart rate) [1, 2]. Moreover, researchers also revealed that a high level of aerobic capacity is a prerequisite to improved efficiency of anaerobic capacity during performing high-intensity intermittent exercise [13]. Better aerobic capacity also improves the course of post-exercise recovery of the organism [14]. The most important index of aerobic capacity and a crucial determinant of exercise intensity is maximal oxygen uptake (VO_{2max}). Two other variables of exercise intensity: lactate threshold and running economy, were also shown to rise with increasing VO_{2max}, which points to the need to indirectly examine this index outdoors (by way of coaching tests) as well as directly, in laboratory conditions [15].

Authors dealing with soccer as a subject of research, generally agree that anthropometric traits and high levels of motor preparation do affect the selection of young athletes. In consequence, talented individuals who mature late are eliminated at a very early stage of selection, and the long-term negative impact on sport talent identification procedures can be observed [7].

Research studies on young soccer players are often limited to assessment anthropometric traits and biological maturity in separation from players' functional abilities and soccer-specific skills [16]. A review of literature shows that relationships between anthropometric traits, body composition and aerobic capacity in adolescent soccer players have rarely been studied.

Therefore, the aim of the present study was to examine the relationships between anthropometric traits, body composition and aerobic capacity in young male soccer players at a targeted stage of soccer training.

The following research questions were formulated:

- What is the course of physical development of the selected young soccer players during a two-year study?
- How does the young players' physical development course compare with the age population norms?
- What are the relationships between body anthropometric traits, body composition and aerobic capacity in the studied soccer players?
- What are the players' levels of aerobic capacity indices?
- Do the players' physical development and training affect the strength of relationships between the examined variables?

Material and methods

The study was conducted in the Central Research Laboratory at Józef Rusiecki Olsztyn University College in Olsztyn. A two-year observation was carried out on a group of selected 27 circumpubertal soccer players aged 13.59–15.57 years, constituting a homogenous training group from the Provincial Center of Youth Sports Training in Olsztyn (WOSSM). The selection of the boys from the Provincial Center was based on the results of a battery of motor tests. The training length of the selected players before the commencement of a cycle of three testing sessions (1^{st} session – initial tests; 2^{nd} session – after 12 months of training; 3^{rd} session - after 24 months of training) was 4.6 years. Until completion of the study, the players underwent a uniform training program in accordance with the guidelines developed by the Polish Soccer Association for youth soccer (PZPN, 2010). The frequency of the training protocol was 5 training sessions per week (from Monday to Friday, plus playing regional league matches). The duration of the standard training session was 90 minutes. The protocol was mainly based on both continuous and intermittent exercises at intensities lower than those associated with maximal oxygen uptake – VO_{2max}. To improve aerobic capacity, soccer players had one continuous session during a single microcycle (15–20 minutes, 1500–4500 m at 90% maximal heart rate – HR_{max}) and one session (from 60 to 90 minutes) dedicated to aerobic activities (soccer, running) and intermittent exercises (10 × 10 m, 6 × 200 m, 4 × 600 m at 80% HR_{max}). The aim and the protocol of the study were described to the coaching staff, the players and their parents, and their written consent was obtained.

Before the exercise test measurements of players' basic anthropometric traits and selected body components were carried out. Body height (BH) [kg] was measured to the nearest 0.1 mm with a stadiometer of calibrated medical scales (WB-150, Tryb-Wag ZPU, Poland). Body mass (BM) [kg], body mass index (BMI) [kg/m^2], body fat (BF) [kg and %] and fat-free mass (FFM) [kg] were measured with a Tanita BC 418 MA body composition analyzer (Tanita Corporation, Japan) using bioelectric impedance analysis (BIA). Skeletal muscle mass (SMM) was calculated according to the formula by Lee et al. [17]:

$$SMM\ [kg] = (0.226 \times BM) + (13 \times BH) - (0.089 \times age) + 6.3 \times sex + race - 11$$

where:

sex = 1 – men, 0 – women; race = 1.4 – African-American, 0 = Caucasian or Hispanic, 1.2 – Asian

The variables were compared against standard Polish national growth charts and scoring boards for body height, body mass and BMI [18]. All the measurements were carried out in accordance with the standards of the International Society for the Advancement of Kinanthropometry (ISAK).

