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Influence of sexual maturation on anaerobic performance of male adolescent wrestlers

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Abstract

This study aimed to examine the impact of sexual maturation on the anaerobic performance of male adolescent wrestlers. *Methods:* We included a sample of 29 freestyle and Greco-Roman wrestlers from various clubs in Barinas, Venezuela. Their physical characteristics were as follows (mean ± SD): age, 14.99 ± 1.83 years; body mass, 54.68 ± 16.80 kg; height, 161.06 ± 12.78 cm; body fat, 12.09 ± 4.11%; body mass index (BMI), 20.58 ± 3.79 kg/m^2; and training experience, 3.66 ± 2.27 years. Sexual maturation was evaluated using Tanner's criteria, while anaerobic performance was assessed with the 30-second Wingate test for both lower and upper body. *Results:* There were moderate to strong significant correlations between maturation development and both peak power (PP) and average power (AP) — for both absolute and relative measures — for the lower and upper body. The fatigue index (%FI) for the lower body did not show any correlation with maturation development or with the pubescent and postpubescent maturation categories. Conversely, the %FI for the upper body demonstrated a significant moderate correlation with maturation development and with the postpubescent maturation category. Additionally, a strong significant correlation was observed between the pubescent maturation category and both PP and AP (absolute and relative) for the lower body. A moderate correlation was found between the postpubescent category and PP (absolute) for the upper body. PP (absolute) and AP (relative) for the upper body had a moderate correlation with the pubescent maturation category, while the postpubescent category showed a strong correlation with PP (absolute), AP (absolute), and AP (relative). *Conclusion:* The stages of sexual maturation significantly influence the anaerobic capacity of adolescent wrestlers, potentially affecting their training adaptations for peak performance. Future research should explore the physiological responses to training protocols tailored to specific stages of maturation.

Keywords: Martial arts; combat sports; freestyle wrestling; Greco-Roman wrestling; maturation; anaerobic power; anaerobic capacity; high-intensity training.

Influencia de la maduración sexual en el rendimiento anaeróbico de luchadores adolescentes masculinos

Resumen

El objetivo de este estudio fue determinar la influencia de la maduración sexual en el rendimiento anaeróbico de luchadores adolescentes masculinos. *Métodos:* Se incluyó una muestra de 29 luchadores del estilo libre y greco-romana de diferentes clubes de lucha del Estado Barinas, Venezuela con las siguientes características físicas (M ±

Influência da maturação sexual no desempenho anaeróbio de lutadores adolescentes do sexo masculino

Resumo

O objetivo deste estudo foi determinar a influência da maturação sexual no desempenho anaeróbico de lutadores de wrestling adolescentes do sexo masculino. *Métodos:* Uma amostra de 29 lutadores de estilo livre e greco-romana de diferentes clubes de luta de Barinas, Venezuela, com as seguintes características físicas (M ± DP) foram

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DE), edad: 14.99 ± 1.83 años, masa corporal: 54.68 ± 16.80kg, estatura: 161.06 ± 12.78cm, grasa corporal: 12.09 ± 4.11%, índice de masa corporal: 20.58 ± 3.79 kg/m^2 y experiencia de entrenamiento en el deporte: 3.66 ± 2.27 años. La maduración sexual se evaluó usando los criterios de Tanner y el rendimiento anaeróbico se midió con la prueba de Wingate de 30 segundos del tren inferior y superior. *Resultados:* Se observaron correlaciones significativas moderadas y fuertes entre el desarrollo madurativo con la Potencia Pico [PP] y la Potencia Media [AP] (absoluta y relativa) del tren inferior y superior. El índice de fatiga (%IF) de la parte inferior del cuerpo no mostró relación con el desarrollo madurativo o con las categorías de maduración pubescente y pospubescente. Sin embargo, el %IF de la parte superior del cuerpo reveló una correlación moderada significativa con el desarrollo madurativo y la categoría de maduración pospubescente. Además, se encontró una fuerte correlación significativa entre la categoría de maduración pubescente con la PP y AP (absoluta y relativa) de la parte inferior del cuerpo y una relación moderada entre la categoría pospubescente con solo la PP (absoluta). La PP (absoluta) y AP (relativa) de la parte superior del cuerpo presentaron una relación moderada con la categoría de maduración pubescente, y la postpubescente tuvo una fuerte correlación con la PP (absoluta), AP (absoluta) y PA (relativa). *Conclusión:* Las etapas de maduración sexual influyen en la capacidad anaeróbica de los luchadores, lo que puede influir en las adaptaciones del entrenamiento para el máximo rendimiento. Futuros estudios necesitan investigar las respuestas fisiológicas a protocolos de entrenamiento específicos para la maduración.

Palabras clave: Artes marciales; deportes de combate; lucha libre olímpica; lucha grecorromana; maduración; potencia anaeróbica; capacidad anaeróbica; entrenamiento de alta intensidad.

