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The relationship of testosterone levels with sprint performance in young professional track and field athletes

The relationship of testosterone levels with sprint performance in young professional track and field athletes

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Abstract
Evidence suggests that higher testosterone levels may provide an athletic advantage. Therefore, it is of practical interest to examine the association between testosterone levels and power- and strength-related traits in young professional track and field athletes, and to consider the factors that determine testosterone levels. The study involved 68 young professional athletes (45 females, 17.3 ± 2.6 years; 23 males, 18.2 ± 1.9 years). Testosterone levels were assessed via liquid chromatography-mass spectrometry. All subjects performed two 20 m and two 30 m sprint trials, and countermovement jump without arm-swing. A bioimpedance analysis of body composition was carried out and biological maturity was examined using the Khamis-Roche method. The average testosterone levels were 26.4 ± 9.6 nmol/l and 1.5 ± 0.7 nmol/l in males and females, respectively. In female athletes, testosterone levels did not correlate with any of traits. Males with the highest testosterone levels were significantly faster in the 20 m ($p = 0.033$) and 30 m ($p = 0.014$) sprint trials compared to males with lower testosterone levels. Testosterone levels in males were positively associated with fat mass ($p = 0.027$), and degree of biological maturation ($p = 0.003$). In conclusion, we found a positive relationship between testosterone levels and sprint performance in young male athletes.

Keywords: Athlete; Body composition; Speed; Elite performance; Testosterone

Introduction

The association between endogenous testosterone and strength/power and speed is well-known [1]: i.e., higher testosterone levels are associated with greater strength/power and faster speed. Testosterone is considered one of the most important factors when explaining the differences between men's and women's sporting results, which can range from 10 to 20% performance difference [2]. In specific sports where muscle mass and/or explosive power are especially important, this sex difference can reach as high as 50% [3]. Similarly, testosteronee can provide a competitive advantage for female athletes, by increasing muscle mass, power, stimulating erythropoiesis, promoting competitive behavior and as such improving physical performance [2,4]. Furthermore, it has been reported that testosterone is responsible for the sex differences in visuo-spatial neural activation, which may partially explain the advantage that athletes with hyperandrogenism have in sports where visuo-spatial abilities are closely associated with improved performance [5].

The positive effect of increased testosterone concentrations on athletic performance may be associated with improved physical performance and on several psycho-emotional factors, such as motivation, focus and dominance [6,7]. In this regard, it is not surprising that female athletes with high levels of androgens (endogenous or exogenous origin) are purported to have a 2 to 5% advantage compared to female athletes within the typical female range of androgens [5]. Previously, this notion has been supported, highlighting that in elite female athletes, higher concentrations of free testosterone provided an advantage, at least in the 400- and 800 meter run, 400 meter hurdles, pole vault and hammer throw [8]. Similar data were obtained by Akhmetov et al. [9] who, after analyzing data from nearly 600 female athletes, showed that testosterone concentrations were positively associated with athletic success in elite sprinters and that 50% of elite sprinters had testosterone levels >1.9 nmol/l, while less successful sprinters had testosterone levels <1.9 nmol/l.

In developing athletes, the concentration of endogenous testosterone does not differ between the sexes at ages of ~6–10 years old [10]. Although there is an increase in testosterone concentration in the early teen years, which, most likely, supports a rapid improvement in athletic performance in male adolescents (aged 12 years and older) when compared to their female counterparts and younger males [10]. In girls, testosterone concentrations do tend to increase with puberty, but to a much lesser extent [11]. According to Senefeld et al. [11] the average testosterone concentration in girls aged 6–20 years old increases from 0.08 nmol/l to 1.02 nmol/l with a plateau at ~14 years old. However, their male peers (6 to 20 years old) experience a sharp rise (0.07 nmol/l to 17.9 nmol/l) in testosterone levels to the age of 20 years, with a gradual plateau initiating at 17 years old. This difference in testosterone concentration levels may in part explain the enhanced results reported by 17-year-old male swimmers compared to female swimmers, although at 10 years old there is negligible difference between boys and girls in performance and testosterone concentrations [11].The International Olympic Committee (IOC) has previously stated that testosterone concentration must be <10 nmol/l for at least 12 months prior to and during competition as a threshold for female athletes' participation [12]. These regulations have been in place since 2015. Simultaneously, World Athletics have set female athlete participation criterion of testosterone levels in some disciplines at <5 nmol/l. However, notably, the scientific community is not in total agreement or support of this regulation [13,14].