The players' HR_{max} was calculated using the following formula: 205 – 0.5 x age [19]. Aerobic capacity was assessed indirectly on the basis of PWC_{170} test (Physical Working Capacity) results [19]. PWC_{170} index is an estimated power of effort with heart rate at 170 beats per minute (bpm). After a 5-minute warm-up, the players performed three standard submaximal 4-min cycloergometer tests (Monark Exercise AB, Sweden). The intensity of these tests was adjusted for individual players so that their HR during physiological steady state ranged between 120 and 150 bpm.

During the exercise test, the players' HR was measured with a Polar heart rate monitor (Polar Electro OY, Finland). The mean HR values taken at the end of each 4-min test were used to calculate the PWC_{170} index in Watts and Watts/kg and then VO_{2max} in L/min and in mL/kg/min, using the Karpman's formula [20]:

$$VO_{2max} = 10.2 \times PWC_{170} + 1240$$

where:

10.2; 1240 – dimensionless constant.

Statistical analysis

The descriptive statistics included arithmetic mean (M), standard deviation (SD), Pearson (*R*) correlation coefficient (r), coefficient of determination (R^2), and linear regression equation (y). The significance of differences was checked with a t-test. The level of statistical significance was set at $\alpha = 0.05$. All statistical calculations were made using the STATISTICA v. 7.1 software package (StatSoft Inc., USA).

Results

During the two-year study, dynamic physical development of young soccer players was observed, as illustrated by the results in table 1. All the measured indices increased significantly ($p < 0.01$), with the exception of body fat percentage ($p < 0.01$).

Table 2 demonstrates the assessment of physical development of young soccer players. Their body height (BH), body mass (BM) and body mass index (BMI) were

Table 1. The anthropometric, body composition and aerobic capacity values of soccer players aged 13–15 years (N = 27)

Variables	Age [years]	BH [cm]	BM [kg]	BF [%]	FFM [kg]	SMM [kg]	BMI [kg/m²]	VO_{2max} [L/min]	VO_{2max} [mL/kg/min]	PWC_{170} [W]	PWC_{170} [W/kg]
M	13.59	166.44	53.33	16.59	44.45	27.78	18.42	2.686	50.94	141.72	2.67
SD	0.25	5.92	7.39	1.89	6.05	2.31	4.11	0.277	6.22	27.18	0.44
M	14.51	172.11	59.95	16.40	50.02	29.93	20.19	2.831	47.80	155.98	2.63
SD	0.23	5.44	7.50	2.27	5.63	2.23	1.94	0.265	6.58	25.98	0.47
M	15.57	177.11	65.43	15.80	55.04	31.73	20.85	3.019	46.44	174.40	2.68
SD	0.22	5.51	6.54	2.16	5.05	1.96	1.75	0.265	4.88	25.43	0.38
Difference	(%)	3.40	12.42	–1.14	12.53	7.74	5.29	5.42	–6.16	10.06	–1.65
age 13 vs. 14	*p*	0.0000	0.0000	0.5813	0.0000	0.0000	0.0288	0.0025	0.0003	0.0025	0.5544
Difference	(%)	2.91	9.14	–3.68	10.02	5.99	3.25	6.64	–2.85	11.81	1.91
age 14 vs.15	*p*	0.0000	0.0000	0.0098	0.0000	0.0000	0.0000	0.0001	0.0645	0.0001	0.4272

Comments: BH – body height, BM – body mass, BF – body fat, FFM – fat free mass, SMM – skeletal muscle mass, BMI – body mass index, VO_{2max} – maximal oxygen uptake, PWC_{170} – estimated power of effort with heart rate at 170 bpm, M – mean, SD – standard deviation, Difference (%) – percentage difference between the results in consecutive years, p – probability.