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Palavras-chave: Artes marciais; desportos de combate; luta livre olímpica; luta greco-romana; maturação; potência anaeróbia; capacidade anaeróbia; treinamento de alta intensidade.

1. Introduction

Biological maturation is a dynamic process regulated by various genetic and environmental factors (de Almeida-Neto et al., 2022; Torres-Moreno et al., 2022). This process spans a period of life during which individuals grow and develop until they reach their maximum potential and begin to initiate reproductive functions (Boutios et al., 2021). Adolescence, typically considered to span from age 10 to the late teens (Graber, 2023), is a crucial period involving physical and hormonal changes. These changes, which begin at puberty, lead to the maturation of primary sexual characteristics (genital organs) and secondary sexual characteristics (changes in hairiness, voice tone, onset of menarche and ovulation in females, and first spontaneous ejaculations in males). These changes generally occur between 10-16 years of chronological age, regardless of ethnic backgrounds (Prado et al., 2009; Malina, 2009). Taking this aspect into account, secondary sexual characteristics (breast development in females [B] (Moreira et al., 2020); genital development in males [G], and pubic hair [PH] in both) are among the most commonly used indicators to assess maturation in young people (Malina & Bouchard, 1991). Therefore, Tanner's criteria (Marshall & Tanner, 1970; Tanner, 1962) offer a way to assess maturation through the appearance of secondary sexual characteristics of children and adolescents in a cross-sectional manner (Lätt et al., 2009; Vera-Assaoka et al., 2020).

A literature review revealed a limited number of studies investigating how physical and physiological variables affect the growth and maturation of young wrestlers. Pişkin et al. (2018) assessed the effects of intense training during somatic growth in early puberty on the development of adolescent wrestlers. The main finding was that training did not significantly affect resting sex hormones or alter the onset of puberty as determined by Tanner's pubertal stages. Demirkan (2015) examined the physical and physiological differences based on the chronological age of young wrestlers. The study showed that stature, body mass, fat-free mass, anaerobic power and capacity of the upper and lower body (absolute and relative), speeds, and isometric hand grip and leg strength increased within an age range and between two ages as chronological age progressed, with significant statistical differences observed between two age groups ($p < 0.05$ in the group of wrestlers aged 15 vs. 17 years).

Nindl et al. (1995) assessed power outputs of the upper and lower body using the 30-second Wingate anaerobic test. They obtained anaerobic values for power and capacity and compared them between male and female adolescent athletes, after normalization for body mass, fat-free mass, and muscle area or cross-section. No statistically significant differences ($p > 0.05$) were reported between sexes in sexual maturity, chronological age, or general training activity. However, a statistically significant difference in the anaerobic power and capacity of the upper and lower body (absolute) was reported when males were compared to females ($p < 0.001$), concluding that significant sex differences in anaerobic performance exist among adolescent athletes, even after controlling for anthropometric measures and training activity. These findings are consistent with other studies (Carl et al., 2017; Grendstad et al., 2020).

Roemmich and Sinning (1997) investigated the effects of dietary restriction on growth, maturation, body composition, protein nutrition, and muscular strength in a wrestling season. The wrestlers followed a high-carbohydrate (61±2% kcal) and low-fat (24±2% kcal) diet during the season, but their energy intake (24.7 ± 3.5 kcal·kg^{-1}·day^{-1}) and protein intake (0.9 g·kg^{-1}·day^{-1}) were inadequate. The deficient dietary intake reduced prealbumin levels and slowed the accrual of cross-sectional muscle areas in the arms and thighs, as well as decreased body mass, relative fat (%), and fat mass (kg). The researchers concluded that dietary restriction reduced protein nutrition and muscular performance but had little effect on linear growth and maturation. A positive correlation between prealbumin levels and the rate of lean tissue accrual ($r = 0.43$, $p < 0.05$) was found.

Despite efforts, to date, published reports on the physiological effects of amateur wrestling on the age group between puberty and adulthood are mostly scarce, even in the non-English literature of countries where the sport plays a more dominant role within the sports community.

On the other hand, a considerable number of research studies have been published on the anaerobic performance of wrestlers of different levels of competition, using the 30-second Wingate test for arm-cranking and lower-body to determine the anaerobic power (peak power) and anaerobic capacity (average power) profiles of successful wrestlers and their less successful counterparts. These studies have concluded that anaerobic performance is related to success in wrestling (Cieśliński et al., 2021; Horswill, 1992; Martínez-Abellán et al., 2010; López, 2013; López-Gullón et al., 2011; Nikooie et al., 2017; Song & Garvie, 1980; Yoon, 2002; Zi-Hong et al., 2013). However, the effects of growth and maturation on anaerobic performance in boys and adolescent wrestlers remain inconclusive.