In light of the prior, the purpose of the present study was to assess testosterone concentrations in a group of young professional athletes and to examine the correlation between total testosterone and the explosive physical qualities of power and speed. We hypothesize that testosterone concentration correlates with power and speed measures in young professional athletes regardless of sex.

2. Methods

2.1. Subjects

The current investigation collated data from a cohort of 68 young professional athletes from an elite European “Academy of Talents” during the August 2021 training camp. Athletes were considered as professional, as athletics was their primary occupation for financial reward, and they were studying in a specialized sports school. All subjects had no contraindications and had participated in athletics for 3–13 years. All athletes were selected by a special expert council, consisting of five elite coaches with at least 20 years of experience, to participate in camps in their respective age groups. All athletes at the time of camp participation were ranked in the Top-3 in their age group in Russia and were in the Top-20 in Europe according to https://www.tilastopaja.eu/. All athletes specialized in disciplines where strength/power and speed are key qualities for sporting success, for example; the short sprint (100 m, 200 m, 400 m), the 110 m and 400 m hurdles, long jump (single and triple), high jump and throwing disciplines. The inclusion criteria for this study were as follows: regular professional athletic participation for minimum of three years; a medal winning place in the national championship 12 months prior to participation in the training camp; and the absence of injury that resulted in missing more than three training sessions during the month prior to the study commencement. Additionally, the exclusion criteria for the study included: history of disqualification for anti-doping rule violation and consumption of any dietary supplements and pharmaceutical substances 7 days or less prior to blood testing. However, no anti-doping testing was performed prior to the study. Athletes with polycystic ovarian syndrome, disorders of sex development or any transgender athletes were also excluded.

2.2. Skill level

All athletes were divided into several groups, depending on skill level (i.e., experience). The purpose of this was to observe for any relationship between the skill level and other variables including testosterone. This selection was conducted according to the classification adopted in Russia, in which the highest rank is held by “honored masters of sports” (most often these are Olympic medalists and World Champions), "international-class masters of sports" (most often participants in the Olympic Games, winners of the World and European championships), "masters of sports" (most often champions and prize-winners of Russian championships at different age groups), and "candidates for master of sports" (most often participants in the finals of Russian championships). In previous years, young athletes who have the “first-class” and “secondclass” rank have most often been the winners of the adult Russian regional championships.

2.3. Blood tests

All subjects had a single blood sample taken in the morning (August 2021). Blood sampling was carried out between 8:00 and 10:00 a.m. from the cubital vein by an experienced technician. All athletes were instructed to rest on the day prior to the day of blood sampling, and refrain from alcohol consumption. They fasted from midnight for the purposes of the blood test. Analysis of total testosterone in the blood was performed by liquid chromatography-mass spectrometry (LC-MS) on an Agilent 1200 liquid chromatography (Agilent Technologies, Santa Clara, CA, USA) combined with an AB Sciex 3200 MD mass detector (Sciex, Framingham, MA, USA). The separation of substances was carried out in a gradient mode, an acetate buffer was used as the aqueous phase, and methanol was the organic phase. A reverse-phase column (Phenomenex, Torrance, CA, USA) was used as a stationary phase. All reagents used were labeled no lower than HPLC-grad, standards for substances produced by TRC (Toronto Research Chemicals, Toronto, Ontario, Canada). These procedures have been previously validated and are based on previously published guidelines for obtaining the most valid, reliable and accurate testosterone values [1,15].

2.4. Biological maturity

Determination of biological maturity was conducted using the Khamis-Roche method which has been previously validated and considered most applicable when assessing Caucasian boys and girls aged between 4 and 18 years old [16]. Within this formula, maturity is defined as the percentage of real height from the predicted growth of an adult. For this calculation, the assessed height and weight of the athlete, and the height of their biological parents were used [16]. We calculated biological maturity only for athletes less than 18 years old of age.

2.5. Speed and power testing

After the standardized warm-up routine, subjects performed two 20 m and two 30 m sprint trials on an official running track surface (Regopul®, Bad Berleburg, Germany). Between the sprint efforts a 3-minute recovery period was provided. The best single effort from the straight sprints was used for analysis. Sprint times were recorded using SmartSpeed®Pro-timing lights (Fusion Sport®, Coopers Plains, Australia),with gates at 0 m, 20 m and 30 m. This system uses a singlebeam design to improve battery life and ease of setup, however, incorporates novel error detection algorithms to reduce false triggers. In the event of multiple triggers, the algorithm interprets the longest trigger as the true start time. Gates were set at a height of 1 m from the floor. Each attempt was recorded with an accuracy of one hundredth of a second. The SmartSpeed® Pro-timing system has previously been validated and used to evaluate sprint performances in male students and recreational female athletes [17]. Subjects started all sprint trials from a two-point start position, with their front foot 0.3 m behind the first timing gate, and were instructed to complete with maximum effort. All tests were carried out in specific athletic shoes regularly worn by the subjects. All subjects were familiar with the sprint test protocols, having completed several practice testing sessions.