Table 2. The evaluation of physical development in centiles and points in T scale according to population standards (Dobosz, 2012)

Age (years)	Evaluation	BH [cm]	BM [kg]	BMI [kg/m²]
13.59	Centiles	61.6	50.9	45.2
	Points	53	50	49
14.51	Centiles	60.7	53.6	49.6
	Points	53	51	50
15.57	Centiles	60.2	52.4	48.9
	Points	53	51	50

calculated against Polish national growth norms for boys [18] on a T scale from 1 to 100 points, where the arithmetic mean (M) of a given variable was 50 points, and the standard deviation (SD) – 10. Thus, each result at M + 1SD corresponded to "60 points" points on the T scale, and at M – 1SD to "40 points". The norms above population standards were based on the results of a study carried out in the 2009/2010 school year on a representative sample of boys aged 7–19 years (N = 25.908) from selected schools from every province in Poland.

Particular indices of aerobic capacity displayed different directions of change. The absolute maximal oxygen uptake VO_{2max} (L/min) and PWC_{170} (W) increased in consecutive testing sessions, and the differences between consecutive sessions were statistically significant ($p < 0.01$). The relative PWC_{170} (W/kg) did not change significantly. Unexpectedly, relative VO_{2max} (mL/kg/min) decreased significantly ($p < 0.01$), despite a dynamic increase in fat free mass (FFM) and skeletal muscle mass (SMM) (Fig. 1).

