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Comparative Evaluation of Lower-Body Anaerobic Power and Fatigue Characteristics in Youth Athletes Across Distinct Sport Categories

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Abstract
Optimum lower-body anaerobic power represents a decisive physiological prerequisite for athletic execution across varied competitive disciplines. This cross-sectional investigation evaluated lower-limb anaerobic power profiles and examined the distinct and interactive influences of sex, chronological developmental age, and sport categorization. Three hundred and seventy-six competitive adolescent athletes (N = 376, ages 12–21 years) completed a standardized 30-second Wingate Anaerobic Test (WAnT) on an electromagnetically braked cycle ergometer. Peak power (PP), average power (AP), minimum power (MP), and the fatigue index (FI) were calculated. A three-way multivariate analysis of variance (MANOVA) indicated significant main effects for sex ($p < 0.001$), developmental age group ($p = 0.013$), and sport discipline classification ($p < 0.001$) on overall anaerobic parameters. Male athletes exhibited significantly superior PP (11.5 ± 1.4 W/kg vs. 8.7 ± 1.5 W/kg), AP (8.2 ± 0.7 W/kg vs. 6.4 ± 0.8 W/kg), and MP outputs relative to females across developmental cohorts. Athletes specialized in explosive power disciplines generated the greatest PP (10.3 ± 2.0 W/kg) and AP (7.3 ± 1.1 W/kg), whereas endurance athletes demonstrated higher MP preservation and the lowest fatigue indices (50.2 ± 8.2%). Establishing age-, sex-, and sport-specific anaerobic benchmarks enables athletic conditioning specialists to monitor conditioning progress and structure targeted power-development protocols.
Keywords: Anaerobic Power, Wingate Test, Peak Power, Fatigue Index, Youth Athletes, Sports Conditioning.

1. Introduction
High-level athletic performance in intermittent and explosive sports relies heavily on muscular power output driven by rapid anaerobic energy pathways. The rapid replenishment and breakdown of adenosine triphosphate and phosphocreatine (ATP-PCr), combined with intense glycolytic activation, underpins decisive sporting actions such as terminal sprint acceleration, vertical jumping, multidirectional changes of direction, and repeated high-intensity bouts. Deficits in lower-limb anaerobic capacity correlate with diminished match-play running intensities and an amplified susceptibility to musculoskeletal strain.
The physiological demands placed on anaerobic systems fluctuate substantially across competitive

sporting disciplines. Power-dominant events (e.g., sprinting, combat arts, weightlifting) prioritize instantaneous force production, whereas endurance events rely on sustaining fractional anaerobic thresholds over extended durations. Furthermore, pubertal maturation induces pronounced sexual dimorphism in absolute and relative power capabilities, driven by shifts in endocrine activity, skeletal muscle cross-sectional area, and glycolytic enzymatic function. While adult power profiling is well documented, empirical investigations detailing stratified anaerobic reference standards across youth demographics within institutional athletic academies remain limited. Consequently, this study aimed to: (1) establish lower-body anaerobic power profiles across developmental stages using the Wingate protocol, and (2) analyze the interactive effects of biological sex, chronological age, and sport discipline on power output and fatigue dynamics.

2. Materials and Methods

2.1 Participants and Sampling

A cohort of competitive adolescent athletes (N = 376; 121 males, 255 females; age range: 12–21 years) actively participating in structured academy conditioning regimens for a minimum of 24 months volunteered for the study. Participants were categorized by chronological age brackets: early adolescence (12–14 years), middle adolescence (15–17 years), and late adolescence (18–21 years). Based on metabolic and mechanical profiles, athletes were categorized into power sports (sprinting, jumping, combat), endurance sports (rowing, middle-distance), and mixed intermittent sports (football, basketball). Ethical clearance conformed to the Declaration of Helsinki, and written informed consent was acquired from participants and legal guardians prior to testing.

2.2 Anaerobic Wingate Testing Protocol

Assessments were conducted on an electromagnetically calibrated cycle ergometer (Monark 894E) interfaced with computerized analytical software. Ergometer geometry was individually adjusted to ensure knee flexion of approximately 15° at terminal extension. Following a standardized 5-minute dynamic warm-up and brief submaximal cadence familiarization, resistance was calibrated to 7.5% of each participant's body weight. Upon the initiation command, participants pedaled with maximal volition; the predetermined braking resistance was applied instantaneously once cadence reached 70 rpm. Standardized verbal encouragement was provided uniformly throughout the 30-second assessment.

