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The Relationship Between Lower Extremity Post-Activation Performance Enhancement and Body Morphology, Physiological Development, and Kinetics in Adolescent Athletes: A Key Factor Analysis

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Abstract

Objectives

This study aimed to investigate the correlation between lower-limb post-activation performance enhancement (PAPE) and morphological, physiological, and kinetic variables in adolescent athletes, and to identify key determinants.

Methods

One hundred and fifteen adolescent athletes underwent assessments of body morphology, maturity offset (APHV), and lower-limb kinetics (1RM and rate of force development [RFD]). Following a conditioning activity (3×3 half-squats at 85% 1RM), PAPE was quantified via countermovement jump performance at seven time points up to 12 minutes. Stepwise multiple regression identified key predictors.

Results

The majority (58%) exhibited peak PAPE at 8–10 min post-activation. Significant between-group differences were observed in PAPE magnitude based on morphological and strength variables ($p < 0.05$). PAPE enhancement showed strong correlation with 1RM RFD ($r = 0.802$) and moderate correlations with age, height, weight, and APHV ($r = 0.301–0.367$). Regression analysis revealed that 1RM RFD ($\beta = 0.864$), APHV ($\beta = 0.188$), and 1RM ($\beta=-0.207$) were significant predictors (all $p < 0.001$).

Conclusions

PAPE is most prevalent 8–10 minutes post-activation in adolescents. Its magnitude is predominantly determined by the rate of force development and biological maturation, rather than training experience or body proportion indices.

1 Introduction

Post-activation potentiation (PAP) and post-activation performance enhancement (PAPE) are two pivotal concepts in exercise physiology, both describing the transient enhancement of muscle force or overall athletic performance induced by specific conditioning stimuli. In previous studies, these two concepts have frequently been conflated. Although they share core phenomenon of "activation-induced enhancement”, they are fundamentally distinct in their underlying physiological mechanisms (1). Specifically, PAP refers to the brief increase in muscle force following a high-intensity, electrically evoked (via action potential), involuntary contraction, which is primarily mediated by the phosphorylation of myosin regulatory light chains (2). In contrast, PAPE describes a temporary improvement in voluntary

muscular contractile function elicited by a high-load conditioning stimulus. Its potential mechanisms may include increased recruitment of high-order motor unit, elevated neural excitability, enhanced muscle tissue hydration, and improved metabolism efficiency and conduction velocity associated with increased muscle temperature (3). However, a comprehensive consensus on these mechanisms has not yet been established.

PAP and PAPE also differ in their assessment methods and temporal characteristics: PAP has a relatively short half-life of approximately 28 seconds (4), whereas the peak enhancement of PAPE typically occurs 6 to 10 minutes after activation and generally persists longer than that of PAP (1). Furthermore, in terms of assessment methodologies, research on PAP focuses on quantifying involuntary muscle contractile force, often employing techniques such as electromyography (2), while research on PAPE centers on evaluating overall athletic performance through metrics including jump height and sprint speed (1).

Over the past two decades, research has consistently demonstrated significant inter-individual variability in both PAP and PAPE effects, which is primarily attributed to the diversity of the activation protocols and their modulating factors. These modulators mainly include activation mode(5, 6), load intensity (7, 8), rest intervals (9, 10), muscle fiber type (11, 12), strength level (13, 14), resistance training experience (15), as well as gender and age (15, 16). However, conceptual confusion has led to methodological misapplications in some studies, such as using performance-based metrics designed for PAPE assessment (e.g., jump performance) to evaluate PAP effects, while failing to directly measure involuntary muscle contractile force. Recently, Blazevich and Babault (3) provided a theoretical clarification, emphasizing that PAP and PAPE are distinct physiological phenomena and highlighting that investigating the determinants of PAPE holds more direct practical value for enhancing athletic performance.

Human growth from birth to adulthood is a non-linear process; characterized by two distinct growth spurts: infancy (0–1 year) and adolescence. During these periods, the rate of morphological and functional development increases significantly, accompanied by rapid improvements in various physical fitness components. Peak height velocity (PHV) is defined as the period of maximum height growth rate during adolescence, and its onset typically coincides with the initiation of puberty (17). During the PHV period, a series of adaptive changes occur in the endocrine environment and the musculoskeletal system, which indirectly affect physical fitness. These changes are manifested as increased androgen secretion, differentiation of muscle fiber types, maturation of muscle-tendon units, and resting stores of adenosine triphosphate(ATP) and phosphocreatine(PCr). These physiological alterations are closely associated with the underlying mechanisms of both PAP and PAPE.

Furthermore, during adolescence, the timing of growth spurts differs between the trunk and lower limbs: the lower limbs reach their growth peak earlier than the trunk (18), leading to inter-individual variations in the leg-to-trunk length ratio. Notably, within a certain range, athletes with a lower leg-to-trunk ratio tend to exhibit superior explosive power, which is attributable to their biomechanical advantages. However,

direct evidence regarding the substantial influence of adolescent body morphology on lower-limb PAPE remains scarce.

The Long-Term Athlete Development (LTAD) model establishes a theoretical framework anchored to PHV, describing the heterochronic development rates of various physical fitness components in adolescents. This model aims to optimize the developmental potential of adolescent athletes' physical qualities and maximize training-induced adaptive effects (19). The LTAD model further indicates that the marked acceleration phase of strength development typically occurs 12 to 18 months after PHV, a phenomenon primarily driven by elevated circulating androgen levels, which in turn facilitates rapid gains in muscle mass. Additionally, previous research has demonstrated that resistance training induces adaptive changes in both the nervous system and muscle morphology (20). Given the high neural plasticity characteristic of the pre-pubertal period, the developmental rate of the neuromuscular system is correspondingly enhanced during adolescence (21).

In a systematic review, Blazevich and Babault (3) summarized various factors that may influence PAPE, including muscle temperature, pH, blood flow, and hydration status. As these factors tend to improve with increasing muscle mass, a plausible association between muscle mass and PAPE can be inferred. Moreover, studies have confirmed that adolescent physical fitness components exhibit heterochronic development relative to PHV: the sprint speed spurt occurs prior to PHV, whereas the strength and endurance spurts occur after PHV (22). According to the Youth Physical Development (YPD) model (18), adolescent males exhibit accelerated adaptive development in agility, speed, power, strength, and muscle hypertrophy. Improvements in these physical qualities contribute to enhanced lower-limb maximal strength and overall athletic performance.