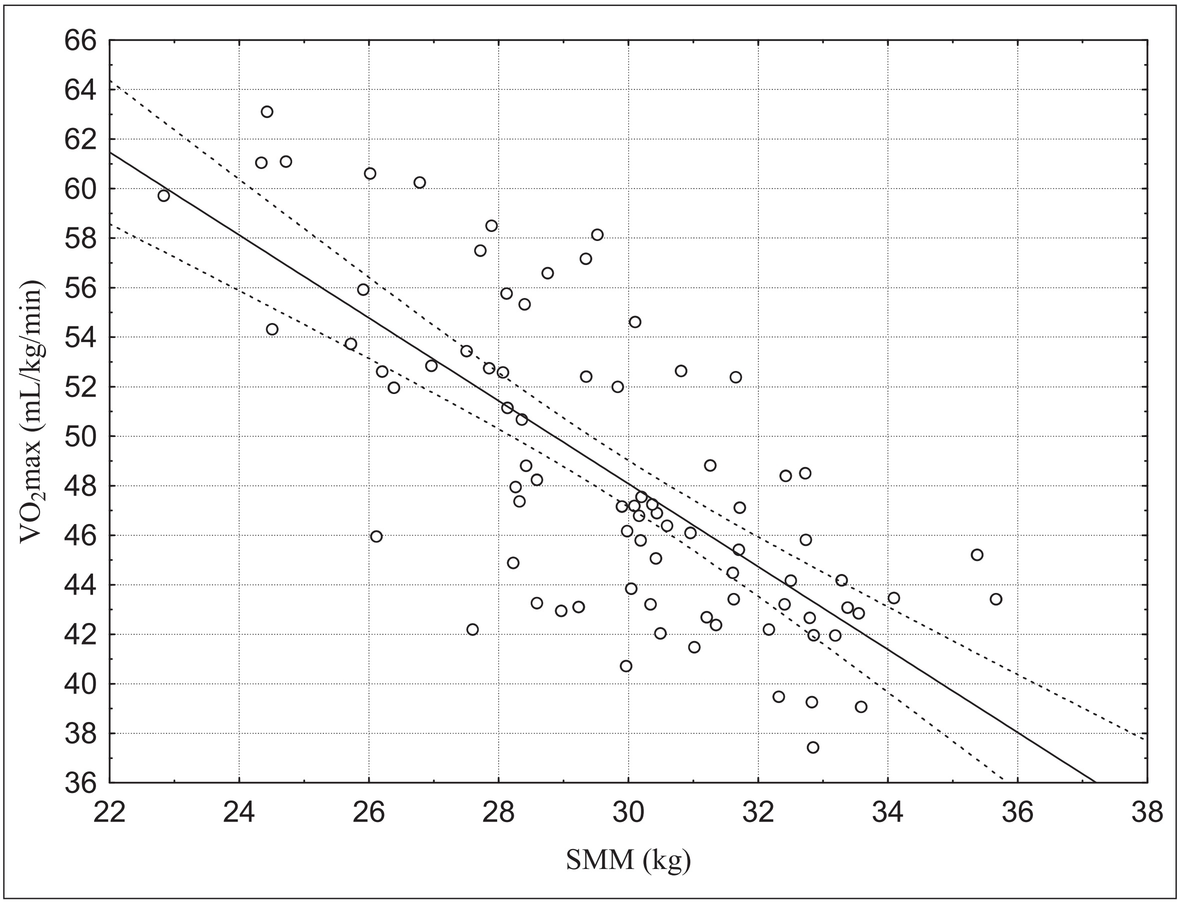

Fig. 1. The relationships between skeletal muscle mass (SMM) and maximal oxygen uptake (VO_{2max}) in soccer players aged 13–15 years (N = 81). SMM (kg): VO_{2max} (mL/kg/min); $R^2 = 0.5330$; $R = -0.7300$; $p = 0.0000$; $y = 98.3 - 1.674 \cdot x$.

According to the accepted norms, the players' physical development during the two-year study was correct and above the mean (points) and median (centiles) body height (BH). The players' body mass (BM) was close to the mean and median values, whereas the BMI was below the means and medians. The dynamics of changes decreased for BH and increased for BM and BMI. It must be noted that body fat percentage (BF%) decreased as BM increased, and these changes were statistically significant ($p < 0.01$).

To examine the relationships between physical development (anthropometric traits and composition) and aerobic capacity for particular variables during each testing session, the Pearson's (R) correlation coefficients were calculated and presented in the form of correlation matrices (Tables 3, 4, 5).

As expected, positive correlations were found between BM, FFM and SMM, and absolute VO_{2max} and PWC_{170} ($p < 0.05$). The negative correlations between BM, FFM, SMM, and relative VO_{2max} were quite

Table 3. Values of Pearson's (*R*) correlation coefficients of physical development and aerobic capacity indices in soccer players aged 13.6 years (N = 27)

Variables	BH	BM	BF	FFM	SMM	BMI	VO_{2max}	VO_{2max}	PWC_{170}	PWC_{170}
BH [cm]	1.000	0.762	0.005	0.779	0.884	0.252	0.242	–0.683	0.242	–0.356
BM [kg]	0.762	1.000	0.206	0.987	0.976	0.348	0.525	–0.701	0.525	–0.228
BF [%]	0.005	0.206	1.000	0.048	0.148	0.095	0.243	–0.056	0.243	0.086
FFM [kg]	0.779	0.987	0.048	1.000	0.973	0.338	0.494	–0.709	0.494	–0.250
SMM [kg]	0.884	0.976	0.148	0.973	1.000	0.337	0.459	–0.735	0.459	–0.284
BMI [kg/m²]	0.252	0.348	0.095	0.338	0.337	1.000	–0.118	–0.467	–0.118	–0.408
VO_{2max} [L/min]	0.242	0.525	0.243	0.494	0.459	–0.118	1.000	0.226	1.000	0.704
VO_{2max} [mL/kg/min]	–0.683	–0.701	–0.056	–0.709	–0.735	–0.467	0.226	1.000	0.226	0.850
PWC_{170} [W]	0.242	0.525	0.243	0.494	0.459	–0.118	1.000	0.226	1.000	0.704
PWC_{170} [W/kg]	–0.356	–0.228	0.086	–0.250	–0.284	–0.408	0.704	0.850	0.704	1.000

Table 4. Values of Pearson's (*R*) correlation coefficients of physical development and aerobic capacity indices in soccer players aged 14.5 years (N = 27)