Following the 3 minute recovery after the final sprint attempt, CMJ (countermovement jump) without arm-swing (maximal vertical jump with a preparatory counter-movement with athletes keeping hands placed on hips) data were collected. All participants were familiar with the jumping protocols, having completed jumps regularly as part of the academy assessment procedures and participating in several practice testing sessions. All jump tests were conducted in an indoor facility to avoid any external variations in surface that might affect results. For each jump test, three attempts were performed, and the best result was recorded in centimeters (cm) and used in analysis. A recovery interval of 3 minutes between jumps was provided. A commercially available jump mat (Vald Performance™, FusionSport, Brisbane, Queensland, Australia) was used which has been previously validated [18,19]. Subjects performed the tests in their normal sports shoes in an indoor facility with a non-slip, flat surface at a room temperature of 18–20 ◦C.

2.6. Body composition

Musculoskeletal mass was assessed using bio-impedance analysis on the day following the blood sampling procedure. The assessment was performed in the morning following a fasting period starting midnight. The ABC-02 “MEDASS” (Medass LLC, Moscow, Russia) analyzer was used for bio-impedance analysis. The parameters in the analysis were calculated using previously validated equations [20,21]. Body height and weight measurements were obtained from all subjects. The musculoskeletal mass analysis was conducted in the morning on an empty stomach using a single measurement methodology. During the study, the girls/women were not menstruating, however the actual menstrual cycle status of female athletes was not assessed in this study. In all athletes, their muscle, body fat mass (kg), phase angle (%), lean weight (kg) and proportion of active cell mass (%) were assessed. In a number of studies, the phase angle has shown to be higher in athletes than in the general population and that its value correlates positively with muscle mass and intracellular/extracellular water ratio [22,23] thus the phase angle was measured in the current study. This parameter purportedly reflects the relationship between intra- and extra-cellular fluid as well as cell integrity and is defined as the ratio between bioelectrical

and reactive impedance [24]. The advantage of the phase angle is that it is estimated directly from raw bioelectrical measurements without the need for weight, height or any other conversion equation.

2.7. Statistical analysis

Normality of the quantitative data was tested using Kolmogorov-Smirnov test. A two-sample independent T-test for unequal variances was used to assess the inter-group differences in case of normal distribution. The Mann-Whitney U test was used to assess the significance of inter-group differences for variances distributed non-normally. To assess the relationship between quantitative variables, Pearson correlation and Spearman rank correlation (either denoted by 'r') were used in cases of normal distribution and non-normal distribution respectively. To examine the influence of testosterone on performance, male and female athletes were classified in quartiles according to their hormonal concentration and the power, speed, and body composition measures were then compared using Mann-Whitney or T-test [25]. When considering the dependence of power and speed measures and body composition on testosterone concentration, a linear regression model was used, which included age when analyzed by sex. To determine the influence of testosterone concentration on the level of skill and discipline, the Kruskal-Wallis test was used. Values at $p \leq 0.05$ were considered statistically significant. All statistical analysis was performed in Jamovi v. 2.3.21 (Open Statistical Software, Sydney, Australia).

2.8. Ethical aspects

Ethical approval was granted by the local Ethics Committee of Sechenov University (N 11–19 dated 25/07/2019) and the study was performed in accordance with the Helsinki Declaration principles. To ensure confidentiality, all data were anonymized before analysis. Subjects were fully familiarized with the experimental procedures within this study due to the regular testing protocols implemented as part of the Academies monitoring strategy. All subjects provided informed written consent. For subjects under 18 years old, written consent was provided by parents or guardians.

3. Results

Height, weight, BMI and testosterone concentration were significantly greater in male than female athletes ($p < 0.023$). There was no statistically significant difference in age between males and females ($p = 0.15$). Male athletes also demonstrated greater power and faster sprint speed, and had a higher phase angle and more muscle mass (Table 1) than their female counterparts. The degree of biological maturation in athletes between the ages of 13 and 18 years, defined as a percentage of predicted adult height, ranged from 90.25% to 100% ($p > 0.05$).