For this reason, special attention has been paid to athletes during developmental periods in which growth and maturation can pose both threats and opportunities for physical performance (Capranica & Millard-Stafford, 2011) and sports training during this period can have positive or negative effects on some physiological processes, such as growth (Bertelloni et al., 2006), because the levels of growth and maturation do not occur at a linear increase per year for each subject (Bayraktar, 2017). For example, there is a growth spurt during adolescence, particularly in boys, that occurs during mid-adolescence between the ages of about 12-16 years (most commonly about age 13½) and usually begins a year after the testes start enlarging. Boys grow about 4 inches (about 10 cm) during their year of maximum growth (Graber, 2023; Tanner & Davies, 1985). Additionally, it has been speculated that individual differences in biological maturation, particularly among male adolescents, are a significant factor in sport performance. Advanced pubertal development is associated with size and performance advantages, affecting measures of strength, power, and speed (Malina et al., 2004). This can, in turn, influence success in sport or the decisions made by adults regarding the future of young athletes in a sport (Malina, 2009).

Although several studies have examined the effects of physical performance on the growth and maturation of athletes from various backgrounds, understanding the impact that one variable has on the other can provide valuable insights into variations in sports performance and their association with the pubertal development of young athletes. Therefore, the objective of this research was to determine the influence of sexual maturation on the anaerobic performance of male adolescent wrestlers

2. Methods

2.1. Study design

This cross-sectional study was approved by the local ethics committee of the Observatory for Research in Physical Activity and Sports Sciences at the National Experimental University of the Western Plains ''Ezequiel Zamora'', Barinas (Approval #131, issued by the research nucleus of the Pedagogical Institute of Caracas), in accordance with the ethical principles outlined by the World Medical Association (WMA) in the Declaration of Helsinki.

2.2. Sample

The sample was selected using intentional non-probabilistic convenience sampling. There was a study population of 30 subjects in total. The sample size was determined using a formula suitable for finite populations, as described by Aguilar-Barojas (2005). The formula applied was:

$$n=\frac{N\,Z^2S^2}{d^2(N-1)+Z^2\,S^2}$$

Where: n= sample size; N= population size; Z= critical Z value, also called the confidence level; S^2= variance of the study population; d= absolute precision level.

Furthermore, the study established the following inclusion criteria: participants should be healthy and physically active males, aged between 11 and 17 years, free from any physical damage or musculoskeletal injuries, and actively involved in Olympic Freestyle and Greco-Roman wrestling.

Twenty-nine male adolescent participated in the study, including freestyle (n = 13) and Greco-Roman (n = 16) wrestlers from different official competition categories: U13 years old, children [28-58 kg]; U15 years old, children [34-85 kg]; and U17 years old, cadets [41-110 kg]. They were actively engaged in training and represented various wrestling clubs in the state of Barinas. The participants were healthy, physically active males, aged 11 to 17 years (M_{age} = 14.99 ± 1.83 years), with a body mass ranging from 29.5 to 102.5 kg ($M_{\text{body mass}}$ = 54.68 ± 16.80 kg), and height ranging from 142 to 189 cm (M_{height} = 161.06 ± 12.78 cm). Their body fat percentage varied from 5.8% to 22.7% ($M_{\text{body fat}}$ = 12.09 ± 4.11%), and their body mass index (BMI) ranged from 14.8 to 28.4 kg/m^2 (M_{BMI} = 20.58 ± 3.79 kg/m^2). The participants had been training for at least five days a week, two hours per day, and were at the end of a preparation period in an annual training cycle, with a mean training experience of 3.66 ± 2.27 years. Written informed consent was obtained from a parent of each participant after the potential risks and benefits of the study were explained.

2.3. Data and measurements

All measurements were taken by an experienced anthropometrist (ISAK level II), following the recommendations of Esparza-Ros et al. (2019). Each variable was measured three times, except for skinfolds, which were measured until three consecutive readings were within 5% of each other, after which the mean was calculated. Skinfolds were measured at the same site. Body mass was measured with a digital scale (Electronic XACTA-150, USA), stature with a Harpenden wall-mounted stadiometer (Holtain, UK), and skinfolds with a Holtain Tanner caliper (UK).

Prediction of body fat. The body fat percentage was predicted using the equation developed by Slaughter et al. (1988) for male children aged 8 to 18 years [Males: PFDWB = 0.735 (triceps + calf) + 1.0]. This process involved measuring skinfolds at the triceps and calf sites. The chronological age and training experience, in years, were recorded for each participant, along with their BMI. All measurements were taken at the same time of day, from 7:00 to 11:00 a.m., in the exercise physiology laboratory at the Barinas State National Center for Applied Sciences in Sport, Venezuela, during each evaluation period.

Assessment of sexual maturation

The assessment of sexual maturation was carried out by a medical surgeon with more than 15 years of experience in the field of medicine. The surgeon is currently registered with the

Venezuela Medical Federation and has a good reputation in the Venezuela Medical Society. The surgeon was previously trained to assess the sequence of secondary sexual characters in boys and young men, including pubic hair appearance [PH] and genital development [length of the phallus G]). To ensure that participants were examined in a lawful, ethical, and protected manner, parental consent was obtained, and the assessment was performed under the supervision of a parent of each subject.