Variables	BH	BM	BF	FFM	SMM	BMI	VO_{2max}	VO_{2max}	PWC_{170}	PWC_{170}
BH [cm]	1.000	0.661	0.033	0.733	0.821	0.227	–0.040	–0.687	–0.040	–0.552
BM [kg]	0.661	1.000	0.565	0.980	0.971	0.880	0.331	–0.731	0.331	–0.441
BF [%]	0.033	0.565	1.000	0.391	0.441	0.724	0.305	–0.345	0.305	–0.151
FFM [kg]	0.733	0.980	0.391	1.000	0.979	0.806	0.289	–0.740	0.289	–0.464
SMM [kg]	0.821	0.971	0.441	0.979	1.000	0.742	0.240	–0.774	0.240	–0.510
BMI [kg/m²]	0.227	0.880	0.724	0.806	0.742	1.000	0.449	–0.525	0.449	–0.234
VO_{2max} [L/min]	–0.040	0.331	0.305	0.289	0.240	0.449	1.000	0.389	1.000	0.694
VO_{2max} [mL/kg/min]	–0.687	–0.731	–0.345	–0.740	–0.774	–0.525	0.389	1.000	0.389	0.932
PWC_{170} [W]	–0.040	0.331	0.305	0.289	0.240	0.449	1.000	0.389	1.000	0.694
PWC_{170} [W/kg]	–0.552	–0.441	–0.151	–0.464	–0.510	–0.234	0.694	0.932	0.694	1.000

Table 5. Values of Pearson's (*R*) correlation coefficients of physical development and aerobic capacity indices in soccer players aged 15.6 years (N = 27)

Variables	BH	BM	BF	FFM	SMM	BMI	VO_{2max}	VO_{2max}	PWC_{170}	PWC_{170}
BH [cm]	1.000	0.532	–0.115	0.612	0.770	–0.085	0.159	–0.394	0.159	–0.222
BM [kg]	0.532	1.000	0.432	0.970	0.950	0.797	0.408	–0.639	0.408	–0.318
BF [%]	–0.115	0.432	1.000	0.201	0.284	0.600	0.104	–0.340	0.104	–0.214
FFM [kg]	0.612	0.970	0.201	1.000	0.957	0.703	0.412	–0.606	0.412	–0.292
SMM [kg]	0.770	0.950	0.284	0.957	1.000	0.569	0.368	–0.626	0.368	–0.320
BMI [kg/m²]	–0.085	0.797	0.600	0.703	0.569	1.000	0.368	–0.471	0.368	–0.215
VO_{2max} [L/min]	0.159	0.408	0.104	0.412	0.368	0.368	1.000	0.438	1.000	0.733
VO_{2max} [mL/kg/min]	–0.394	–0.639	–0.340	–0.606	–0.626	–0.471	0.438	1.000	0.438	0.931
PWC_{170} [W]	0.159	0.408	0.104	0.412	0.368	0.368	1.000	0.438	1.000	0.733
PWC_{170} [W/kg]	–0.222	–0.318	–0.214	–0.292	–0.320	–0.215	0.733	0.931	0.733	1.000

surprising ($p < 0.01$). Moreover, negative correlations were also found between BMI and relative VO_{2max} ($p < 0.05$).

Discussion

The aim of this study was to examine relationships between anthropometric traits, body composition and aerobic capacity in selected young male soccer players aged 13–15 years at the targeted training stage. Since there have been few studies dealing with the relationships between anthropometric traits, body components and aerobic capacity indices in young soccer players, some of the noted correlations were partially compared with the results of elite soccer players.

It is well known that during progressive physical development increase anthropometric traits, body mass, skeletal muscle mass, heart and lung mass, hemoglobin level and blood volume as well as maturation of the nervous system. Together, all these changes determine the body's aerobic capacity [4]. Research shows that the peak dynamics of BM growth in boys (20–25 kg) occurs between 12 and 16 years of age. Another 10 kg of BM is gained between the age of 16 and 20 [10]. It must be emphasized that fluctuations in BM are generally rare in young male soccer players with a slender body build in comparison to their non-training counterparts [21, 22]. In view of these data, the examined players in the present study were at the period of dynamic biological development.

