

Assessment of physical performance across selected age categories in football

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Abstract:

Assessing an individual's functional fitness is a key prerequisite for optimizing the training process in response to the progressively increasing physiological and performance demands placed on youth football categories. Systematic monitoring of functional parameters allows coaches and sports medicine professionals to better individualize training loads and support long-term athletic development. This study aimed to evaluate the physical fitness of football players from different age categories, with a focus on their functional status and the identification of potential age-related differences in selected respiratory, circulatory, and performance parameters. The study sample included 64 male football players categorized as U16 (n = 21), U17 (n = 11), U19 (n = 18), and senior players (n = 14). Pulmonary function was assessed using spirometry by measuring forced vital capacity (FVC), forced expiratory volume (FEV₁), and the FEV₁/FVC ratio as pulmonary function parameters. To evaluate ventilatory–circulatory efficiency, spiroergometric testing was performed to determine maximal oxygen uptake (VO₂max). Additional circulatory and performance-related parameters included ventilatory thresholds (aerobic and anaerobic), maximal heart rate (HRmax), and oxygen pulse. Performance indicators were analyzed in both absolute terms and relative to body mass to allow for a more accurate comparison across age groups with different anthropometric characteristics. A one-way analysis of variance (OW-ANOVA) was used to assess differences among the observed age categories. The results showed statistically significant differences in the absolute values of most monitored functional parameters across the age groups, reflecting the influence of biological maturation and training experience. However, no significant age-related effect was confirmed for the aerobic threshold ($F(3,60) = 1.915$, $p = 0.137$) or anaerobic threshold ($F(3,60) = 2.583$, $p = 0.062$) when expressed relative to HRmax. These findings offer valuable insights for coaches and sports physicians, providing evidence-based guidance for age-specific training recommendations and for the structured development of functional fitness in football players at different stages of athletic progression.

Keywords: spirometry, spiroergometry, respiratory system, circulatory system, exercise testing

Introduction

Football is currently one of the most physically demanding team sports, characterized by repeated high-intensity actions, rapid changes in movement patterns, and continuous transitions between aerobic and anaerobic metabolic processes. Over the past decades, the game has changed considerably because of a faster match pace and greater physical demands on players at all competitive levels. Modern football performance relies not only on technical and tactical skills but also on the athlete's functional readiness and physiological efficiency. As a result, the evaluation of functional fitness has become an essential part of training diagnostics and long-term athlete development.

Recent trends in football indicate a continuous increase in the physical and speed-related demands of the game. Modern football is characterized by intermittent bursts of high to maximal intensity lasting 1–5 s, alternating with low-intensity activity or brief recovery periods (Orendurff et al., 2010). The total distance covered by players during a match typically ranges from 8 to 14 km, depending on playing position (Buchheit & Laursen, 2013). These physiological demands place considerable stress on the respiratory, cardiovascular, and neuromuscular systems. Similar conclusions were reported by Kozák et al. (2025), who emphasized that intermittent match activity places high demands on players' motor abilities, particularly endurance, speed–strength abilities, and explosive power.

According to Slimani and Nikolaidis (2019), these physiological demands are already apparent in youth categories from the U15 level onward. Several authors (Carling, 2010; Di Salvo et al., 2007; Jefferson et al., 2021; Osgnach et al., 2021) have identified functional status as an important determinant of success in football. Understanding physiological responses to match-related load can help prevent technical and tactical errors caused by fatigue (Tealdo et al., 2017). The increasing intensity of football has therefore led to growing interest in assessing functional and cardiorespiratory parameters in both youth and adult players.

Performance in intermittent sports depends mainly on aerobic capacity (Lakka et al., 2003), which is essential for maintaining activity throughout a football match and for the total distance covered (Buchheit & Laursen, 2013; Stolen et al., 2005). Adequate aerobic fitness allows players to repeatedly execute high-intensity actions and improves recovery between efforts (Slimani & Nikolaidis, 2019). Its importance is evident in maximal oxygen uptake (VO_2max), which is correlated with the total distance covered during match play (Bangsbo et al., 2006; Castagna et al., 2003).

Higher VO_2max values are linked to lower post-exercise blood lactate concentrations after high-intensity intermittent efforts (Stolen et al., 2005). Conversely, adequate anaerobic capacity enables players to perform high-speed runs during decisive match situations. Sučka et al. (2024) further reported that the high-intensity demands of football are closely linked to the contractile properties of the lower limb muscles, which may vary according to playing position and the specific movement requirements of match play.