In summary, adolescent athletes during puberty tend to exhibit positive developmental trends in body morphology, physiological maturity, and physical fitness. These dimensions show substantial overlap with the established modulators of lower-limb PAPE, suggesting a plausible correlation between them. A more comprehensive understanding of the correlates, key predictors, and population-specific characteristics of PAPE may assist coaches in better evaluating athletes' strength development potential, thereby providing a scientific basis and improving the practical effectiveness of strength training. However, research on the correlates and key determinants of lower-limb PAPE in adolescent populations remains limited, and no consensus has been reached regarding its common population characteristics. This research gap poses a practical barrier to both the optimization of training protocols and the advancement of theoretical frameworks. Accordingly, the present study aimed to explore the correlations between lower-limb PAPE and selected indicators of body morphology, physiological development, and lower-limb kinetics in adolescent athletes, with the goal of identifying potential key predictors of lower-limb PAPE.

2 Methods

2.1 Study design

This study adopted a prospective observational design with post-hoc grouping based on test results. All study procedures were approved by the Human Research Ethics Committee of Guangzhou Sport University (No. 2024LcLL-59) and registered in the Chinese Clinical Trial Registry (Number: ChiCTR2400086599; Registration date: July 8, 2024; http://www.chictr.org.cn/). The study was conducted in strict accordance with the principles of the Declaration of Helsinki. The experimental protocol comprised three phases: general warm-up, lower-limb PAPE activation, and performance testing. As illustrated in Fig. 1, participants first completed a standardized 25-minute warm-up, which included the following components: foam rolling (6 min), running (3 min), the World's Greatest Stretch (3 min), single-leg Romanian deadlifts (3 min), walking lunges (2 sets of 10 repetitions per leg), vertical jumps (2 sets of 8 repetitions), and 30-meter sprints (3 sets). Following a 3-minute rest period after the warm-up, participants performed two countermovement jump (CMJ) trials to establish baseline performance. After an additional 3-minute rest, the activation protocol was implemented, consisting of three sets of three repetitions of barbell half-squats at 85% of each participant's predetermined one-repetition maximum (1RM), with 2–3 minutes of passive rest between sets to induce PAP. Upon completion of the activation task, two CMJ trials were performed at each of the seven post-activation time points: 15 s, 2 min, 4 min, 6 min, 8 min, 10 min, and 12 min. Changes in jump height and relative power derived from these trials were used to quantify the fluctuation in lower-limb explosive performance, thereby reflecting the magnitude of lower-limb PAPE.

All participants completed a two-week familiarization period prior to the main experiment to minimize potential bias arising from unfamiliarity with exercises protocols or cognitive differences. One week before the experimental session, baseline characteristics—including age, height, leg length, sitting height, resistance training experience, and lower-limb maximal strength indices (1RM and 1RM RFD)—were collected from all eligible participants. Body mass was measured on the day of testing, prior to the warm-up. All testing sessions were conducted at the Strength and Conditioning Facility of Guangdong Provincial Youth Competitive Sports School, with consistent scheduling between 14:30 and 16:30 to control for diurnal variations in performance. Due to the large sample size, participants were tested in batches grouped by sport discipline.

The testing procedure was as follows: each batch completed a standardized group warm-up, after which they were subdivided into 3–4 small groups for baseline CMJ testing. Concurrently, 3–4 independent "activation zones" and "testing zones" were established, with each activation zone staffed by at least one researcher and each testing zone by at least two researchers. Each small group was sequentially numbered and proceeded through the activation protocol, with no more than four participants per group. Participants rotated between activation and testing zones in an alternating order. Immediately upon completing the activation protocol, participants reported to the testing zone and awaited instruction for CMJ testing. Researchers in the testing zone initiated timing from the moment each participant concluded the activation protocol and strictly to the predetermined post-activation time points to schedule testing, thereby minimizing the risk of timing errors. Throughout both the activation and testing phases, standardized verbal encouragement was consistently provided to ensure all participants exerted maximal effort during each trial.

2.2 Participants

A sample size calculation was performed using G*Power 3.1 software, with a correlation coefficient of 0.3, an alpha level of 0.05, and a statistical power of 0.8, indicating a minimum required sample size of 84 participants. Consequently, a total of 115 adolescent athletes (32 males, 83 females; age range: 11–16 years) from the Guangdong Provincial Youth Sports School to participate in this study. The baseline characteristics of the participants are presented in Table 1. Participants were drawn from seven sport disciplines: athletics, badminton, judo, weightlifting, taekwondo, wrestling, and boxing. Inclusion criteria specified that all participants had ≥ 1 year of structured resistance training experience and were free from any musculoskeletal, neurological, or cardiovascular conditions. Additionally, participants were required to refrain from vigorous exercise and abstain from caffeine, alcohol, nutritional supplements, or any medication within 24 hours prior to testing. No participant reported significant discomfort during the testing procedures. Prior to enrollment, participants were required to provide written informed consent from both themselves and their legal guardians.

Table 1
Descriptive statistics results of the participants' test indicators

Category	Outcome	M ± SD	95%CI	
			Lower limit	Upper limit
Body Morphology	Height (cm)	163.1 ± 7.81	161.7	164.5
	Weight (kg)	52.9 ± 12.23	50.6	55.1
	BMI (Kg/m²)	19.7 ± 3.41	19.1	20.4
	Leg Length (cm)	76.7 ± 4.50	75.9	77.5
	Sitting Height (cm)	86.4 ± 4.54	85.5	87.2
	Manouvrier's skelic index (Year)	88.9 ± 5.05	88.0	89.8
	lower-limb Muscle Mass (kg)	12.4 (7.82,24.2)		
Physiological Development	Age (Year)	13 (11, 16)		
	Resistance Training Experience (Year)	3 (10, 1)		
	APHV (Year)	0.13 ± 1.36	1.0	1.5
Lower limb Kinetics	1RM (kg)	82.8 ± 26.69	77.8	87.7
	1RM RFD (N/s)	2522 ± 1000.59	2337	2707
	CMJ-high Pre (cm)	29.3 ± 4.77	28.4	30.2
	CMJ-RP Pre (W/kg)	44.5 ± 6.83	43.2	45.8
	Magnitude of PAPE (cm)	3.53 ± 2.78	3.0	4.1

2.3 Testing Methods

Body Characteristics

Basic information, including sex, age, sport discipline, and resistance training experience, was collected using an interview checklist. Body mass and lower-limb muscle mass were measured via bioelectrical impedance analysis (InBody). Participants were required to fast for at least 4 hours and to avoid vigorous exercise for 24 hours prior to measurement to ensure data accuracy. Height was measured using a stadiometer (DHM-300), and body mass index (BMI) was calculated as body mass divided by height squared (kg/m²). The Manouvrier's skelic index was calculated using the formula [(height - sitting height) / sitting height] × 100 to quantify the leg-to-trunk ratio. For sitting height measurement, participants sat on a 60cm high plyometric box with their back against the wall and feet suspended

above the ground. The vertical distance from the top of the head to the ground was measured, and sitting height was obtained by subtracting the box height from this value. Leg length was derived indirectly by subtracting sitting height from standing height.