Table 1. Subject anthropometry, body composition, performance, and testosterone levels.

	Male (mean ± SD; min - max) n = 23	**Female (mean ± SD; min - max) n = 45**	**P value**	**Test**
Age, years	18.2 ± 1.9 (15.5 - 23.1)	17.3 ± 2.6 (12.8 - 23.2)	0.15	T-test
Height, cm	185 ± 7.3 (166 - 198)	171 ± 6.0 (162 - 184)	<0.001	T-test
Weight, kg	74.5 ± 10.5 (53.9 - 99.0)	61.6 ± 16.5 (36.3 - 95.0)	<0.023	Mann-Whitney
BMI, kg/m^2	21.8 ± 2.5 (18.8 - 31.2)	20.3 ± 2.5 (16.6 - 30.1)	0.002	Mann-Whitney
Testosterone, nmol/l	26.4 ± 9.6 (13.6 - 45.3)	1.5 ± 0.7 (0.6 - 4.5)	<0.001	Mann-Whitney
Fat mass (kg)	12.4 ± 3.6 (8.0 - 23.6)	12.0 ± 4.8 (6.2 - 33.2)	0.79	Mann-Whitney
Muscle mass(kg)	61.9 ± 8.1 (53.9 - 75.5)	54.2 ± 8.8 (22.5 - 84.8)	<0.001	Mann-Whitney
Biological maturity (%)	99.2 ± 1.1 (96.0 - 100)	98.0 ± 2.4 (90.3 - 100)	0.06	Mann-Whitney

Phase angle	8.70 ± 0.8 (3.71 - 4.22)	7.54 ± 0.6 (6.44 - 9.49)	<0.001	T-test
Sprint 20m (sec)	2.89 ± 0.1 (2.67 - 3.07)	3.24 ± 0.1 (2.98 - 3.50)	<0.001	T-test
Sprint 30m (sec)	4.02 ± 0.1 (3.71 - 4.22)	4.53 ± 0.2 (4.01 - 5.14)	<0.001	T-test
CMJ (cm)	51.7 ± 6.9 (39.4 - 62.2)	37.7 ± 4.3 (28.7 - 46.5)	<0.001	T-test

BMI - body mass index. CMJ – countermovement jump.

In male athletes, age significantly correlated with testosterone concentrations ($r = 0.62$, $p<0.001$), height ($r = 0.38$, $p = 0.05$) and weight ($r = 0.39$, $p = 0.05$), but did not correlate with BMI ($r = 0.19$, $p = 0.36$). In the female athletes, age also significantly correlated with height ($r = 0.35$, $p = 0.014$), weight ($r = 0.53$, $p<0.001$), and BMI ($r = 0.46$, $p = 0.001$), but did not significantly correlate with testosterone concentration ($r = 0.05$, $p = 0.75$) (Table 2).

Testosterone in the male athletes was significantly correlated with fat mass ($p = 0.027$, $b = 0.23$, $r^2 = 0.23$), and the degree of biological maturation ($p = 0.003$, $b = 0.03$, $r^2 = 0.48$). In the female athletes, no physical measure was associated with testosterone concentration levels (Table 2).

Table 2. Correlation between athlete's age and testosterone, height, weight, and BMI. Pearson and Spearman rank correlations.

	Testosterone	**Height**	**Weight**	**BMI**
Age, male	r=0.62 p<0.001	r=0.38 p=0.05	r=0.39 p=0.05	r=0.19 p=0.36
Age, female	r=0.05 p=0.75	r=0.35 p=0.014	r=0.53 p<0.001	r=0.46 p=0.001

The average concentration of testosterone in male athletes was 18.9 nmol/l and 31.1 nmol/l from the 25th and 75th percentile groups, respectively. When comparing athletes from these percentiles, a significant difference was found in the 20m ($p = 0.033$; 2.9 ± 0.09 vs 2.91 ± 0.11) and 30m ($p = 0.014$; 4.12 ± 0.13 vs 4.06 ± 0.11) sprint times, notably athletes from the 75th percentile were faster (Table 3). Testosterone levels did not correlate with 20m ($r=0.07$, $p=0.75$) or 30m ($r=0.03$, $p=0.88$) sprint times when all the meanings were taken into account.

Table 3. Difference between sprint times of male athletes. T-test.