Currently, the assessment of football players' functional performance is increasingly focused on the comprehensive evaluation of cardiorespiratory responses through spiroergometry. This laboratory method allows for a more accurate determination of aerobic and anaerobic capacity under exercise conditions and enables the individualization of training loads (Buchheit & Laursen, 2013). Spiroergometric testing has become a standard procedure not only in youth categories but also among professional teams, where it is used to assess players' physiological profiles according to playing position and competition level (Sarmiento et al., 2024; Teixeira et al., 2022). Studies have shown that players competing in higher divisions attain higher VO_2max and ventilatory threshold values, which are closely associated with tactical demands and match workload (Angoorani et al., 2021; Slimani & Nikolaidis, 2019).

Modern approaches increasingly combine spiroergometry with field-based tests, such as the Yo-Yo Intermittent Recovery Test, establishing an objective link between laboratory measures and sport-specific performance indicators (Buchheit & Laursen, 2013). Kokinda et al. (2022) described spiroergometry as one of the most comprehensive methods for evaluating the oxygen transport system and optimizing training diagnostics in athletes.

The evaluation of a player's functional status should also be considered in relation to biological age. During adolescence, rapid somatic growth and hormonal changes support the development of the musculoskeletal and cardiorespiratory systems, leading to improvements in functional parameters (Naughton et al., 2000). Understanding the functional characteristics of youth football players provides a foundation for more objective training management and helps meet the demands of higher levels of competition (Nikolaidis et al., 2014). Adolescence represents a critical developmental period during which maturation-related changes may considerably affect physiological testing results and training prescription. Kozák et al. (2025) also highlighted the importance of systematic long-term sports preparation during adolescence to optimize motor abilities and athletic performance in young soccer players.

Although the growing body of research on football physiology has expanded, several issues remain insufficiently clarified, particularly regarding developmental age categories. Existing studies often focus either on elite adult footballers or on isolated youth categories, without directly comparing physiological characteristics across multiple stages of maturation. Previous studies have also reported conflicting findings on age-related changes in VO_2max , ventilatory thresholds, and cardiovascular responses in football players (Slimani & Nikolaidis, 2019; Tønnessen et al., 2013; Aziz et al., 2008).

Therefore, further research is needed to better understand the physiological characteristics associated with different developmental stages in football.

This study aims to assess the physical fitness of football players using functional status indicators in relation to specific age categories. It specifically focuses on identifying age-related differences in respiratory, circulatory, and performance parameters among U16, U17, U19, and senior football players through laboratory-based spirometry and spiroergometric testing. The findings may contribute to a better understanding of developmental changes in football physiology and offer practical recommendations for age-specific conditioning and performance optimization in football training practice.

Materials and methods

Participants

The study sample consisted of **64 male football players** grouped into categories by age. The **Senior** category included players older than 18 years who competed in the second-highest national league, where they finished second in the final standings of the previous season.

The **U19** category consisted of players aged 17–18 years who qualified to compete in the first national league of their age category in the following season.

The **U17** category included 16-year-old players competing in the first national league, where they also finished in second place. The **U16** category included players younger than 16 years who competed in the first national league of their age category.

Table 1. Characteristics of the study sample

Category	n	Age (years)	Height (cm)	Body mass (kg)	Body fat Percentage (%)
Mean $\pm$ standard deviation					
Seniors	14	26.29 $\pm$ 5.78	182.10 $\pm$ 5.79	77.01 $\pm$ 8.42	9.66 $\pm$ 2.97
U19	18	17.33 $\pm$ 0.49	182.69 $\pm$ 7.32	73.39 $\pm$ 10.14	10.01 $\pm$ 3.43
U17	11	16.00 $\pm$ 0.00	180.18 $\pm$ 8.32	67.89 $\pm$ 6.64	9.25 $\pm$ 2.72
U16	21	14.76 $\pm$ 0.44	175.17 $\pm$ 7.28	63.14 $\pm$ 8.43	10.35 $\pm$ 2.88

(Source: authors' own data)

After being fully informed about the study's purpose and procedures, all participants provided their **written, signed informed consent** before inclusion. For players under 18 years of age, informed consent was also obtained from their **parents or legal guardians**; a template of these consent forms is provided in the *Supplementary Materials*. The study was **approved by the Ethics Committee of the University of Presov, Slovak Republic** (approval no. ECUPO62O24PO) and was performed in accordance with the **principles of the most recent version of the Declaration of Helsinki (Hariss et al., 2018)**.