To assess participants' growth and development status, age at peak height velocity (APHV) was used as a maturity offset indicator. A negative APHV value indicates that the participant had not yet entered the period of peak height growth, whereas a positive value indicates that this period had already commenced (17). The calculation formulas are as follows (unit: cm):

$$APHV_{male} = -9.236 + (0.0002708 \times leglength \times sittingheight) + (-0.001663 \times age \times leglength) + (0.007216 \times age \times sittingheight) + (0.02292 \times bodymass/height \times 100)$$

$$APHV_{female} = -9.376 + (0.0001882 \times leglength \times sittingheight) + (0.0022 \times age \times leglength) + (0.005841 \times age \times sittingheight) + (-0.002658 \times age \times bodymass) + (0.07693 \times bodymass/height \times 100) \quad (23)$$

CMJ Test

The CMJ test is a widely used method for assessing instantaneous lower-limb explosive performance (24). During testing, participants stood on a SmartJump mat with hands placed on their hips, descended to a self-selected depth at a comfortable eccentric velocity, and immediately jumped upward with maximal effort. Jump height (CMJ height) and relative power (CMJ relative power, CMJ-RP) were recorded for each trial. The highest CMJ height observed across the seven post-activation time points was defined as the peak lower-limb PAPE value. If the pre-activation baseline value was the highest recorded, the participant was considered to have not exhibited a PAPE effect. The magnitude of lower-limb PAPE was quantified by calculating the difference between CMJ height at each post-activation time point and the baseline value. The time point at which the peak value occurred was defined as the peak PAPE timing (25).

Maximal Strength Testing

A linear position transducer (Gymaware Power Tool; Kinetic Performance Technologies, Canberra, Australia) was attached to a standard 20 kg barbell to collect kinematic and kinetic data during each back squat trial. Prior to testing, all participants completed a standardized general warm-up consistent with the protocol used in the main experiment. After a 3-minute rest, participants were tested in groups

of four for back squat 1RM. An incremental loading protocol was employed: participants first completed a preparatory phase consisting of 50% 1RM (5 repetitions), 70% 1RM (3 repetitions), 80% 1RM (2 repetitions), and 90% 1RM (1 repetition). Thereafter, the load was progressively increased based on each participant's subjective readiness and capability until they failed to complete a standard repetition. For each attempt, participants were required to descend to a depth where the superior aspect of the thigh was at or slightly below parallel to the ground. The load successfully lifted on the final successful attempt was recorded as the 1RM value, and the rate of force development (RFD) during that specific trial was simultaneously captured. A 2–3 minute rest interval was provided between the 90% 1RM preparatory attempt and the subsequent 1RM attempts. If a 1RM attempt was unsuccessful, participants were permitted to make additional attempts after a 3-minute rest, with a maximum of three 1RM attempts allowed per participant. Throughout the testing procedure, standardized verbal encouragement was provided by the researchers to elicit maximal effort.

2.5 Statistical analysis

Experimental data were collected in batches grouped by sport discipline. All statistical analyses were performed using SPSS version 26.0. Results are presented as mean ± standard deviation (M ± SD), along with 95% confidence intervals (95% CI). The threshold for statistical significance was set at $p < 0.05$ (significant) and $p < 0.001$ (highly significant). Normality of data distribution was assessed using the Shapiro-Wilk test. Participants were divided into high-value and low-value groups based on the median of each variable, and independent samples t-tests were used to compare the magnitude of lower-limb PAPE enhancement between the two groups. For normally distributed data, effect sizes were calculated using Cohen's d and interprettations as follows: 0.20–0.49 = small, 0.50–0.79 = moderate, and ≥ 0.80 = large. For non-normally distributed data, effect sizes were evaluated using the rank-biserial correlation coefficient, with values < 0.3 considered small, 0.3–0.5 moderate, and > 0.5 large (26). Simple linear regression analyses were conducted to examine the relationships between each variable and the magnitude of PAPE enhancement, with the correlation coefficient (r) used to quantify the strength of association. Correlation strength was interpreted as follows: 0.10–0.29 = weak, 0.30–0.49 = moderate, 0.50–0.69 = strong, 0.70–0.89 = very strong, and 0.90–0.99 = nearly perfect (27). Multiple linear stepwise regression analysis was performed to identify the key predictors of lower-limb PAPE enhancement. Effect sizes for the regression model were expressed as the coefficient of determination (R^2) and interpreted as follows: 1%–8% = weak, 9%–24% = moderate, and ≥ 25% = strong (27). Additionally, a pie chart was used to illustrate the distribution of time points at which participants achieved their peak lower-limb PAPE. Prior to multiple regression analysis, multicollinearity among predictors was assessed using variance inflation factor (VIF) and tolerance values. A VIF value greater than 5 was considered indicative of potential multicollinearity, while VIF > 10 indicated severe multicollinearity requiring cautious interpretation (28, 29).

3 Results

The present study aimed to investigate the correlations between the magnitude of lower-limb PAPE enhancement and indicators of body morphology, physiological development, and lower-limb kinetics in

adolescent athletes, as well as to identify key predictors of PAPE enhancement. A total of 115 valid data samples were collected. Among these samples, nine participants showed no improvement in CMJ height from pre- to post-activation, indicating the absence of a PAPE effect. To ensure the comprehensiveness of the investigation and the integrity of the dataset, these nine samples were retained in the final statistical analysis.

3.1 Temporal Distribution of Peak PAPE

Analysis of the time points at which participants achieved peak lower-limb PAPE revealed that, among the 115 participants, 35 (30.4%) reached their peak PAPE at 480 s (8 min) post-activation, and 32 (27.8%) peaked at 600 s (10 min). Collectively, 67 participants (58.3%) exhibited their peak PAPE within the 480 s to 600 s (8–10 min) time window. Additionally, 17 participants (14.8%) achieved their peak PAPE at 120 s (2 min) post-activation (Fig. 2).