	Below 25th percentile of testosterone levels	**Above 75th percentile of testosterone levels**	**p**
Sprint 20m	2.9±0.09	2.91±0.11	0.033
Sprint 30m	4.12±0.13	4.06±0.11	0.014

The average concentration of testosterone in female athletes from the 25th percentile was 1.09nmol/l, and from the 75th percentile testosterone concentration was 1.59nmol/l. There were no differences reported in the strength or speed measures in athletes from the 25th and 75th percentile groups ($p>0.05$). The individual correlations of various parameters and testosterone levels can be found in Table 4.

Table 4. Relationship between testosterone concentration levels and various physical measures in both male and female athletes (reported as p-values).

Indicator	**Male**	**Female**
Fat mass	p=0.027 $b = 0.23$, $r^2 = 0.23$	p=0.99
Muscle mass	p=0.24 $b = 0.03$, $r^2 = 0.48$	p=0.46
Biological maturity	p=0.003	p=0.39

Phase angle	p=0.60	p=0.52
Sprint 20m	p=0.37	p=0.48
Sprint 30m	p=0.23	p=0.68
CMJ	p=0.53	p=0.52

CMJ – countermovement jump.

The skill level of the male and female athletes depended on sporting experience (years of training) ($p<0.001$) (Table 5). The experience of the male athletes did not significantly correlate with any strength or speed measure or testosterone concentration. Furthermore, the experience of the female athletes also did not significantly correlate with any strength or speed measure or testosterone concentration. There were no significant differences in testosterone concentration levels between male ($p = 0.48$, Kruskal-Wallis test) and female ($p = 0.09$, Kruskal-Wallis test) athletes when stratified relative to skill (*N.B.*, small sample sizes for comparisons). Additionally, there were no significant differences in testosterone concentration levels in male ($p = 0.80$, Kruskal-Wallis test) and female ($p = 0.18$, Kruskal-Wallis test) athletes of various athletic disciplines (within-sex comparisons; data not presented).

Table 5. Subject skill level and experience.

	Years in sport (mean ± SD; min - max)
Second grade (n = 2)	3.0
First grade (n = 17)	4.4 ± 2.2 (1 - 9)
Candidate for master of sport (n = 29)	6.8 ± 2.4 (2.5 - 13)
Master of sport (n = 17)	7.4 ± 1.8 (5 - 10)
World-class (n = 3)	11.0 ± 3.0 (8 - 14)

4. Discussion

The present study aimed to assess the testosterone concentrations in a group of young professional athletes and to examine the correlation between total testosterone and the explosive physical qualities of power and speed. The analysis was conducted to assess within- and between sex differences of testosterone concentration and physical performance measures. Taken together, the results showed that the levels of testosterone concentration in young female athletes are much lower than the upper limit set by World Athletics or the IOC. The results also highlighted hat testosterone in males was significantly correlated with fat mass and the degree of biological maturation, while in the female athletes, no physical measure was associated with testosterone concentration.

The concentration of testosterone in our female athletes was 1.5 ±0.7 nmol/l (range 0.6–4.5 nmol/l) and in male athletes it was ~17 times higher. These data are consistent with the results of earlier studies involving elite athletes [1,9,26]. Specifically, Ahmetov et al. [9] when investigating 599 Russian international-level female athletes (16–35 years old), reported that the concentration of total testosterone in female athletes is comparable to the concentration in a control group of non-athletes (representatives of the general population). Interestingly, in this latter study, the authors reported a correlation between testosterone levels and athletic success for female sprinters but no correlation was found in any other athletic disciplines/parameters. The authors suggested that testosterone levels could be used as part of a talent identification strategy in female sprinters [9]. However, in our study, we found no such relationship. Although, importantly, we employed a more eliable method (LC-MS) to determine testosterone concentration in contrast to the immunoassay method used by Ahmetov et al. As such, our methods may be more sensitive to determining marginal differences in testosterone concentration levels.

In the current study, no significant correlations were found between testosterone concentration levels and measures of power, speed, body composition and the degree of biological maturation in young female athletes. Contrastingly significant correlations were observed between testosterone levels and fat mass and the degree of biological maturation in males. Most likely, this may be explained by the noteworthy (i.e., magnitude) and rapid rise in the concentration of testosterone during puberty in male compared to female athletes in this cohort [10].

