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Evaluating the Efficacy of Sport-Specific Physical Adaptations in National Youth Track and Field Athletes in Ho Chi Minh City Across a Training Macrocycle

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Abstract:

Background: Monitoring physiological and physical adaptations throughout successive training cycles represents a fundamental component of the Long-Term Athlete Development (LTAD) framework, particularly during adolescence when biological maturation substantially influences athletic performance. This study investigated changes in physiological characteristics and sport-specific physical performance among elite youth track and field athletes training at the National Sports Training Center, Ho Chi Minh City, following a general preparatory training cycle.

Methods: A longitudinal observational study was conducted involving 15 elite youth track and field athletes (10 males and 5 females; aged 15–17 years). Participants completed a comprehensive battery of 19 validated field-based assessments before and after the training cycle. Measurements included anthropometric characteristics, maximal strength (one-repetition maximum [1RM]), explosive power (countermovement jump [CMJ] and standing long jump), and aerobic endurance estimated indirectly using the 20-m shuttle run (Beep Test) for predicted VO_2max. Within-group changes were analyzed using paired-samples *t*-tests, with statistical significance established at $p< 0.05$.

Results: Following the training intervention, both male and female athletes demonstrated statistically significant improvements in maximal and explosive strength variables, including squat, deadlift, snatch, and standing long jump performances ($p< 0.05$). Aerobic endurance, assessed by the Beep Test, also improved significantly in both sexes ($p< 0.05$). Conversely, no significant changes were observed in anthropometric variables (height and body mass) or short-sprint performance over 30 m and 60 m ($p> 0.05$). Female athletes exhibited a significant reduction in body fat percentage following the training cycle ($p< 0.05$).

Conclusion: The general preparatory training program effectively promoted neuromuscular and cardiovascular adaptations in elite youth track and field athletes. However, the absence of significant improvements in maximal sprint speed suggests that subsequent macrocycles should place greater emphasis on event-specific speed development and advanced sport-specific training to facilitate the transfer of strength gains into sprint performance.

Keywords: youth track and field; neuromuscular adaptation; training cycle; field-based assessment; Long-Term Athlete Development (LTAD).

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INTRODUCTION

The optimal development of talented youth track and field athletes requires a systematic training approach grounded in the principles of periodization and training load monitoring (Bompa & Buzzichelli, 2019). Within an annual training plan, the General Preparatory Phase (GPP) serves as the foundation-building stage, during which training primarily targets the enhancement of maximal strength, muscular power, and aerobic capacity to establish the physiological prerequisites for subsequent event-specific preparation and competitive performance (Suchomel et al., 2016).

Athletes between the ages of 15 and 17 undergo rapid biological maturation accompanied by substantial changes in body morphology, musculoskeletal structure, and endocrine function (Kraemer et al., 2005). Previous investigations (Cormie et al., 2011; Ford et al., 2011) have demonstrated that physiological adaptations to identical training loads during adolescence are highly individualized and frequently confounded by concurrent growth and maturation processes. Consequently, the routine implementation of validated field-based performance assessments has become an evidence-based strategy for monitoring training adaptations and optimizing individualized training prescription (Buchheit, 2014; McGuigan et al., 2012).

In Vietnam, track and field is recognized as one of the country's priority high-performance sports. Nevertheless, longitudinal evidence describing physiological and sport-specific physical adaptations among elite youth athletes remains limited. Most existing studies have employed cross-sectional designs or relied on performance assessments that lack biomechanical specificity for athletics. This gap in both the scientific literature and practical coaching applications highlights the need for longitudinal investigations capable of evaluating training-induced adaptations throughout a complete training cycle.

Therefore, the present study aimed to evaluate sport-specific physical adaptations in elite youth track and field athletes training at the National Sports Training Center in Ho Chi Minh City following a general preparatory macrocycle by quantifying changes in anthropometric characteristics, neuromuscular performance, and cardiovascular endurance. It was hypothesized that the preparatory training cycle would produce significant improvements in maximal strength and aerobic endurance while eliciting minimal changes in anthropometric characteristics, which are primarily influenced by natural biological maturation during adolescence.