Experimental design

Functional performance parameters were assessed as part of a medical examination at the beginning of the **2023/2024 pre-season period**. During the six-week transition period preceding testing, the players did not participate in any structured training program. The diagnostics were performed by a physician certified in sports medicine, assisted by a registered nurse.

Procedures

First, **body composition** was assessed using an *InBody 270* device (Biospace, Seoul, North Korea). Subsequently, **spirometry** was performed using a *piston medical ergospirometer (Piston Ltd, Budapest, Hungary)* to assess *forced vital capacity (FVC)*, *forced expiratory volume in one second (FEV₁)*, and the *FEV₁/FVC ratio* as indicators of pulmonary volume. Functional status was then evaluated using **spiroergometric testing** on an *MGC Diagnostics 870A* treadmill (MCG Diagnostics, Minnesota, USA) equipped with a gas analyzer. A ramp protocol was used, beginning at a running speed of 5 km·h⁻¹ with a 0° incline; the speed and incline were then increased by 1 km·h⁻¹ and 0.5° per minute, respectively.

The following parameters were assessed: **VO₂max** as a ventilatory-circulatory indicator; **aerobic (VT₁) and anaerobic (VT₂) thresholds**, **HRmax**, and **oxygen pulse (O₂·pulse⁻¹)** as cardiovascular parameters. Performance was analyzed in **absolute and relative terms** with respect to body mass. All subjects completed the spiroergometric test without complications, within **8–12 min**.

Statistical analysis

To verify the **normality of the data distribution**, the *Shapiro-Wilk test* was applied. Given the normal distribution of the data, mean ($\bar{x}$) values were used as the measure of central tendency and standard deviation (s) as the measure of variability. In the **inferential** analyses, a one-way analysis of variance (*OW-ANOVA*) was performed, with the significance level set at $\alpha = 0.05$. The assumption of homogeneity of variances was tested using *Levene's test*; if violated, the results of *Welch's test* were considered. Effect size was expressed using *eta squared* (η^2), interpreted as follows: $\eta^2 < 0.06$ – small effect; $0.06 \leq \eta^2 < 0.14$ – medium effect; $\eta^2 \geq 0.14$ – large effect. For post hoc comparisons, the *Tukey HSD test* was applied, and *Cohen's d* was calculated as a complementary measure of effect size ($d < 0.50$, small; $0.50 \leq d < 0.80$, medium; $d \geq 0.80$, large). The data obtained were statistically analyzed using the Statistical Package for the Social Sciences software (Version 27.0, IBM SPSS Statistics, Armonk, USA).

Results

A summary of the results of the **OW-ANOVA** of functional parameters by age is presented in **Table 2**.

Table 2. Physical performance parameters of football players by age

Parameter	Category	Mean $\pm$ SD	OW-ANOVA			Tukey HSD post hoc test		
			F	P	η^2	ISK	P	d
FVC (l)	Seniors	5.41 $\pm$ 0.66	13.532	<0.001	0.404 [‡]	Seniors/U19	0.321	0.49
	U19	5.04 $\pm$ 0.68				Seniors/U17	0.007	1.07 [‡]
	U17	4.59 $\pm$ 0.38				Seniors/U16	<0.001	1.62 [‡]
	U16	4.18 $\pm$ 0.58				U19/U17	0.23	0.58 [†]
						U19/U16	<0.001	0.45
FEV ₁ (l)	Seniors	4.56 $\pm$ 0.51	5.67	0.002	0.221 [‡]	U17/U16	0.252	0.89 [‡]
	U19	4.44 $\pm$ 0.54				Seniors/U19	0.97	0.14
	U17	3.66 $\pm$ 1.3				Seniors/U17	0.015	1.13 [‡]
	U16	3.82 $\pm$ 0.51				Seniors/U16	0.022	0.93 [‡]
						U19/U17	0.029	0.99 [‡]
						U19/U16	0.044	0.41
						U17/U16	0.929	1.19 [‡]