Currently there are insufficient data on the effects of testosterone on female physical performance [27]. In one of the studies on this topic, the authors [25] evaluated the participants of the World Athletics Championships in 2011 and 2013 respectively. The hormonal profile of 849 elite female athletes was studied and it was shown that the level of testosterone concentration in this group of athletes was 3.08 nmol/l (the 99th percentile) [25]. However, the concentration of testosterone was assessed in light of the results achieved in competition, and not against physical performance test data as in the current study (free-living vs. laboratory environment). Albeit, the two approaches may be similar, however, several limitations are presented. Numerous factors may influence testosterone levels in such settings including the type and duration of exercise [28], as well as the success achieved in competition and subsequent motivation [29]. For example, in a study by Oliveira et al. [30], it was shown that successful performance in sporting competitions can cause an increase in testosterone levels in winners and a decrease in losers. Testosterone concentration also depends on diurnal rhythms and thus the sampling time of day is a significant factor [31–33]. Therefore, the approach to sampling times and competition level of the athletes subjects) needs to be standardized in order for any meaningful comparative analysis to be made between the abovementioned studies and our results. Furthermore, some previous studies were conducted in the general population or lower-level athletes, where differences in testosterone concentration during the day or in response to successful performance may be even more different than in high-level athletes [34,35].

Within our data, even though there were differences in testosterone concentration in female athletes from the 25th and 75th percentiles (statistically significant; 1.09 nmol/l and 1.59 nmol/l, respectively), no differences were found in any of the power and speed parameters and body composition measured. Most likely, this may in part be clarified by the actual differences in female athlete testosterone values being relative very small, unlike in their male athlete counterparts. Specifically, male athletes with testosterone concentrations from the 25th percentile (18.9 nmol/l) were statistically significant (slower) in the 20 m ($p = 0.033$) and 30 m ($p = 0.014$) sprint distances compared with male athletes with testosterone levels from the 75th percentile (31.1 nmol/l).

Our study had several limitations which means our findings must be interpreted cautiously. For example, the age of the female athletes was rather young, however, it is worth mentioning, that in females maturation occurs earlier than in males [26]. Although, if the plateau in testosterone levels in females, that occurs before the age of ~16 years, is considered, our results might not have changed significantly by increasing the age of this sample group of athletes. Our study also did not include female athletes with polycystic ovarian syndrome, disorders of sex development or any transgender athletes, which are important athletic populations to research, and future studies should consider these populations. Another limitation is that body composition analyzer used in our study was not formally validated for inter- and intra-variability of measurements per se, however, as stated above, the parameters in the analysis were calculated using previously validated equations [20,21]. We also did not assess menstrual status in the female athletes (i.e., the phase of the menstrual cycle besides menses or regularity of the cycle) which can be a factor influencing testosterone levels in females. Finally, no anti-doping testing was performed prior to study, as such, this may have potentially skewed the results; i.e., if any of the athletes used doping, particularly use of anabolic androgenic steroids. However, we did ask the athletes to attest that they were not violating World Anti-doping Agency (WADA) policies.

5. Perspective

Our study appears to be one of the first to assess the relationship between testosterone level and power, speed and body composition in young professional athletes, employing the LC-MS method, which is regarded as the most reliable method to determine testosterone levels. Although our findings did not support our hypothesis, that testosterone concentration correlates with power and speed measures in young professional athletes of either sex, further studies are warranted with larger samples of athletes from differing sports to address this issue. Additionally, as more individuals undergo gender affirming hormone therapy studies analyzing athletic performance before, during and after exogenous testosterone administration are needed (e.g., male to female transition) [36]. Conducting such research seems particularly relevant regarding the contemporary issue of transwomen participation in sports.

6. Conclusion

The concentration of total testosterone in young professional female track-and-field athletes are within the reference values accepted for the general population and the limit set by World Athletics. In this sample of athletes, no correlational relationship was found between the concentration of testosterone and measures of power and speed, as well as body fat and muscle mass in female athletes. However, our findings support male athletes with higher testosterone levels did perform better in selected sprint performance tests.

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CRediT authorship contribution statement

Eduard Bezuglov: Conceptualization, Investigation, Methodology, Writing – original draft. Ildus I. Ahmetov: Resources, Supervision, Writing – review & editing. Artemii Lazarev: Conceptualization, Investigation, Writing – original draft. George Mskhalaya: Data curation, Resources. Oleg Talibov: Data curation, Project administration. Vjacheslav Ustinov: Formal analysis, Supervision. Maria Shoshorina: Formal analysis, Writing – review & editing. Elizaveta Bogachko: Conceptualization, Investigation, Methodology, Writing – original draft. Violetta Azimi: Formal analysis. Ryland Morgans: Investigation, Project administration, Writing – original draft. Anthony C. Hackney: Conceptualization, Methodology, Writing – review & editing.

Declaration of Competing Interest

The authors report there are no competing interests to declare.

Data availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

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