METHODS

Participants

This study employed a longitudinal observational design to examine physiological and performance adaptations following a general preparatory training cycle. The study sample comprised 15 elite youth track and field athletes representing the Vietnamese national development program, including 10 males (age: 16.2 ± 0.8 years; height: 178.20 ± 3.88 cm; body mass: 66.00 ± 5.44 kg) and 5 females (age: 16.4 ± 0.7 years; height: 165.80 ± 5.25 cm; body mass: 52.22 ± 3.30 kg). All participants were enrolled in a centralized full-time training program at the National Sports Training Center, Ho Chi Minh City, Vietnam.

Prior to participation, athletes and their legal guardians provided written informed consent. All testing procedures conformed to the ethical principles outlined in the Declaration of Helsinki for research involving human participants.

Experimental Procedures

Athletes were evaluated at two standardized time points: immediately before (Pre-test) and immediately after (Post-test) completion of a general preparatory macrocycle.

A comprehensive battery of 19 field-based performance tests, previously validated through expert evaluation (n = 15), was employed to assess multidimensional physical performance. The testing battery consisted of the following domains:

Anthropometric assessment

Anthropometric measurements included standing height (cm), body mass (kg), and body fat percentage (%). Body composition was assessed using a standardized InBody bioelectrical impedance analyzer according to the manufacturer's recommended procedures.

Neuromuscular strength and power

Neuromuscular performance was evaluated using:

Standing long jump;

Three-step standing long jump;

Countermovement Jump (CMJ);

Maximal muscular strength (1RM) was assessed through the following resistance exercises:

Bench Press; Back Squat; Deadlift; Snatch

To facilitate comparisons across athletes, strength outcomes were normalized relative to body mass whenever appropriate.

Speed and anaerobic performance

Linear sprint ability and anaerobic capacity were assessed using:

30-m sprint (standing start)

60-m sprint (standing start)

274-m shuttle run

Aerobic endurance

Aerobic fitness was estimated indirectly using the 20-m Multistage Shuttle Run Test (Beep Test), from which predicted maximal oxygen uptake (VO_2max) was calculated using established prediction equations.

To minimize measurement error, all assessments were conducted under strictly standardized environmental conditions, at the same time of day, and following an identical dynamic warm-up protocol (Halson, 2014).

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics version 26.0 (IBM Corp., Armonk, NY, USA).

Continuous variables are presented as mean ± standard deviation (Mean ± SD). The coefficient of variation (CV%) was calculated to evaluate data dispersion.

Within-sex comparisons between Pre-test and Post-test measurements were analyzed using paired-samples t-tests. Statistical significance was established at $\alpha = 0.05$, with $p < 0.05$ considered statistically significant.

RESULTS

Data obtained from the 15 elite youth track and field athletes were statistically analyzed to examine changes in physiological characteristics and physical performance before (Pre-test) and after (Post-test) completion of the general preparatory training cycle. For clarity, the findings are organized into three principal domains of physiological adaptation: (1) anthropometric characteristics and body composition, (2) neuromuscular and sport-specific strength adaptations, and (3) sprint performance and aerobic capacity.

3.1. Anthropometric Characteristics and Body Composition

During adolescence (15–17 years), skeletal dimensions are generally expected to remain relatively stable over a short-term training macrocycle, whereas body composition is considerably more responsive to training-induced physiological adaptations. Statistical analyses demonstrated no significant changes in standing height or body mass in either female or male athletes following the intervention (all $p > 0.05$). However, female athletes exhibited a significant reduction in body fat percentage, decreasing from 18.24 ± 1.63% at baseline to 16.20 ± 1.02% following the training cycle ($t = 2.38$, $p < 0.05$). In contrast, although male athletes also demonstrated a reduction in body fat percentage (12.30 ± 0.91% vs. 11.88 ± 0.50%), this change represented only a favorable trend and did not reach statistical significance ($p > 0.05$).

These findings indicate that the general preparatory training program produced measurable improvements in body composition, particularly among female athletes, while exerting minimal influence on anthropometric variables largely determined by biological maturation.

Table 1. Changes in anthropometric characteristics and body composition following the general preparatory training cycle.

Group	Variable	Pre-test (Mean ± SD)	Post-test (Mean ± SD)	Δ (%)	*t*	*p*
Female (n = 5)	Height (cm)	165.80 ± 5.25	166.00 ± 5.28	0.03	0.06	>0.05
	Body mass (kg)	52.22 ± 3.30	52.20 ± 2.17	–0.01	0.01	>0.05
	Body fat (%)	18.24 ± 1.63	16.20 ± 1.02	–2.97	2.38	<0.05*
Male (n = 10)	Height (cm)	178.20 ± 3.88	178.56 ± 4.35	0.05	0.14	>0.05
	Body mass (kg)	66.00 ± 5.44	66.19 ± 4.24	0.07	0.06	>0.05
	Body fat (%)	12.30 ± 0.91	11.88 ± 0.50	–0.87	0.90	>0.05

Note. *Values are presented as Mean ± SD. Δ (%) represents the relative percentage change.* Significant difference between Pre-test and Post-test ($p < 0.05$; paired-samples t-test).