FEV ₁ /FVC (%)	Seniors	84.5 ± 4.96	5.73	0.003	0.148 [‡]	Seniors/U19	0.311	0.59 [†]
	U19	88.56 ± 7.44				Seniors/U17	0.655	0.44
	U17	87.55 ± 9.07				Seniors/U16	0.012	1.04 [‡]
	U16	91.67 ± 4.87				U19/U17	0.977	0.15
						U19/U16	0.454	0.45
VO ₂ max (ml·kg ⁻¹ ·min ⁻¹)	Seniors	46.23 ± 4.31	9.461	<0.001	0.321 [‡]	U17/U16	0.335	0.6
	U19	48.8 ± 5.67				Seniors/U19	0.392	0.48
	U17	54.3 ± 3.77				Seniors/U17	<0.001	1.5 [‡]
	U16	52.87 ± 3.91				Seniors/U16	<0.001	1.23 [‡]
						U19/U17	0.012	1.02 [‡]
HR VT ₁ (beats·min ⁻¹)	Seniors	115.43 ± 9.91	4.347	0.008	0.179 [‡]	U19/U16	0.035	0.76 [†]
	U19	127.78 ± 14.32				U17/U16	0.828	0.27
	U17	128.27 ± 13.73				Seniors/U19	0.033	0.93 [‡]
	U16	129.81 ± 11.12				Seniors/U17	0.057	0.97 [‡]
						Seniors/U16	0.007	1.08 [‡]
HR VT ₂ (beats·min ⁻¹)	Seniors	149.29 ± 11.05	5.597	0.002	0.219 [‡]	U19/U17	1	0.04
	U19	162.39 ± 12.08				U19/U16	0.956	0.15
	U17	163.09 ± 11.08				U17/U16	0.987	0.12
	U16	162.76 ± 9.36				Seniors/U19	0.007	1.1 [†]
						Seniors/U17	0.013	1.15 [‡]
HRmax (beats·min ⁻¹)	Seniors	178.29 ± 7.33	5.648	0.002	0.22 [‡]	Seniors/U16	0.003	1.13 [‡]
	U19	187.28 ± 9.88				U19/U17	0.998	0.06
	U17	188.09 ± 9.41				U19/U16	1	0.03
	U16	189.67 ± 6.96				U17/U16	1	0.03
						Seniors/U19	0.019	0.97 [‡]
O ₂ pulse (ml O ₂ ·beat ⁻¹)	Seniors	19.54 ± 2.44	3.973	0.012	0.166 [‡]	Seniors/U17	0.026	1.06 [‡]
	U19	19.02 ± 2.75				Seniors/U16	0.001	1.23 [‡]
	U17	19.38 ± 1.56				U19/U17	0.994	0.09
	U16	17.2 ± 2.1				U19/U16	0.811	0.26
						U17/U16	0.958	0.17
Power (W)	Seniors	322.86 ± 32.62	2.195	0.098	0.099 [†]	Seniors/U19	0.924	0.21
	U19	331.39 ± 39.25				Seniors/U17	0.998	0.06
	U17	340 ± 20.49				Seniors/U16	0.024	0.95 [‡]
	U16	310.95 ± 33.97				U19/U17	0.977	0.15
						U19/U16	0.077	0.74 [†]
Relative Power (Wmax kg ⁻¹)	Seniors	4.22 ± 0.36	14.129	<0.001	0.414 [‡]	U17/U16	0.063	0.89 [‡]
	U19	4.54 ± 0.36				Seniors/U19	0.096	0.66 [†]
	U17	4.98 ± 0.37				Seniors/U17	<0.001	1.59 [‡]
	U16	4.96 ± 0.4				Seniors/U16	<0.001	1.55 [‡]
						U19/U17	0.015	0.93 [‡]
						U19/U16	0.005	0.89 [‡]
						U17/U16	0.999	0.05

Legend:

SD – standard deviation; F – F-statistic; P – significance level; η^2 – effect size (**eta squared**); ISK – intergroup comparison; d – Cohen's coefficient; † – medium effect; ‡ – large effect; FVC – forced vital capacity; FEV₁ – forced expiratory volume in one second; VO₂max – maximal oxygen uptake; HR VT₁ – aerobic threshold heart rate; HR VT₂ – anaerobic threshold heart rate; HRmax – maximal heart rate

Source: authors' own data

The analysis of **FVC** revealed significant age-related differences with a large effect size, and intergroup comparisons showed that these differences were significant, particularly between non-consecutive age categories. Based on the mean values, FVC increased progressively with age, indicating an age-related improvement in pulmonary volume.