In the clinical office, the participant wore a surgical gown and the doctor asked them to uncover their intimate area to examine the genital area. The doctor observed the presence of pubic hair [PH] and the volume or length of the phallus [G], allowing participant to be classified according to the stage of maturity at the time of evaluation. The reliability of the physician's assessments was evaluated by using repeat observations on the same day.

This procedure was described by Marshall and Tanner (1970), following the recommendations of Macías de Tomei (2013). In addition to classifying maturational development for each participant within Tanner's stages, they were also grouped by maturation categories, as in other previous studies. This categorization corresponds to genitals [G] (Macías de Tomei, 2004; Nicoletti, 1992) and pubic hair [PH] (Melo et al., 2014). The categories are as follows: prepubertal G1 and PH1 (before puberty); G2–3 pubescent; PH2–3 (progression of puberty) and post-pubescence: G4–5; PH4–5 (advanced puberty or early adult build).

Assessment of anaerobic performance

The Wingate Anaerobic Test (WAnT) (Bar-Or, 1987) was administered to assess short- and medium-term anaerobic performance, as well as fatigue (McDougall et al., 2005; Pearson et al., 2006). This test involves 30 seconds of pedaling or cranking at maximum speed against a constant braking force, predetermined to elicit maximum mechanical power (Hawley & Williams, 1991). The performance indices derived from this test include: a) Peak Power (PP), the highest mechanical power achieved during any 5-second period; b) Average Power (AP), the mean power sustained over the 30-second duration of the test; and c) Fatigue Index (FI), the percentage decrease in power over the course of the test (Blimkie et al., 1988; Dotan & Bar-Or, 1983; Hawley & Williams, 1991).

Previous warm-up. Prior to the 30-second Wingate anaerobic test, subjects completed a warm-up phase, pedaling on a cycle ergometer (Monark 894Ea, Sweden) for seven minutes for lower-body preparation and five minutes of crank-arm exercises for the upper body. This warm-up phase also allowed them to familiarize themselves with the test execution. The beneficial effects of a warm-up have been previously documented (Inbar & Bar-Or, 1975). Consequently, the warm-up protocol from the exercise physiology laboratory at the Pedagogical Institute of Caracas (IPC) was adopted. The warm-up protocol is presented in Table 1.

Table 1. Time, load and cadence considered in the warm-up.

Lower-body			Upper-body		
Time (min)	**Load (%)**	**Cadence (rpm)**	**Time (min)**	**Load (watt)**	**Cadence (rpm)**
3	30	60	**1**	0	60
4	40	60	**2**	50	60
5	50	60	**3**	50	60
6	60	60	**4**	50	60
7	70	60	**5**	50	60

Note. The 50 Watts load, equivalent to the weight of the cycle ergometer's basket, was used as a standard braking load for all subjects during the last four minutes of the upper body warm-up.

Lower-Body Wingate

Lower-body Wingate test adjustment. After completing the warm-up, subjects stood on the left side of the cycle ergometer (Monark 894Ea, Sweden), positioned close and parallel to the saddle, allowing for the seat to be adjusted to 100% of the trochanteric height. Straps were used to secure the feet on the pedals to prevent any sudden stops during pedaling. Once mounted, subjects were instructed to maintain a slight knee flexion throughout the pedaling process. For this test, the load was set based on body mass, with a standard resistance of 75 g·kg^{-1} of body mass applied, consistent with previous studies (Ayalon et al., 1974; Bar-Or, 1987). Subjects seated on the stationary Monark ergometer began pedaling at maximum frequency; after three seconds, the evaluator instructed an assistant to "release the load now," initiating the measurement system. Subjects then pedaled at maximum speed for the duration of the 30-second test.

Upper-Body Wingate

Forty-eight hours after completing the lower-body Wingate test, the upper-body Wingate test was conducted. It is generally accepted that 20-24 hours of recovery are needed to normalize muscle glycogen levels after they have been significantly depleted by intense exercise (Burke et al., 2017; Coyle, 1991). This recovery period is deemed sufficient for optimally restoring the anaerobic energy production system and maintaining the capacity to meet the demands of the tests once muscle glycogen stores have been replenished.

Arm crank-modified Wingate test. A modified cycle ergometer (Monark 894Ea, Sweden) was used for the upper-body test, with the pedals replaced by lightly padded spindles. The ergometer was elevated to a height of 75 cm and positioned on a table. Subjects were seated on a bench 60 cm in height, located behind the ergometer, and cranked their arms forward while keeping their feet on the ground and their trunk stationary. The resistance for arm cranking was determined based on body mass, with load settings of 36.9 g·kg^{-1} of body mass (Blimkie et al., 1988; Dotan & Bar-Or, 1983). This braking resistance was defined as a load that provides optimal power outputs and maximum cranking-rate values in young males. Subjects cranked at maximum frequency, and after three seconds, the evaluator instructed an assistant to "release the load now", thereby activating the measurement system. Subjects continued cranking at maximum speed throughout the 30-second test duration.