3.2 Effects of Various Body Morphology, Physiological Development, and Lower-Limb Kinetics Indicators on the Magnitude of Lower-Limb PAPE Enhancement

As shown in Table 2, regarding body morphology indicators, among athletes aged 11–16 years, individuals with greater height, body mass, and BMI exhibited significantly larger lower-limb PAPE enhancements compared to those with lower values, with mean differences of 1.27 cm ($p < 0.01$, Cohen's $d = 0.46$), 1.98 cm ($p < 0.01$, $d = 1.01$), and 1.53 cm ($p < 0.01$, $d = 0.38$), respectively. Participants with greater sitting height and longer leg length also demonstrated significantly greater PAPE enhancements, with mean differences of 0.96 cm ($p = 0.04$, $d = 0.22$) and 1.34 cm ($p < 0.01$, $d = 0.61$), corresponding to small and a moderate effect size, respectively. Participants with greater lower-limb muscle mass exhibited a significantly larger PAPE enhancement (1.78 cm, $p < 0.01$, $d = 0.84$) compared to those with less lower-limb muscle mass. However, no significant difference in PAPE enhancement was observed between the high and low Manouvrier's skelic index groups ($p = 0.55$, rank-biserial correlation = 0.07).

Regarding physiological development indicators, older participants exhibited a significantly greater PAPE enhancement(1.76 cm, $p < 0.01$, $d = 0.83$) compared to younger participants. Individuals with higher APHV also showed a significantly larger PAPE enhancement (1.46 cm, $p < 0.01$, $d = 0.67$) relative to those with lower APHV. However, no significant difference in PAPE enhancement was found between groups with high versus low resistance training experience ($p = 0.75$, rank-biserial correlation = 0.04).

Regarding lower-limb kinetics indicators, participants with higher 1RM values demonstrated a significantly greater PAPE enhancement (1.82 cm, $p < 0.01$, $d = 0.86$) compared to those with lower 1RM values. Furthermore, individuals with higher 1RM rate of force development (RFD) exhibited a markedly larger PAPE enhancement (3.40 cm, $p < 0.01$, $d = 0.83$) relative to those with lower RFD.

Table 2
Between-Group Comparisons of Test Indicators Between High-Value and Low-Value Groups

Category	Outcome	M ± SD		Normality test	p	ES
		HV	LV			
Body Morphology	Height (cm)	3.89 ± 2.36	2.87 ± 2.12	0.05	0.02	0.46
	Weight (kg)	4.42 ± 2.17	2.35 ± 1.92	0.35	< 0.01	1.01
	BMI (Kg/m²)	4.13(8.20,0.00)	2.65(7.91,0.00)	0.03	< 0.01	0.38
	Leg Length (cm)	4.01 ± 2.27	2.67 ± 2.13	1.00	< 0.01	0.61
	Sitting Height (cm)	4.02(8.20,0.00)	2.50(8.10,0.00)	0.02	0.04	0.22
	Manouvrier's skelic index (Year)	3.58(8.10,0.00)	2.80(8.20,0.00)	0.01	0.55	0.07
	lower-limb Muscle Mass (kg)	4.27 ± 2.10	2.50 ± 2.15	0.05	< 0.01	0.84
Physiological Development	Age (Year)	4.37 ± 1.93	2.61 ± 2.27	0.05	< 0.01	0.83
	APHV (Year)	4.12 ± 2.27	2.66 ± 2.09	0.09	< 0.01	0.67
	Resistance Training Experience (Year)	3.50 (8.10,10.00)	3.24 (8.20,0.00)	< 0.01	0.75	0.04
Lower limb Kinetics	1RM (kg)	4.30 ± 2.14	2.48 ± 2.08	0.13	< 0.01	0.86
	1RM RFD (N/s)	5.07(8.20,1.02)	1.45(6.41,0.00)	0.02	< 0.01	0.83

*Note: *p < 0.05; *p < 0.01.

3.3 Correlations Between Body Morphology, Physiological Development, and Lower-Limb Kinetics Indicators and the Magnitude of Lower-Limb PAPE

Among the body morphology indicators (Table 3), lower-limb muscle mass exhibited the strongest correlation with the magnitude of lower-limb PAPE enhancement, showing a moderate positive correlation ($r = 0.347$, $p < 0.01$) and accounting for 12.1% of the variance in PAPE enhancement. The magnitude of lower-limb PAPE enhancement also demonstrated moderate positive correlations with

height ($r = 0.320$, $p < 0.001$), weight ($r = 0.343$, $p < 0.001$), and BMI ($r = 0.301$, $p = 0.001$), explaining 10.2%, 11.8%, and 9.1% of the variance, respectively. Weak positive correlations were observed between PAPE enhancement and leg length ($r = 0.286$, $p = 0.002$) and sitting height ($r = 0.267$, $p = 0.004$), accounting for 8.2% and 7.1% of the variance, respectively. Furthermore, no significant correlation was found between PAPE enhancement and the Manouvrier's skelic index ($r = 0.040$, $p = 0.675$).

Among the physiological development indicators (Table 2), age showed the strongest correlation with PAPE enhancement, presenting a moderate positive correlation ($r = 0.367$, $p < 0.001$) and explaining 13.4% of the variance. A moderate positive correlation was also observed between PAPE enhancement and APHV ($r = 0.313$, $p = 0.001$), accounting for 9.8% of the variance. However, no significant correlation was detected between PAPE enhancement and resistance training experience ($r = 0.046$, $p = 0.624$).

Regarding lower-limb kinetics indicators (Table 2), the strongest correlation with PAPE enhancement was observed for 1RM RFD, demonstrating a very strong positive correlation ($r = 0.802$, $p < 0.001$) and explaining 64.3% of the variance. A moderate positive correlation was found between PAPE enhancement and 1RM ($r = 0.311$, $p = 0.001$), accounting for 9.6% of the variance. Additionally, PAPE enhancement showed a moderate positive correlation with the time to peak PAPE ($r = 0.428$, $p < 0.001$), explaining 18.4% of the variance.

Table 3
Correlation between test indicators and the increase in lower limb PAPE

Predictor	The Magnitude of Lower-Limb PAPE (CMJ-height)						
	r	R^2	Adjusted R^2	Durbin-Watson	F	t	P
Height (cm)	0.320	0.102	0.094	1.355	12.893	3.591	<0.001
Weight (kg)	0.343	0.118	0.110	1.467	15.073	3.882	<0.001
BMI (Kg/m²)	0.301	0.091	0.083	1.325	11.291	3.360	0.001
Leg Length (cm)	0.286	0.082	0.074	1.238	10.065	3.172	0.002
Sitting Height (cm)	0.267	0.071	0.063	1.369	8.684	2.947	0.004
lower-limb Muscle Mass (kg)	0.347	0.121	0.113	1.440	15.484	3.935	<0.001
Manouvrier's skelic index	0.040	0.002	-0.007	1.129	0.177	0.421	0.675
Age (Year)	0.367	0.134	0.127	1.314	17.549	4.189	<0.001
APHV (Year)	0.313	0.098	0.090	1.292	12.279	3.504	0.001
Resistance Training Experience (Year)	0.046	0.002	-0.007	1.150	0.242	0.492	0.624
1RM (kg)	0.311	0.096	0.088	1.298	12.065	3.473	0.001
1RM RFD (N/s)	0.802	0.643	0.640	1.967	203.420	14.263	<0.001
PAPE peak time (s)	0.428	0.184	0.176	1.291	25.407	5.041	<0.001