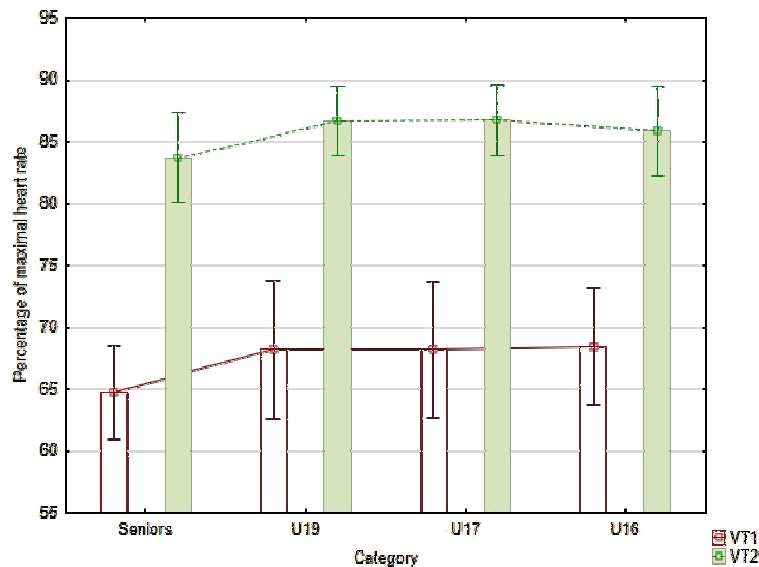
For the **forced expiratory volume in one second (FEV₁)**, significant age-related differences with a large effect size were observed. Intergroup comparisons indicated significant differences between the **Seniors/U19** and **U17/U16** categories.

The analysis of the **FEV₁/FVC ratio** also showed significant age-related effects with a large effect size; however, post hoc comparisons identified a significant difference only between the **oldest (Seniors)** and **youngest (U16)** age categories. The comparison of mean values suggested that the FEV₁/FVC ratio tends to **decrease** as **age** increases, indicating maturation-related changes in respiratory efficiency.

With regard to **VO₂max**, the analysis showed significant differences with a large effect size across age categories. Post hoc tests revealed that these differences were significant between **Seniors/U17**, **Seniors/U16**, **U19/U17**, and **U19/U16**. A comparison of mean values indicated that VO₂max declined with increasing age, which may reflect the influence of body mass and metabolic adaptations during maturation.

The analysis of **circulatory** variables revealed significant age-related differences with a large effect size. Intergroup comparisons showed significant differences in **VT₁** between the **Seniors/U19** and **Seniors/U16** categories, and in **VT₂** and **maximal heart rate (HRmax)** between **Seniors/U19**, **Seniors/U17**, and **Seniors/U16** (Figure 1). However, the statistical analysis did not reveal significant differences between categories when VT₁ and VT₂ were expressed as a percentage of **HRmax** (VT₁: $F(3,60) = 1.915$, $P = 0.137$; VT₂: $F(3,60) = 2.583$, $P = 0.062$).

Figure 1. Illustration of aerobic and anaerobic threshold levels in relation to maximal heart rate



(Source: authors' own data)

Significant differences in **oxygen pulse (O₂·pulse⁻¹)** were observed between the **oldest (Seniors)** and **youngest (U16)** categories, with a large effect size. In contrast, **absolute power output (W)** did not differ significantly by age. However, when expressed **relative to body mass (W·kg⁻¹)**, significant age-related differences with a large effect size were found between **Seniors and U17**, **Seniors and U16**, as well as between **U19 and U17**, and **U19 and U16**.

Discussion

Higher FVC and FEV₁ values were observed with increasing age. According to Gólczewski et al. (2012), these parameters increase during adolescence independently of growth, whereas Chinn et al. (2006) noted that somatic and pulmonary growth may not be synchronized, particularly during puberty. The relationship of FVC and FEV₁ with maturation suggests a similar dependence for the FEV₁/FVC ratio.²¹ The recorded FEV₁/FVC values showed a decrease with age, consistent with the findings of Gólczewski et al. (2012).

Regarding VO₂max, Slimani and Nicolaidis (2019) reported higher values in players aged 14–16 years, which is consistent with our findings. Similarly, Tønnessen et al. (2013) observed higher VO₂max values in players under 18 years than in those aged 23–26 years. Chamari et al. (2005) also reported no significant difference between 16- and 17-year-old players. Higher VO₂max values may occur in football players during late puberty because senior players are typically heavier and their results may therefore seem underestimated (Castagna et al., 2003). Conversely, Aziz et al. (2008) found higher VO₂max values among senior players. According to Mendez-Villanueva et al. (2010), this difference may be attributed to anthropometric differences and higher training volumes in senior footballers.