The following performance indices were obtained on both tests: absolute peak power ($PP_{abs.}$ in Watts) and relative ($PP_{rel.}$ in w·kg^{-1}); anaerobic capacity or absolute mean power ($AP_{abs.}$ in Watts) and relative ($AP_{rel.}$ in w·kg^{-1}) and fatigue index (FI in percentage). These indices were automatically calculated by a computerized system that had an interface between the Monark and a desktop computer (Intel® Core™ DELL, USA), which contained the Monark Anaerobic Test software v. 3.0.

2.4. Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistical Package version 26 for Windows (SPSS Inc, Chicago, IL). The basic characteristics of the subjects are presented as mean values ± standard deviation ($M \pm SD$), minimum and maximum values, and the coefficient of proportional variation (Cvp) proposed by Hernández (2011), expressed in percentage, as: Cvp= $2 * S_x / R_x$, where "S" is the standard deviation (unbiased estimator) and "R" is the -empirical- score range (the difference between the maximum value and the minimum value observed in a certain distribution).

A reliability analysis was carried out in SPSS of the repeated evaluations carried out by the surgeon corresponding to the examination of male secondary sexual characteristics (sexual maturation). The Intraclass Correlation Coefficient (ICC) obtained was calculated using a two-way mixed effects model, absolute agreement and mean measurements with 1 evaluator in 29 subjects, in keeping with Koo and Li's (2016) recommendations. In this case, for the genital part [G] the ICC value obtained is 0.955 (indicating excellent reliability), its 95% confidence interval ranged between 0.884 and 0.980, which means that there is a 95% chance of that the true ICC value lands on any point between 0.884 and 0.980. For pubic hair [PH] the ICC value obtained is 0.909 (indicating excellent reliability), its 95% confidence interval ranged between 0.751 and 0.962, which means that there is a 95% chance that the true ICC value lands on any point between 0.751 and 0.962. Therefore, based on statistical inference, it would be more appropriate to conclude the level of reliability to be between "good" and "excellent" for both [G] and [PH].

The normality of data was verified using the Shapiro Wilk test. For data that were not normally distributed ($p < 0.05$), the non-parametric Mann–Whitney U test, and the probability of superiority (PS_{est}) was calculated as the Mann–Whitney U effect size for the study variable that is not normally distributed. Grissom's (1994) classification was used to report the effect size of each anaerobic performance index that makes up the study variable that was not normally distributed. The effect size classification values were presented by Ventura-León (2016) as: no effect ($PS_{est} \leq =$ 0.0); small ($PS_{est} \geq 0.56$); medium ($PS_{est} \geq 0.64$) and large ($PS_{est} \geq 0.71$)

The Spearman's correlation test was used to determine the relationship between the variables. A significance level of $p \leq 0.05$ was assumed to appreciate the degree of relationship analyzed. In addition, a logistic regression analysis was used with the Wald statistics method. This regression analysis is a modeling technique used to analyze the relationship between a binary dependent variable (a variable with two categories, such as post-pubescent vs. pubescent) and one or more independent variables.

A significance level of $p \leq 0.05$ was assumed for the interpretation of the association measures between the variables, and the coefficient and its classification established by Chourio (2011) were considered.

3. Results

Table 2 illustrates the increase in physical characteristics such as body mass, stature, body mass index (BMI), and years of training experience as subjects aged. The statistical analysis revealed significant differences in these variables but in body fat percentage between the two categories.

Table 2. Physical characteristics of subjects by maturation categories.

	Pubescents (*n* = 13)		**Post-pubescents (*n* = 16)**		***p-Value***
	M ± SD	**Cv*p***	***M ± SD***	**Cv*p***	
Age (years-old)	13.72 ± 1.76	0.69	16.01 ± 1.12	0.60	*<0.001*
Body mass (kg)	43.05 ± 12.12	0.59	64.12 ± 14.03	0.56	*<0.001*
Stature (cm)	152.09 ± 11.39	0.49	168.35 ± 8.64	0.63	*<0.001*
Body fat (%)	11.37 ± 3.19	0.45	12.67 ± 4.76	0.47	*>0.05*
Body mass index (kg/m^2)	18.27 ± 2.81	0.63	22.46 ± 3.48	0.58	*<0.01*
Training exp. (years)	2.63 ± 2.90	0.75	4.50 ± 1.10	0.55	*<0.05*

Note. Cvp = coefficient of proportional variation.

Table 3 presents the anaerobic performance results. The performance indices include absolute peak power ($PP_{abs.}$), peak power relative to body mass ($PP_{rel.}$), absolute average power ($AP_{abs.}$), average power relative to body mass ($AP_{rel.}$), and fatigue index (FI). The anaerobic performance of the lower-body was higher than that of the upper-body. The FI obtained in both tests was similar. These results are presented in a practical and relevant manner for easy interpretation.