3.4 Key Predictors of Lower-Limb PAPE Enhancement

A multiple linear stepwise regression analysis was conducted with the magnitude of lower-limb PAPE enhancement as the dependent variable. Ten indicators that demonstrated significant between-group differences in the independent samples t-tests were entered into the model as independent variables to identify the key predictors of PAPE enhancement. The regression analysis results (Table 4) revealed that three indicators significantly predicted the magnitude of PAPE enhancement: 1RM RFD (B = 0.002, t = 13.933, p < 0.001), APHV (B = 0.317, t = 3.275, p < 0.001), and 1RM (B = -0.018, t = -3.167, p < 0.001). Based on these findings, the following multiple regression equation was derived:

$$\mathrm{Y} = -0.511 + 0.002 * (1\mathrm{RM\ RFD}) + 0.317 * (\mathrm{APHV}) - 0.018 * (1\mathrm{RM})$$

Collinearity diagnostics revealed that the key predictors identified in the stepwise regression—namely 1RM RFD (VIF = 1.57), APHV (VIF = 1.57), and 1RM (VIF = 3.15)—all exhibited VIF values below 5, indicating no substantial multicollinearity among these core variables. However, among the anthropometric variables that were not retained in the final model (e.g., height, weight, and BMI), VIF

values exceeded 10, ranging from 24.47 to 75.36. These high values reflect the expected physiological correlations between body size indicators. Although this multicollinearity precludes reliable interpretation of their individual regression coefficients, it does not affect the validity of the final parsimonious model, which focuses on the key predictors of PAPE enhancement.

Table 4
Multiple linear stepwise regression analysis for predictors of lower-limb PAPE enhancement

Predictor	R^2	Adjusted R^2	F	B	β	t
Constant	0.687	0.679	10.032	-0.511		-1.215
1RM RFD				0.002	0.864	13.933**
APHV				0.317	0.188	3.275**
1RM				-0.018	-0.207	-3.167**

*Note: *p < 0.05; *p < 0.01.

4 Discussion

The present study focused on adolescent athletes aged 11–16 years. Previous research has clearly established that PAPE exhibits substantial inter-individual variability, which arises from the interplay of multiple physiological mechanisms. Drawing upon fundamental theories of adolescent growth and development, and integrating data from the current experiment, this study aimed to investigate the correlations between PAPE and indicators of body morphology, physiological development, and lower-limb kinetics in adolescent athletes, identify key predictors of the magnitude of PAPE enhancement, and systematically discuss the underlying mechanisms.

The experimental results indicated that, with the exception of the leg-to-trunk ratio (quantified by the Manouvrier's skelic index), all body morphology indicators exhibited varying degrees of positive correlation with the magnitude of lower-limb PAPE enhancement—consistent with the correlation analysis results showing moderate positive correlations between PAPE enhancement and height (r = 0.320), body mass (r = 0.343), BMI (r = 0.301), and lower-limb muscle mass (r = 0.347), as well as weak positive correlations with sitting height (r = 0.267) and leg length (r = 0.286). It is worth noting that these morphological changes are fundamentally manifestations of adolescent growth and development. Contrary to the findings of the present study, Pääsuke et al. observed no significant association between age-related increases in lower-limb PAPE enhancement and body mass. According to the Long-Term Athlete Development (LTAD) model, maturity in adolescent individuals can be assessed using PHV or peak weight velocity (PWV) (30). The PWV phase is characterized by rapid increases in body mass, primarily driven by elevated sex hormone levels that lead to accelerated muscle accretion (31). Because determining PWV requires longitudinal tracking of body mass changes, and the present study employed a cross-sectional, acute experimental design, PWV was not included as a measurement variable.

Nevertheless, inferences based on PHV suggest that height and body mass in adolescents increase progressively throughout pubertal development. Furthermore, research has demonstrated that both lean mass and muscle cross-sectional area increase with age during adolescence (32), and that increases in lean mass, together with neuromuscular system maturation, contribute to enhanced muscle strength (33, 34). The current results revealed that, among all body morphology indicators, lower-limb muscle mass exhibited the strongest correlation with PAPE enhancement (r = 0.347)—accounting for 12.1% of the variance in PAPE enhancement. Collectively, these findings suggest a potential positive association between body mass and lower-limb PAPE enhancement in adolescents. A plausible explanation is that pubertal gains in body mass reflect, to some extent, the concurrent development of muscle quantity and quality—, process that may enhance an individual's responsiveness to the activation protocol, thereby manifesting as greater PAPE enhancement.

Additionally, weak correlations were observed between PAPE enhancement and both leg length and sitting height, a trend that may be attributable to the optimizing effect of pubertal development on lower-limb athletic performance. From a biomechanical perspective, during squatting or jumping movements, individuals with longer legs can generate greater joint torque compared to those with shorter legs, thereby achieving a higher RFD at movement onset. Given that 1RM RFD was identified as the strongest predictor of PAPE enhancement in the present study, adolescent athletes with longer legs may derive greater PAPE benefits from this biomechanical advantage.

Blazevich and Babault, in a systematic review, synthesized the physiological mechanisms underlying lower-limb PAPE, noting that this effect is influenced by multiple factors, thereby exhibiting substantial inter-individual variability. These factors include post-activation changes in muscle temperature, the types of muscle fibers recruited, muscle blood flow, and myocellular hydration status (3). The present study observed positive effects of both chronological age and physiological maturity (assessed by APHV) on the magnitude of lower-limb PAPE enhancement within the 11–16 year age range—consistent with the correlation results showing moderate positive correlations between PAPE enhancement and age (r = 0.367, accounting for 13.4% of variance) and APHV (r = 0.313, accounting for 9.8% of variance). This finding contrasts with that of Arabatzi et al. (2014), who, using an isometric barbell squat protocol (3 sets × 3 s) in adolescents aged 10–12 and 14–15 years, failed to observe performance enhancement at 20 s and 4 min post-activation (16). Comparative analysis suggests that Arabatzi et al.'s exclusive reliance on chronological age (10–12 vs. 14–15 years) to delineate pubertal stages may have overlooked the phenomena of early and late maturation, which are common among adolescent populations. Consequently, employing APHV as a marker of physiological maturity may offer a more objective approach. Furthermore, due to the presence of fatigue, the ergogenic effects of PAPE may require a longer time window (e.g., 8–10 min) to manifest (1). The current study observed a positive correlation between the magnitude of PAPE enhancement and the time to peak PAPE(r = 0.428, accounting for 18.4% of variance), with the majority of participants(58.3%) achieving their peak values 8–10 min post-activation (35 participants at 8 min, 32 participants at 10 min). This finding further supports the necessity of extending the post-activation testing period, which is consistent with the view of Balyi et al.. The present study further revealed that participants with higher physiological maturity