3.2. Neuromuscular and Sport-Specific Strength Adaptations

The general preparatory training program elicited substantial neuromuscular adaptations in both male and female athletes. Significant improvements were observed across nearly all maximal strength assessments, indicating enhanced neuromuscular function and force-generating capacity following the intervention.

For female athletes, one-repetition maximum (1RM) performance increased significantly in the bench press ($t = 3.52$), back squat ($t = 4.46$), deadlift ($t = 4.30$), and snatch ($t = 5.31$), with all comparisons reaching statistical significance ($p < 0.05$). Similarly, male athletes demonstrated significant gains in bench press ($t = 2.13$), back squat ($t = 2.04$), deadlift ($t = 4.62$), and snatch ($t = 3.03$) performances (all $p < 0.05$).

Notably, the greatest improvement was observed in the Olympic lifting exercise (snatch), suggesting enhanced intermuscular coordination, neuromuscular synchronization, and technical efficiency in force production. Conversely, although countermovement jump (CMJ) height increased slightly in both sexes, these improvements did not achieve statistical significance ($p > 0.05$), indicating that increases in maximal strength had not yet been fully translated into vertical explosive power.

Overall, these findings demonstrate that the general preparatory phase effectively enhanced maximal strength capacity and neuromuscular performance, whereas adaptations related to explosive vertical power remained comparatively limited.

Table 2. Changes in maximal strength and vertical power following the general preparatory training cycle.

Group	Test	Pre-test (Mean ± SD)	Post-test (Mean ± SD)	Δ (%)	*t*	*p*
Female (n = 5)	Bench Press 1RM	28.40 ± 2.19	33.40 ± 2.30	4.05	3.52	<0.05*
	Back Squat 1RM	74.00 ± 5.48	91.00 ± 6.52	5.15	4.46	<0.05*
	Deadlift 1RM	46.80 ± 1.64	50.40 ± 0.89	1.85	4.30	<0.05*
	Snatch 1RM	21.80 ± 2.05	29.00 ± 2.24	7.09	5.31	<0.05*
	CMJ (cm)	47.29 ± 4.60	47.92 ± 4.50	0.33	0.22	>0.05
Male (n = 10)	Bench Press 1RM	56.30 ± 5.10	63.70 ± 5.87	3.08	2.13	<0.05*
	Back Squat 1RM	98.00 ± 8.88	110.50 ± 10.39	3.00	2.04	<0.05*
	Deadlift 1RM	53.40 ± 3.86	63.00 ± 2.58	4.12	4.62	<0.05*
	Snatch 1RM	52.50 ± 4.95	61.60 ± 4.55	3.99	3.03	<0.05*
	CMJ (cm)	58.66 ± 5.53	63.80 ± 6.36	2.10	1.36	>0.05

Note.*Significant difference between Pre-test and Post-test (p < 0.05; paired-samples t-test).*

3.3. Sprint Performance and Aerobic Capacity

Despite the substantial improvements observed in maximal strength, these gains were not accompanied by statistically significant enhancements in linear sprint performance. Sprint times over both 30 m and 60 m improved modestly in male and female athletes; however, none of these changes reached statistical significance ($p > 0.05$). Likewise, performance in the 274-m shuttle run showed only small, non-significant improvements following the training cycle.

In contrast, the general preparatory phase produced marked improvements in aerobic endurance. Female athletes significantly increased their Beep Test distance from **1,408 ± 102.57 m**to **1,545± 46.10 m** ($t = 2.72$, $p < 0.05$), while male athletes improved from **1,744 ± 174.00 m**to**2,067 ± 173.51 m** ($t = 2.94$, $p < 0.05$). These improvements were accompanied by corresponding increases in estimated VO_2max in both sexes. Nevertheless, although estimated VO_2max values increased numerically, these changes did not reach statistical significance ($p > 0.05$).

Collectively, these findings suggest that the general preparatory training program effectively enhanced cardiovascular endurance while producing only limited improvements in speed-related performance during this stage of the annual training cycle.