Table 3. Anaerobic performance lower and upper body of all subjects (*n* = 29).

	Lower-body WAnT		**Upper-body WAnT**	
	M ± SD	**Cv*p***	***M ± SD***	**Cv*p***
$PP_{(abs.)}$ (watts)	584.08 ± 241.43	0.52	329.60 ± 158.40	0.59
$PP_{(rel.)}$ (w·kg^{-1})	10.38 ± 1.94	0.54	5.74 ± 1.80	0.52
$AP_{(abs.)}$ (watts)	411.10 ± 150.73	0.57	216.13 ± 95.57	0.58
$AP_{(rel.)}$ (w·kg^{-1})	7.38 ± 1.09	0.49	3.79 ± 0.94	0.51
Fatigue index (%)	61.57 ± 8.75	0.39	62.76 ± 12.29	0.39

Note. $PP_{abs.}$ = absolute peak power; $PP_{rel.}$ = relative peak power; $AP_{abs.}$ = anaerobic capacity or absolute mean power; $AP_{rel.}$ = relative mean power; Cvp = coefficient of proportional variation.

Table 4 presents the results of the anaerobic performance of the lower and upper body classified by maturation categories. The table shows statistically significant differences ($p < 0.05$) in anaerobic performance indices [$PP_{(abs.)}$, $PP_{(rel.)}$, $AP_{(abs.)}$, and $AP_{(rel.)}$] between pubescent and postpubescent subjects for the lower and upper body Wingate tests. This reports that as subjects progress from the pubescent to postpubescent category, there is an increase in anaerobic performance. However, the fatigue index did not show significant differences ($p > 0.05$) between pubescent and postpubescent subjects for both lower and upper body Wingate test.

Table 4. Anaerobic performance lower and upper body by maturation categories.

Lower-Boby	Pubescent (n = 13)		Post-pubescents (n = 16)		PS_{est}	*P-Value*
	M ± SD	*Cvp*	*M ± SD*	*Cvp*		
$PP_{(abs.)}$ (watts)	436.45 ± 216.47	0.57	704.02 ± 192.57	0.57	0.16	*<0.01*
$PP_{(rel.)}$ (w·kg^{-1})	9.63 ± 2.26	0.63	10.99 ± 1.42	0.54	0.28	*<0.05*
$AP_{(abs.)}$ (watts)	302.55±127.34	0.59	499.29 ± 104.54	0.60	0.13	*<0.001*
$AP_{(rel.)}$ (w·kg^{-1})	6.79 ± 1.18	0.66	7.86 ± 0.75	0.48	0.26	*<0.05*
Fatigue index (%)	60.96 ± 6.51	0.58	62.06 ± 10.42	0.46	0.48	>0.05
Upper-Body						
$PP_{(abs.)}$ (watts)	225.13 ± 153.14	0.68	414.48 ± 104.54	0.63	0.16	*<0.01*
$PP_{(rel.)}$ (w·kg^{-1})	4.82 ± 2.16	0.66	6.49 ± 1.01	0.54	0.23	*<0.05*
$AP_{(abs.)}$ (watts)	147.64 ± 87.39	0.66	271.78 ± 59.74	0.64	0.14	*<0.001*
$AP_{(rel.)}$ (w·kg^{-1})	3.23±1.12	0.61	4.25 ± 0.39	0.56	0.23	*<0.01*
Fatigue index (%)	58.05 ± 8.28	0.66	66.59 ± 13.86	0.51	0.32	>0.05

Note. $PP_{abs.}$ = absolute peak power; $PP_{rel.}$ = relative peak power; $AP_{abs.}$ = anaerobic capacity or absolute mean power; $AP_{rel.}$ = relative mean power; Cvp = coefficient of proportional variation; PSest = Effect size, <0.5 (Small).

The correlations presented in Table 5 suggest that there is a significant relationship between sexual maturation and anaerobic performance, particularly for the lower-body. Specifically, the results indicate that as individuals progress through the stages of maturation, their anaerobic performance increases, as evidenced by the strong significant correlation found between maturational development and PP(*abs.*) and AP(*abs.*), and the moderate significant relationship with $PP_{(rel.)}$ and $AP_{(rel.)}$. When the participants were classified by maturation category, the pubescent group showed a strong significant relationship ($p<0.05$) with all $PP_{(abs.)}$, $PP_{(rel.)}$, $AP_{(abs.)}$ and $AP_{(rel.)}$, while the post-pubescent group had a moderate significant relationship ($p<0.05$) only with $PP_{(abs.)}$. However, there was no significant relationship found between sexual maturation and fatigue index in any of the cases analyzed.

Table 5. Bivariate correlations between sexual maturation and anaerobic performance of lower and upper body.