(higherAPHV) exhibited greater PAPE enhancement (mean difference = 1.46 cm, $p < 0.01$, Cohen's d = 0.67), and APHV was identified as a key predictor of PAPE magnitude in adolescent athletes (35). Consistent with these findings, Pääsuke et al. reported that post-pubertal males (aged 16 years) demonstrated significantly greater maximal voluntary contraction force post-activation compared to pre-pubertal males (aged 11 years) (36). Synthesizing previous research with the current findings, it appears that the magnitude of lower-limb PAPE enhancement progressively increases throughout adolescent development.

Previous studies have consistently demonstrated a positive effect of resistance training experience on PAP (11, 37–39). However, these findings cannot be directly extrapolated to the present study, as PAP and PAPE represent distinct physiological phenomena characterized by different modulating factors and temporal profiles. Furthermore, research specifically examining the influence of training experience on PAPE remains scarce. The results of the present study revealed no correlation between resistance training experience and the magnitude of lower-limb PAPE enhancement ($r = 0.046$, $p = 0.624$), nor was any significant difference observed between groups with high versus low training experience ($p = 0.75$, rank-biserial correlation = 0.04). Accordingly, the level of resistance training experience may not influence the magnitude of lower-limb PAPE. Several potential explanations may account for this finding. First, conventional long-term resistance training modalities (e.g., barbell back squats, deadlifts) may be insufficient to induce adaptive increases in PAPE magnitude. Second, differences in PAPE enhancement may only manifest between individuals with versus without resistance training experience, rather than increasing linearly with accumulated training experience.

Previous research has not yet reached a definitive consensus regarding the relationship between lower-limb strength levels and the magnitude of PAPE enhancement. In the present study, lower-limb strength was assessed by measuring 1RM and 1RM rate of force development (RFD). The results revealed that both 1RM and 1RM RFD were positively correlated with the magnitude of lower-limb PAPE enhancement —1RM showed a moderate positive correlation ($r = 0.311$, accounting for 9.6% of variance) and 1RM RFD exhibited a very strong positive correlation ($r = 0.802$, accounting for 64.3% of variance)—and both were identified as key predictors of PAPE. These two factors accounted for 8.8%–64% of the variance in PAPE enhancement, respectively, indicating that adolescent athletes with higher lower-limb strength levels tend to exhibit greater PAPE responses. Specifically, participants with higher 1RM values demonstrated a significantly greater PAPE enhancement (1.82 cm, $p < 0.01$, Cohen's d = 0.86) compared to those with lower 1RM, and individuals with higher 1RM RFD showed a markedly larger enhancement (3.40 cm, $p < 0.01$, Cohen's d = 0.83). This finding is consistent with the results reported by Suchomel et al. (40) and Kilduff et al. (13). Suchomel et al. divided participants into high- and low-strength groups and employed 90% 1RM barbell half-squats as the conditioning activity, assessing jump squat performance every minute from immediately post-activation to 10 minutes. Kilduff et al. had 20 professional rugby players perform 3 sets of 3 repetitions of 87% 1RM back squats and measured CMJ performance at 15 s, 5, 8, 12, and 16 min post-activation. Apart from the age of the participants (all adult males), the experimental protocols of these two studies were comparable to that of the present investigation, and their findings support the notion that greater maximal lower-limb strength is associated with larger PAPE

enhancement. However, the results of the present study diverged from those reported by Batista et al. (41), Mangus et al. (42), and Till et al. (43). A comparison of the experimental protocols suggests that these three studies may not have adequately accounted for the influence of fatigue on PAPE. Batista et al. and Mangus et al. assessed performance within a 3–4 min post-activation window, whereas the peak PAPE response typically occurs later (8–10 min post-activation). This discrepancy in testing windows may partly explain the inconsistent findings. Furthermore, Till et al. incorporated three 20-meter sprint tests prior to CMJ assessments; the higher intensity of the sprint protocol may have exacerbated fatigue and subsequently interfered with the subsequent PAPE response.

The results of the present study revealed a very strong positive correlation between 1RM rate of force development (RFD) and the magnitude of lower-limb PAPE enhancement ($r = 0.802$, $p < 0.001$), establishing 1RM RFD as the strongest predictor among all measured variables—accounting for 64.3% of the variance in PAPE enhancement, which is far higher than the variance explained by APHV (9.8%) and 1RM (9.6%). Currently, research examining the relationship between RFD at maximal or near-maximal loads and PAPE enhancement remains limited. 1RM RFD is a key indicator of explosive strength, reflecting the rate of force and torque development during muscle contraction (44), i.e., the ability to achieve maximal muscle force within a very short time frame. PAPE is typically characterized by a transient enhancement of voluntary muscle contractile performance, with potential underlying mechanisms including increased muscle temperature, improved muscular and myocellular hydration status, and elevated autonomic neural drive (3). Stein et al. proposed that the reaction rate of myosin ATPase is modulated by muscle temperature, thereby influencing cross-bridge cycling kinetics, which underpins RFD (45). Nuzzo et al. suggested that changes in voluntary muscle contractile force (i.e., the magnitude of PAPE enhancement) may be associated with increased spinal excitability (i.e., enhanced net motor neuron output)(46). Furthermore, research indicates that autonomic neural drive (implicated in PAPE) is significantly elevated following high-intensity exercise, leading to an increased RFD during maximal voluntary contractions (i.e., RFD at 1RM) (47). This notion aligns with the findings of the present study. Collectively, the evidence supports that individuals with higher 1RM RFD tend to exhibit greater lower-limb PAPE enhancement—consistent with the between-group comparison showing that individuals with higher 1RM RFD had a 3.40 cm greater PAPE enhancement ($p < 0.01$, Cohen's $d = 0.83$).