Table 3. Changes in sprint performance and cardiovascular endurance following the general preparatory training cycle.

Group	Test	Pre-test (Mean ± SD)	Post-test (Mean ± SD)	Δ (%)	*t*	*p*
Female (n = 5)	30-m sprint (s)	4.40 ± 0.20	4.32 ± 0.16	0.47	0.72	>0.05
	60-m sprint (s)	8.09 ± 0.54	7.82 ± 0.31	0.87	1.00	>0.05
	274-m shuttle run (s)	65.01 ± 3.79	63.22 ± 3.06	0.70	0.82	>0.05
	Beep Test (m)	1,408 ± 102.57	1,545 ± 46.10	2.32	2.72	<0.05*
	Estimated VO_2max ($mL \cdot kg^{-1} \cdot min^{-1}$)	42.42 ± 2.21	44.66 ± 1.36	1.29	1.93	>0.05
Male (n = 10)	30-m sprint (s)	3.95 ± 0.19	3.74 ± 0.16	1.34	1.90	>0.05
	60-m sprint (s)	7.24 ± 0.27	6.91 ± 0.29	1.16	1.87	>0.05
	274-m shuttle run (s)	62.46 ± 2.16	61.44 ± 2.16	0.41	0.75	>0.05
	Beep Test (m)	1,744 ± 174.00	2,067 ± 173.51	4.24	2.94	<0.05*
	Estimated VO_2max ($mL \cdot kg^{-1} \cdot min^{-1}$)	48.97 ± 4.17	52.10 ± 5.09	1.55	1.06	>0.05

Note. Sprint performances are expressed in seconds; therefore, a positive Δ (%) reflects improved performance through reduced completion time. *Significant difference between Pre-test and Post-test ($p < 0.05$; paired-samples t-test).*

DISCUSSION

The present study provides a comprehensive evaluation of the physiological and neuromuscular adaptations induced by a general preparatory training cycle in elite youth track and field athletes. The principal finding was the divergence between substantial improvements in maximal strength and aerobic endurance and the absence of statistically significant changes in linear sprint performance and vertical explosive power. These findings highlight the highly specific nature of training adaptations during the early stages of an annual periodized training program.

Neuromuscular Adaptations and Maximal Strength Development

The significant improvements observed in one-repetition maximum (1RM) performance across the squat, deadlift, bench press, and snatch exercises in both male and female athletes are consistent with established theories of anatomical adaptation and neuromuscular development during adolescence (Lloyd et al., 2014; Suchomel et al., 2016). Early strength gains during the general preparatory phase are primarily attributed to enhanced neural adaptations rather than muscular hypertrophy, including improved motor unit recruitment, increased motor unit firing frequency, greater synchronization, and reduced antagonist muscle co-activation.

Among the assessed strength variables, the greatest improvement was observed in the snatch exercise. Because the snatch requires exceptional intermuscular coordination, rapid force production, and precise neuromuscular timing, the significant enhancement in performance ($p < 0.05$) indicates that the training program effectively optimized neural drive and movement coordination rather than merely increasing muscle mass (Cormie et al., 2011). These findings support the premise that early-stage strength development in adolescent athletes is predominantly mediated by neural mechanisms, providing an essential physiological foundation for subsequent sport-specific power development.

The Strength–Speed Paradox: Limited Improvements in Linear Sprint Performance and Vertical Power

Despite the substantial improvements in maximal strength, neither 30-m nor 60-m sprint performance nor countermovement jump (CMJ) height improved significantly following the training cycle. This apparent discrepancy between force-generating capacity and explosive athletic performance has been widely documented in the strength and conditioning literature.

One plausible explanation is provided by the Adaptation Window Theory, whereby the general preparatory phase is intentionally characterized by high training volume designed to maximize foundational physiological adaptations. Such training loads inevitably induce accumulated peripheral fatigue and residual neuromuscular fatigue, temporarily limiting the transfer of increased force production into high-velocity movements (Gabbett, 2016). Consequently, improvements in maximal strength may not immediately translate into enhanced sprint or jump performance until accumulated fatigue is dissipated during subsequent training phases.