2.3 Operational Variables

- **Peak Power (PP):** Highest mechanical power output attained during any individual 5-second interval, expressed relative to body mass (W/kg).
- **Average Power (AP):** Total mechanical work completed across the full 30-second duration (W/kg).
- **Minimum Power (MP):** Lowest power output registered during the terminal 5-second interval (W/kg).
- **Fatigue Index (FI):** Percentage decline between peak and minimum power:
  $$\text{FI} (\%) = \frac{\text{PP} - \text{MP}}{\text{PP}} \times 100$$

2.4 Statistical Procedures

Descriptive metrics are reported as mean ± standard deviation (95% confidence intervals). A 2 × 3 × 3 multivariate analysis of variance (MANOVA) evaluated main and interaction effects of sex, age category, and sport type across all dependent variables. Follow-up univariate ANOVAs with Bonferroni post-hoc pairwise corrections localized group-level discrepancies. Alpha level was set at $p < 0.05$.

3. Results

Multivariate testing identified highly significant main effects on combined anaerobic performance metrics for sex (Pillai's Trace $= 0.373, $p < 0.001$), chronological age group (Pillai's Trace $= 0.053, $p = 0.013$), and sport classification (Pillai's Trace $= 0.168, $p < 0.001$).

Table 1: Main Effects of Sex, Age, and Sport Type on Anaerobic Variables

Variable	Male (n=121)	Female (n=255)	Early Adol. (n=76)	Middle Adol. (n=165)	Late Adol. (n=135)	Power (n=129)	Endurance (n=131)	Mixed (n=116)
PP (W/kg)	11.5 ± 1.4	8.7 ± 1.5	8.9 ± 1.6	9.8 ± 1.9	9.9 ± 2.1	10.3 ± 2.0	9.8 ± 1.9	8.7 ± 1.6
AP (W/kg)	8.2 ± 0.7	6.4 ± 0.8	6.5 ± 0.9	7.1 ± 1.1	7.1 ± 1.2	7.3 ± 1.1	7.2 ± 1.2	6.3 ± 0.8
MP (W/kg)	5.2 ± 0.8	4.0 ± 0.7	4.1 ± 0.7	4.5 ± 0.9	4.5 ± 1.0	4.4 ± 0.9	4.8 ± 1.1	3.9 ± 0.7
FI (%)	53.6 ± 8.6	52.9 ± 9.7	52.3 ± 9.6	52.7 ± 9.4	54.0 ± 9.2	55.8 ± 9.3	50.2 ± 8.2	53.5 ± 9.8

- **Sex Dimorphism:** Male athletes generated significantly greater PP (≈ 32%), AP (≈ 28%), and MP (≈ 30%) than females ($p < 0.001$) across all sport groups.
- **Developmental Progression:** Significant increases in PP occurred between early and middle adolescence ($p = 0.009$), with power levels reaching a plateau between middle and late stages.
- **Sport-Specific Differences:** Power athletes recorded the highest PP and AP outputs, whereas endurance athletes preserved force output during terminal seconds, yielding the lowest fatigue rates ($p < 0.001$).

4. Discussion

The outcomes confirm marked divergence in anaerobic capacity governed primarily by biological sex, followed by discipline-specific conditioning adaptations and age-related development. The male advantage in relative mechanical power stems from larger cross-sectional muscle areas, higher proportions of fast-twitch Type IIx muscle fibers, and elevated enzymatic capacity in phosphofructokinase and lactate dehydrogenase pathways.

Across age categories, the progression from early to middle adolescence coincided with pronounced gains in peak wattage, aligning with peak height velocity and circulating androgen increases. The plateau observed in late adolescence highlights that neuromuscular recruitment stabilizes toward adult levels.

Furthermore, the elevated fatigue indices recorded among power-sport athletes demonstrate that higher peak outputs come at the cost of rapid metabolic depletion, emphasizing the necessity of incorporating tailored lactic tolerance conditioning into strength training blocks.

5. Conclusion

Lower-body anaerobic capacity in youth athletes is shaped by sex, developmental maturation, and competitive discipline. Male athletes consistently outperform females in peak and mean power variables, while power-sport specialists demonstrate superior maximal wattage paired with higher fatigue susceptibility. Strength and conditioning specialists should utilize these stratified reference values to optimize athletic talent development and balance anaerobic power with fatigue resistance.

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