As illustrated in Fig. 3, although lower-limb PAPE enhancement demonstrated substantial correlations with the three key predictors, namely APHV, 1RM, and 1RM RFD ($r = 0.802$)—the scatter plots revealed considerable inter-individual variability. Specifically, some participants with relatively low values on a given predictor still exhibited high PAPE enhancement. This finding suggests that while APHV, 1RM, and 1RM RFD have been identified as critical predictors of PAPE magnitude, the inherent complexity of the underlying physiological mechanisms governing PAPE contributes to non-negligible variability among individuals. Comparison of the trend lines for the three predictors indicated that the linear fit between 1RM RFD and PAPE enhancement ($R^2 = 0.6654$) was substantially stronger than those for APHV and 1RM —consistent with the correlation analysis showing that 1RM RFD explained the largest proportion of variance (64.3%) in PAPE enhancement. Further examination of the data revealed that individuals with relatively low APHV and 1RM values but high PAPE enhancement were consistently characterized by

high 1RM RFD. Consequently, the rate of force development under maximal load may represent the most influential factor affecting the magnitude of lower-limb PAPE enhancement.

Several limitations of this study should be acknowledged. First, due to the large sample size, participants were tested in batches grouped by sport discipline, precluding complete control over environmental variables such as temperature and humidity within the training facility. Second, the present study employed a cross-sectional, exploratory design. Given that adolescence represents a critical period of growth and development characterized by substantial inter-individual variability, cross-sectional data are inherently limited in their ability to infer causal relationships. Third, regarding the regression analysis, substantial multicollinearity was observed among anthropometric variables (e.g., height, weight, and BMI), with VIF values exceeding 10 (ranging from 24.47 to 75.36). This precludes meaningful interpretation of their individual contributions in a multiple regression framework. However, this multicollinearity does not compromise the primary finding of this study, as the key predictors retained in the final model, namely 1RM RFD (VIF = 1.57), APHV(VIF = 1.57), and 1RM (VIF = 3.15)—all demonstrated acceptable VIF values (< 5), indicating stable and reliable coefficient estimates. Future research with larger sample sizes or alternative analytical approaches (e.g., principal component analysis) is warranted to further disentangle the independent effects of closely related morphological characteristics and to corroborate the current findings. In both research and practical applications involving PAPE, careful consideration should be given to individual differences among athletes, with particular emphasis on their physiological maturity(APHV)—one of the key predictors of PAPE enhancement identified in this study. Training programs should be individualized in accordance with the principles of growth and development. Furthermore, coaches may optimize training protocols based on PAPE principles by incorporating high-intensity conditioning stimuli to enhance subsequent strength and power performance—particularly given that 1RM RFD (the strongest PAPE predictor) reflects explosive strength, which is closely linked to PAPE responsiveness. For instance, performing submaximal load squats prior to jumping or sprinting exercises can influence subsequent performance through the level of PAPE activation. Individuals exhibiting a greater PAPE response are likely to achieve more pronounced adaptations in explosive power, thereby maximizing the effectiveness of the training stimulus.

5 Conclusion

Synthesizing the findings of the present study, which explored the correlates and key predictors of lower-limb PAPE enhancement in adolescent athletes aged 11–16 years, the main conclusions are as follows: (1) the vast majority of individuals were capable of inducing a lower-limb PAPE response; (2) the peak PAPE response predominantly occurred within an 8–10 minute post-activation window; (3) the magnitude of lower-limb PAPE enhancement was correlated to varying degrees with body morphology indicators (height, body mass, BMI, sitting height, leg length, lower-limb muscle mass), physiological development indicators (age, maturity status), and lower-limb kinetic indicators (1RM, 1RM RFD), but showed no association with resistance training experience or leg-to-trunk ratio; and (4) physiological maturity (APHV), 1RM, and 1RM rate of force development (RFD) were identified as key predictors of lower-limb PAPE enhancement, with 1RM RFD making the largest predictive contribution.

Declarations

Ethics Approval and consent to participate

This study was approved by the Ethics Committee of Guangzhou Sport University (No. 2024LcLL-59), registered in the Chinese Clinical Trial Registry (Number: ChiCTR2400086599; Registration date: July 8, 2024; http://www.chictr.org.cn/), and conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants and their legal guardians, and participants were fully informed of the study aims, procedures, and their right to voluntary participation.

Consent for publication

Written informed consent for the publication of personal and clinical details, including any potentially identifiable images, was obtained from the parents or legal guardians of all participants, as they were under 18 years of age, in accordance with ethical standards.

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Author Contribution

YG contributed to research concept and study design, reviewing, and submission correspondence; RH contributed to research concept and study design, statistical analyses, and writing of the manuscript; WL contributed to research concept and study design and editing a draft of the manuscript; YM contributed to data collection, statistical analyses, and data analysis and interpretation; KY contributed to data collection and literature review; XB contributed to reviewing and submission correspondence.

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Data Availability

The datasets generated and analysed during the current study are not publicly available due to ethical and privacy restrictions associated with research involving minors, but are available from the

corresponding author on reasonable request.

References

1. Wilson JM, Duncan NM, Marin PJ, Brown LE, Loenneke JP, Wilson SM et al. Meta-analysis of postactivation potentiation and power: effects of conditioning activity, volume, gender, rest periods, and training status. 2013;27(3):854–9.
2. Sale DGJE. reviews ss. Postactivation potentiation: role in human performance. 2002;30(3):138 – 43.
3. Blazevich AJ, Babault NJF. Post-activation potentiation versus post-activation performance enhancement in humans: historical perspective, underlying mechanisms, and current issues. 2019;10:479198.
4. Vandervoort A, Quinlan J, McComas AJE. Twitch potentiation after voluntary contraction. 1983;81(1):141–52.
5. Tillin NA, Bishop DJS. Factors modulating post-activation potentiation and its effect on performance of subsequent explosive activities. 2009;39:147–66.
6. Bogdanis GC, Tsoukos A, Veligekas P, Tsolakis C, Terzis GJTJS, Research C. Effects of muscle action type with equal impulse of conditioning activity on postactivation potentiation. 2014;28(9):2521–8.
7. Fukutani A, Takei S, Hirata K, Miyamoto N, Kanehisa H, Kawakami YJTJS, et al. Influence intensity squat exercises subsequent jump Perform. 2014;28(8):2236–43.
8. Bauer P, Sansone P, Mitter B, Makivic B, Seitz LB, Tschan HJTJS et al. Acute effects of back squats on countermovement jump performance across multiple sets of a contrast training protocol in resistance-trained men. 2019;33(4):995–1000.
9. Gouvea AL, Fernandes IA, Cesar EP, Silva WAB, Gomes, PSCJJoss. The effects of rest intervals on jumping performance: A meta-analysis on post-activation potentiation studies. 2013;31(5):459–67.
10. Liang M, Guo W, Kong Z, Education SQJJoWIoP. Effects of Rest Interval on Countermovement Jump Height Following Post-Activation Potentiation: A Meta-Analysis. 2018;52(2):49–56.
11. Hamada T, Sale DG, MacDougall JD. Tarnopolsky MAJJoap. Postactivation potentiation, fiber type, and twitch contraction time in human knee extensor muscles. 2000.
12. Sweeney H, Bowman BF. Stull JTJAJoP-CP. Myosin light chain phosphorylation in vertebrate striated muscle: regulation and function. 1993;264(5):C1085–95.
13. Kilduff LP, Owen N, Bevan H, Bennett M, Kingsley MI, Cunningham DJJ. Influence of recovery time on post-activation potentiation in professional rugby players. 2008;26(8):795–802.
14. Tsoukos A, Bogdanis GC, Terzis G, Veligekas PJTJS, Research C. Acute improvement of vertical jump performance after isometric squats depends on knee angle and vertical jumping ability. 2016;30(8):2250–7.
15. Rixon KP, Lamont HS, Bemben MGJTJS, Research C. Influence of type of muscle contraction, gender, and lifting experience on postactivation potentiation performance. 2007;21(2):500–5.