Furthermore, sprint speed represents one of the most difficult physical qualities to improve because it depends not only on maximal force production but also on stride mechanics, rate of force development, neuromuscular efficiency, tendon stiffness, and the proportion of genetically determined Type IIx muscle fibers (Bissas et al., 2022). Therefore, the absence of statistically significant improvements in sprint performance at the conclusion of the general preparatory macrocycle should not be interpreted as a failure of the training program. Rather, it reflects the expected physiological sequence of periodized adaptation, in which maximal strength is developed before being converted into sport-specific speed and power during later phases of the annual training cycle.

Similarly, although CMJ performance increased numerically in both sexes, the magnitude of improvement was insufficient to reach statistical significance. This finding further suggests that enhanced maximal force production alone is inadequate to optimize explosive performance without subsequent training emphasizing rapid force development and stretch-shortening cycle efficiency.

Aerobic Adaptations and Improvements in Body Composition

The significant improvements observed in Beep Test performance in both male and female athletes demonstrate that the general preparatory program effectively enhanced aerobic capacity and cardiovascular function. Although the estimated VO_2max values did not reach statistical significance, the consistent increase in running distance achieved during the Beep Test indicates improved exercise tolerance and aerobic efficiency, both of which are essential for sustaining high training volumes and facilitating recovery during repeated high-intensity training sessions.

A particularly noteworthy finding was the significant reduction in body fat percentage among female athletes. Body fat decreased from 18.24% to 16.20% following the intervention, reflecting favorable alterations in body composition during the preparatory phase. From a biomechanical perspective, reducing non-functional body mass improves the power-to-weight ratio, a key determinant of performance in sprinting, jumping, and other locomotor-based athletic events (Impellizzeri et al., 2019). Consequently, these morphological adaptations may contribute indirectly to enhanced athletic performance during subsequent phases of specialized training, even though immediate improvements in sprint speed were not observed.

Limitations

Several methodological limitations should be acknowledged when interpreting the findings of this study. First, the relatively small sample size (N = 15) limited the statistical power of the analyses and increased the likelihood of Type II errors, particularly for variables exhibiting moderate effect sizes, such as countermovement jump performance. Future investigations involving larger cohorts would provide more robust estimates of training-induced adaptations and improve the generalizability of the findings.

Second, the absence of a non-training control group precludes complete differentiation between adaptations attributable to the structured training program and those resulting from normal biological maturation during adolescence. Because athletes aged 15–17 years undergo rapid developmental changes in musculoskeletal structure, endocrine function, and neuromuscular capacity, natural maturation may have contributed to some of the observed improvements (Ford et al., 2011). Future longitudinal studies incorporating maturity status assessment and appropriate control groups are therefore warranted to better isolate the independent effects of training interventions.

Finally, the present study evaluated only one general preparatory macrocycle. Longitudinal investigations spanning an entire competitive season would provide a more comprehensive understanding of how physiological adaptations evolve throughout successive phases of periodized training.

CONCLUSION AND PRACTICAL APPLICATIONS

The present findings demonstrate that the current training model implemented at the National Sports Training Center, Ho Chi Minh City, Vietnam is highly effective in establishing the fundamental physical capacities required for elite youth track and field athletes. Specifically, the general preparatory program produced significant improvements in maximal strength, neuromuscular function, and aerobic endurance, confirming its effectiveness in developing the physiological foundation necessary for subsequent stages of athletic preparation.

However, the absence of statistically significant improvements in sprint performance and vertical explosive power suggests that increases in maximal strength had not yet been effectively transferred into sport-specific performance. This observation reinforces the principle of phase potentiation within periodized training, whereby foundational physical capacities developed during the preparatory phase should subsequently be converted into event-specific performance through appropriately targeted training stimuli.

Practical Applications

Based on the present findings, several practical recommendations can be proposed for coaches working with elite youth track and field athletes.

First, the emphasis of the subsequent macrocycle should shift from the development of maximal strength toward the enhancement of speed-strength and explosive power. This transition can be achieved through the systematic integration of plyometric exercises, velocity-based training (VBT), ballistic resistance training, and exercises specifically targeting stretch-shortening cycle efficiency. Such training strategies are expected to facilitate the transfer of accumulated strength gains into improved sprinting and jumping performance.

Second, the athlete-specific reference values established in this study may serve as an internal performance monitoring framework for ongoing training evaluation. Regular assessment of these physiological and performance indicators would enable coaches to identify early signs of functional overreaching, optimize individualized training loads, and account for sex-specific differences in adaptation and recovery. Implementing individualized monitoring strategies may therefore enhance both athlete development and long-term performance progression within the LTAD framework.

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