	$PP_{(abs.)}$ (watts)	$PP_{(rel.)}$ (w·kg^{-1})	$AP_{(abs.)}$ (watts)	$AP_{(rel.)}$ (w·kg^{-1})	FI (%)
Lower-body WAnT					
Maturational development (n=29; stage II-III-IV-V)	0.733**	0.521**	0.788**	0.526**	0.083
Pubescent (n=13)	0.634*	0.634*	0.634*	0.658*	0.317
Post-pubescent (n=16)	0.600*	0.293	0.687	0.117	-0.044
Upper-body WAnT					
Maturational development (n=29; stage II-III-IV-V)	0.741**	0.578**	0.750**	0.586**	0.490**
Pubescent (n=13)	0.592*	0.508	0.549	0.571*	0.296
Post-pubescent (n=16)	0.717**	0.337	0.658**	0.279	0.585*

Note. $PP_{abs.}$ = absolute peak power; $PP_{rel.}$ = relative peak power; $AP_{abs.}$ = anaerobic capacity or absolute mean power; $AP_{rel.}$ = relative mean power; FI = fatigue index. * The correlation is significant at the 0.05 level (bilateral). ** The correlation is significant at 0.01 level (bilateral)

The anaerobic performance of the upper-body exhibited significant correlations ($p<0.01$) with all -maturational development stages in which the sample was classified (n = 29, stage II-III -IV-V). Specially, there were significant correlations with absolute peak power ($PP_{(abs.)}$) and absolute average power ($AP_{(abs.)}$). Additionally, there was a moderate significant relationship ($p<0.01$) with the relative peak power ($PP_{(rel.)}$), relative average power ($AP_{(rel.)}$), and the fatigue index (FI).

When the subjects were categorized based on maturation, a moderately significant correlation (p<0.05) was observed between absolute peak power PP($_{(abs.)}$) and relative average power (AP$_{(rel.)}$) in the pubescent category. Conversely, the post-pubescent category showed a strong significant relationship (p < 0.01) with absolute peak power (PP$_{(abs.)}$) and absolute average power (AP$_{(abs.)}$); Furthermore, the fatigue index demonstrated a moderate significant correlation with maturational development and post-pubescent group (p < 0.05).

Table 6 presents the results of a logistic regression analysis conducted to investigate the relationship between pubertal maturation and anaerobic performance. The analysis revealed a significant impact (p < 0.001) of average power of the lower body (in Watts) on the differentiation of maturation states.

Table 6. A logistic regression analysis of the interactions between anaerobic performance and sexual maturity states.

Variables in the equation		**B**	**S.E.**	**Wald**	**df**	***p***
Step 1[a]	Average power lower-body (watts)	-.014	.005	7.766	1	.005
	Constant	5.565	2.120	6.890	1	.009
Step 2[b]	Peak power lower-body (watts)	.035	.016	4.894	1	.027
	Average power lower-body (watts)	-.073	.030	6.055	1	.014
	Constant	9.198	3.536	6.765	1	.009

The 1st step of the logistic regression analysis yielded an R^2 (Nagelkerke) value of 0.557, indicating a moderate relationship with the model. In the 2nd step, the R^2 value increased to 0.735, indicating a strong relationship. The model predicted a probability of 87.5% for postpubertal individuals and 84.6% for pubertal individuals in the lower body anaerobic average with respect to the maturity category.

4. Discussion

This study aimed to examine the influence of sexual maturation on the anaerobic performance of male adolescent wrestlers in training. Maturation was assessed based on both statuses, referring to the development of secondary sexual characteristics at a given chronological age, and timing, considering the age at which specific maturation events occur. The Tanner criteria, as proposed by Cameron (2002) and Malina et al. (2004), were utilized as an objective classification system to document and track the maturation status of children and adolescents during the pubertal period. In this investigation, Tanner stages were employed as markers to assess the maturational development of each study participant. Tanner stages are widely recognized as indicators of maturation levels in the child and adolescent population, providing valuable information for determining the optimal age ranges (Ghaly et al., 2008).

Previous studies have utilized Tanner stages as classification criteria to evaluate the sexual maturation of young wrestlers (Gerodimos & Karatrantou, 2013; Sady et al., 1994), examining its potential impact on various physical fitness variables and wrestling training (Roemmich & Sinning, 1997). However, it is important to note that the present study did not aim to investigate the effects of maturation on physical, physiological, or nutritional variables of male adolescent wrestlers. Rather, the primary focus was on determining the influence of sexual maturation on their anaerobic performance, specifically exploring the comparison among the variables under investigation. Therefore, the scope for generating an extensive discussion on the broader aspects of this research was limited.