Age-related changes in VO_2max levels were also confirmed by Angoorani et al. (2021), who noted that this effect does not apply to VT_1 and VT_2 . Similarly, Teixeira et al. (2022) found higher absolute ventilatory threshold values in adolescent footballers than in senior players. On the other hand, as in Buchheit & Laursen (2013), Cunha et al. (2016), and Wrigley et al. (2014), we did not observe any effect of maturation on relative ventilatory threshold values in relation to HRmax .

According to Hoff (2005), the VT_1 in football players ranges from 50% to 75% of HRmax , while the VT_2 ranges from 76% to 90% (Stolen et al., 2005). Lower absolute HRmax values measured during treadmill spiroergometric testing were also observed in senior categories by Nikolaidis (2015), with a 5.2 BPM difference compared with the U16 category. When comparing youth categories, HRmax values did not differ significantly, likely because of the smaller age gaps. According to Perim (2011), HRmax does not influence $\text{O}_2 \cdot \text{pulse}^{-1}$ values. In youth football, $\text{O}_2 \cdot \text{pulse}^{-1}$ increases with age.

As footballers mature, absolute power output also tends to increase (Dilber et al., 2015), which contrasts with our findings. Petrova (2021) reported an average power output of 231.22 W in the U16 category, while Dilber et al. (2015) found an average maximal power output of 320.6 W in youth footballers aged 15–18 years, which is consistent with our results. Relative power output in relation to body mass was reported at 4.87 W/kg, which also corresponds to our findings. In contrast, Chamari et al. (2005) described lower performance despite similar VO_2max levels, attributing this to poorer movement economy.

One limitation of this study is the relatively small number of participants in each age group and the fact that all players were from a single club, which may limit the generalizability of the findings. Another limitation is the study's cross-sectional design, which does not allow for monitoring the long-term development of functional parameters. The results may also have been affected by the fact that players' biological maturity and playing positions were not taken into account, even though these factors can significantly influence the physiological variables assessed.

Practical applications

The observed differences in pulmonary, circulatory, and performance parameters suggest that training programs should be adapted to the athlete's developmental stage. Coaches should therefore use age-appropriate conditioning methods that account for players' physiological maturity, particularly during adolescence, when rapid somatic and functional changes occur. Moreover, the findings indicate that youth players may demonstrate higher relative aerobic capacity than seniors, highlighting the importance of maintaining and further developing endurance potential during the transition to higher competitive levels.

Conclusions

Understanding the body's physiological response to training load is crucial for effectively managing the training process, which should be tailored to specific age categories. The influence of maturation on pulmonary volumes was confirmed by an increase in FVC and a decrease in FEV_1 , as well as in the ratio between these parameters. To maintain optimal respiratory function in senior players, it is advisable to include breathing exercises in warm-up routines to improve breathing patterns and strengthen respiratory muscles. As competition levels increase, the demands on physical conditioning also rise. The results showed a decline in VO_2max with age, with a significant decrease observed between the U19 and senior categories. Considering the time of the season when testing was performed, the recorded values in U19 and senior players may be considered adequate for the demands of second-division competition in Slovakia. However, given the competitive schedule, it is recommended to include training exercises aimed at maintaining or improving VO_2max , with intensity monitored and prescribed according to heart rate, expressed as a percentage of HRmax . The study also showed lower HRmax and lower VT_1 and VT_2 values in senior players, although no significant differences were found when ventilatory thresholds were expressed relative to HRmax . Therefore, prescribing training intensity based on HRmax appears appropriate for players transitioning between age categories. The efficiency of oxygen transport to tissues reflects overall performance status, and the results indicated a plateau in $\text{O}_2 \cdot \text{pulse}$ values from the U17 category onward. Improving the efficiency of oxygen transport may therefore require increasing stroke volume and hemoglobin concentration. Differences in absolute maximum power across categories (U16–Senior) were minimal; however, the decline in relative power with increasing age suggests that performance differences are influenced by the somatic characteristics of individual groups.

Declaration of the use of generative AI and AI-assisted technologies in the writing process:

During the preparation of this work, the authors used ChatGPT (OpenAI, San Francisco, CA, USA) to improve the linguistic quality, readability, and academic style of the manuscript. The tool was also used to assist with text editing and the refinement of scientific phrasing. After using this tool, the authors reviewed and revised the content as needed and assume full responsibility for the content of the publication.

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