On the basis of Polish population norms, it can be stipulated that the boys under study featured a slender body build, which was an indirect manifestation of ectomorphy. At the same time, greater increases in FFM in comparison with BH point to a tendency towards mesomorphy. This should be regarded as a positive manifestation of the soccer players' somatic development since other studies showed that the mesomorphic type of body build was dominant in young male soccer players [8] with more frequent ectomorphy than in adult players [7]. Similar observations were made by Moreno et al. [23], who noted significantly lower BF% in male soccer players aged 9.0–14.9 years in comparison with non-training boys. In Gil et al. [24], 14–17-year-old advanced soccer players were taller, heavier and more slender than their non-selected counterparts.

Some authors found correlations between the age and body composition in adolescent soccer players [25, 9]. However, the direction of these correlations, e.g. in BH and BF%, was different for players in different age categories. For instance, Nikolaidis and Karydis [9] in their cross-sectional study among 290 soccer players aged 12.0–21.0 years, found a weak, although statistically significant, reverse correlation between players' BF% and age. Although they found a positive correlation between the players' BF%, FM and age, the increase of these two indices was not proportionate. The main conclusion of their study was that the under 17 (U-17) age category of soccer players is a critical point in the process of significant changes in the players' FM and FFM: the FFM growth rate decreased while the FM growth rate became stabilized. The present study revealed a regular decrease of BF% in soccer players in consecutive years, which can be indirectly regarded as a positive effect of training because extensive body fat is always an overload that limits a soccer players' motor skills (locomotion).

Vaeyens et al. [26] noted that aerobic capacity was the most important fitness component in elite soccer players below 15 and 16 years of age. They also found that the relative maximal aerobic capacity is reached by adolescent boys during the growth spurt [16]. Chamari et al. [27] noted in significant improvement 18 soccer players' (14.0 ± 0.4 years) VO_{2max} from 65.3 (± 5.0) to 70.7 (± 4.3) mL/kg/min after a two-month experimental training program. It should be stressed that both VO_{2max} levels, before and after the training program, were very high. In a study on 34 soccer players aged 17.5 years (± 1.1), Chamari et al. [15] directly measured absolute VO_{2max} at 4.3 L and relative VO_{2max} at 61.1 mL/kg/min. In the study conducted by Stroyer et al. [28], the relative VO_{2max} in 9 elite soccer players aged 12 years was 58.6 (± 5.0) mL/kg/min, and in their two-year older counterparts, it amounted to 63.7 (± 8.5) mL/kg/min. In view of those data, the absolute and relative VO_{2max} results obtained in the present study may be considered average. Positive correlations between BM, FFM, SMM and absolute VO_{2max} in consecutive years are confirmed by the referenced authors. However, the observed decrease in relative VO_{2max} and negative correlations between BM, FFM, SMM and relative VO_{2max} (mL/kg/min) remain rather difficult to explain. Although studies show that the relationship between anthropometric traits and VO_{2max} is not proportionate [29], the decreasing relative VO_{2max} in the examined soccer players must be unequivocally considered a negative trend in the context of modern soccer motor preparation requirements. The reasons for this may be inadequate implementation of the training program or misconceptions about aerobic training development. The results indicate a need to continue studies on soccer players at different ages and with diverse training experience in order to identify the causes and mechanisms of this negative phenomenon.

Conclusions

A harmonious level of anthropometric traits noted in the present study, which remains within the norm of the Polish population of boys, is an indicator of the proper physical development of the soccer players under study. The observed tendency towards mesomorphy in the players' body build should be regarded as a positive manifestation of the boys' somatic development in view of body build demands of modern soccer.

In terms of modern soccer motor preparation requirements, the obtained aerobic capacity indices should be considered average. The decreasing relative maximal oxygen uptake (VO_{2max}) in consecutive years in the young soccer players is definitely a negative trend, the causes of which still remain unclear.

The observed negative correlations between body mass, fat-free mass, skeletal muscle mass and relative maximal oxygen uptake (VO_{2max}) are difficult to explain.

The results of the present study clearly indicate inefficiencies of soccer training in terms of aerobic capacity development of players. The causes of these inefficiencies may involve inadequate implementation of the training program or incorrect assumptions of the aerobic capacity development program. In order to identify the reasons for decreasing relative VO_{2max} values and to verify implemented aerobic capacity training loads, a thorough examination of coaches' training diaries and training program assumptions is necessary.

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