In contrast, existing scientific literature on Olympic wrestling has consistently highlighted lower and upper body peak power and average power as key anaerobic performance variables in young wrestlers, typically assessed through an isolated 30-second Wingate test protocol involving cycling and arm-cranking (Demirkan et al., 2012; 2013; 2014; Evans et al., 1993; Gierczuk et al., 2012). While it is acknowledged that a single stimulus, such as a 30-second maximum effort test, may not fully replicate the specific metabolic demands of an actual wrestling match, the obtained values from lower and upper body Wingate tests can still serve as reasonable indicators of anaerobic performance in wrestling. Consequently, the authors of this study concur with the findings of

Horswill et al. (1989), who concluded that evaluating the anaerobic performance of the lower and upper body in isolation can provide valuable insights in the context of wrestling science.

In wrestling, maximum anaerobic power, or peak power, plays a crucial role in executing short, explosive movements such as attacking and throwing opponents (Horswill et al., 1988). Anaerobic capacity, measured as average power, is essential for enduring attacks and maintaining the intensity of an opponent's offensive sequence. The fatigue percentage, a measure of muscular endurance under anaerobic conditions, indicates the rate of power decline per second during a 30-second Wingate test involving pedaling or arm-cranking.

When comparing the power outputs between groups, notable differences were observed in the anaerobic performance of the lower and upper body ($p < 0.05$), except for the fatigue index, which showed no significant difference ($p > 0.05$) between the lower and upper body. Demirkan et al. (2013) reported higher values for peak power (PP[*abs.*]) and average power (AP[*abs.*]) in the lower body compared to the present study, highlighting differences in training and maturation levels.

Although the protocols were similar in terms of the instrument used (Monark model 894Ea), the duration of the stimulus (30 seconds of effort), and the load (75 $g \cdot kg^{-1}$) for the lower body Wingate anaerobic test, notable differences in the sample characteristics may contribute to the variations observed in anaerobic performance. The subjects in the studies by Demirkan et al. (2013; 2014) were top cadet and competitive level junior wrestlers from Turkey, respectively, whereas the sample in this study consisted of adolescent wrestlers in training with a wider age range (11-17 years-old).

However, differences in lower body anaerobic performance may also be attributed to the specificity of the wrestlers' training, suggesting that variations in training programs might allow some wrestlers to reach their genetic potential, thus creating physiological differences (Horswill et al., 1989).

The fatigue percentage indicates the rate at which an athlete's power production declines. In this investigation, male adolescent wrestlers experienced approximately a 60% decrease in power during the pedaling 30-second Wingate anaerobic test, suggesting a significant impact on their ability to maintain power. Unfortunately, direct comparisons between the values obtained for peak power, average power, and fatigue index as indicators of upper-body anaerobic performance cannot be made with those reported in previous studies due to differences in the applied loads. Dotan & Bar-Or (1983) determined that a braking resistance of 36.9 $g \cdot kg^{-1}$ for the arm-cranking 30-second Wingate test yields appropriate velocity and power output values for assessing anaerobic performance in boys.

Correlations between anaerobic performance and sexual maturation in male adolescent wrestlers revealed statistically significant relationships, suggesting that sexual maturation directly influences anaerobic performance. These results provide valuable information for coaches considering the maturational development of athletes for specialized training programs (Imbar & Bar-Or, 1986; Housh et al., 1991; Evans et al., 1993).

Due to limited research on the influence of sexual maturation on the anaerobic performance of adolescent wrestlers, a comprehensive discussion is constrained. However, previous studies provide some insights, with observations of a progressive increase in anaerobic power with chronological age (Armstrong et al., 2001; Duché et al., 1992; Santos et al., 2002). Contrarily, Falk and Bar-Or (1993) did not observe significant changes in peak power relative to body mass with chronological age, highlighting the complex relationship between growth, maturation, and athletic performance.

Research limitations

This study has several limitations. First, it is the inaugural investigation into the influence of sexual maturation on lower and upper-body anaerobic performance in adolescent male wrestlers, which restricts the potential for comparison with previous research. Second, the focus on male wrestlers alone means the findings cannot be generalized to female wrestlers. Additionally, the cross-sectional design of the study precludes the establishment of causal relationships. Finally, the exclusion of training experience as part of the inclusion criteria may potentially limit the applicability of the study's results.

Practical applications and recommendations

Future studies should consider employing Tanner's criteria and stages for a longitudinal assessment of the maturational development in both male and female adolescent wrestlers, with respect to short- and medium-duration anaerobic power outputs. This approach would offer a deeper understanding of how muscle power develops during puberty. Additionally, there is a need for further research to investigate the specific contributions of maturational development to anaerobic power outputs during adolescence. Overall, more investigation is required to comprehend the impact of maturation on anaerobic performance in adolescent athletes.

5. Conclusions

The current study discovered a significant relationship between sexual maturation and the anaerobic performance of adolescent male wrestlers. It revealed that stages of sexual maturity are differentiated by biological maturation in relation to chronological age. Furthermore, the 30-second Wingate anaerobic test, involving both pedaling and arm-cranking, effectively distinguishes the anaerobic performance of adolescent wrestlers in sports training by categorizing them according to their maturation stages. Lastly, the maturity conditions of adolescent male wrestlers in training significantly affect their anaerobic performance.

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