16. Arabatzi F, Patikas D, Zafeiridis A, Giavroudis K, Kannas T, Gourgoulis V, et al. The post-activation potentiation effect on squat jump performance. Age sex effect. 2014;26(2):187–94.
17. Rogol AD, Clark PA, Roemmich JNJTA. Growth and pubertal development in children and adolescents: effects of diet and physical activity. 2000;72(2):S521–8.
18. Lloyd RS, Oliver JLJS, Journal C. The youth physical development model: A new approach to long-term athletic development. 2012;34(3):61–72.
19. Balyi I, Hamilton AJO. Long-term athlete development. Trainability Child adolescence. 2004;16(1):4–9.
20. Aagaard PJE. reviews ss. Training-induced changes in neural function. 2003;31(2):61 – 7.
21. Borms JJJoss. The child and exercise: An overview. 1986;4(1):3–20.
22. Viru A, Loko J, Harro M, Volver A, Laaneots L, Viru MJEJPE. Crit periods Dev Perform capacity Dur Child adolescence. 1999;4(1):75–119.
23. Mirwald RL, Baxter-Jones AD, Bailey DA, Beunen GPJM, editors. sports si, exercise. An assessment of maturity from anthropometric measurements. 2002;34(4):689 – 94.
24. Markovic G, Dizdar D, Jukic I, Cardinale MJTJS, Research C. Reliability and factorial validity of squat and countermovement jump tests. 2004;18(3):551–5.
25. Chen C-F, Chuang C-Y, Wang C-C, Liu S-A, Chang H-W, Chan K-HJTJS et al. Lower Repetition Induces Similar Postactivation Performance Enhancement to Repetition Maximum After a Single Set of Heavy-Resistance Exercise. 2024;38(5):848–55.
26. Cureton EE. Rank-biserial correlation. 1956;21(3):287–90.
27. Cohen J. Statistical power analysis for the behavioral sciences. routledge; 2013.
28. Senter HF. Applied linear statistical models. Taylor & Francis; 2008.
29. James G, Witten D, Hastie T, Tibshirani R. An introduction to statistical learning: with applications in R. Springer; 2013.
30. Malina RM, Bouchard C, Bar-Or O. Growth, maturation, and physical activity. Human kinetics; 2004.
31. Ford P, De Ste Croix M, Lloyd R, Meyers R, Moosavi M, Oliver J, et al. The long-term athlete development model. Physiological Evid application. 2011;29(4):389–402.
32. Kanehisa H, Ikegawa S, Tsunoda N, Fukunaga TJI. Strength and cross-sectional areas of reciprocal muscle groups in the upper arm and thigh during adolescence. 1995;16(01):54–60.
33. Housh TJ, Johnson GO, Housh DJ, Stout JR, Weir JP, Weir LL, et al. Isokinetic peak torque young wrestlers. 1996;8(2):143–55.
34. Weir JP, Wagner LL, Housh TJ, Johnson GOJJO, Therapy SP. Horizontal abduction and adduction strength at the shoulder of high school wrestlers across age. 1992;15(4):183–6.
35. Bayli I, Hamilton AJV, British Colombia. National Coaching Institute, Training A, Performance. Long-term athlete development: trainability in childhood and adolescence: windows of opportunity. optional trainability. 2004;8.

36. Pääsuke M, Ereline J, Gapeyeva HJE. Twitch contraction properties of plantar flexor muscles in pre- and post-pubertal boys and men. 2000;82:459–64.
37. Paasuke M, Ereline J, Gapeyeva H, Torop TJMS. Twitch contractile properties of plantarflexor muscles in female power-trained athletes. 2002;55(4):279–86.
38. Pääsuke M, Saapar L, Ereline J, Gapeyeva H, Requena B, Ööpik VJE. Postactivation potentiation of knee extensor muscles in power-and endurance-trained, and untrained women. 2007;101:577–85.
39. Smith JC, Fry ACJTJS, Research C. Effects of a ten-second maximum voluntary contraction on regulatory myosin light-chain phosphorylation and dynamic performance measures. 2007;21(1):73–6.
40. Suchomel TJ, Sato K, DeWeese BH, Ebben WP, Stone MHJTJS, Research C. Potentiation following ballistic and nonballistic complexes: The effect of strength level. 2016;30(7):1825–33.
41. Batista MA, Roschel H, Barroso R, Ugrinowitsch C, Tricoli VJTJS, Research C. Influence of strength training background on postactivation potentiation response. 2011;25(9):2496–502.
42. Mangus BC, Takahashi M, Mercer JA, Holcomb WR, McWhorter JW, Sanchez RJTJS et al. Investigation of vertical jump performance after completing heavy squat exercises. 2006;20(3):597–600.
43. Till KA, Cooke CJTJS, Research C. The effects of postactivation potentiation on sprint and jump performance of male academy soccer players. 2009;23(7):1960–7.
44. Aagaard P, Simonsen EB, Andersen JL, Magnusson P, Dyhre-Poulsen, PJJoap. Increased rate of force development and neural drive of human skeletal muscle following resistance training. 2002;93(4):1318–26.
45. Stein R, Gordon T, Shriver JJB. Temperature dependence of mammalian muscle contractions and ATPase activities. 1982;40(2):97–107.
46. Nuzzo JL, Barry BK, Gandevia SC, Taylor JLJM. sports si, exercise. Acute Strength Train Increases Responses Stimulation Corticospinal Axons. 2016;48(1):139–50.
47. Heckman C, Enoka RMJC. Motor unit. 2012(4):2629–82.

Figures

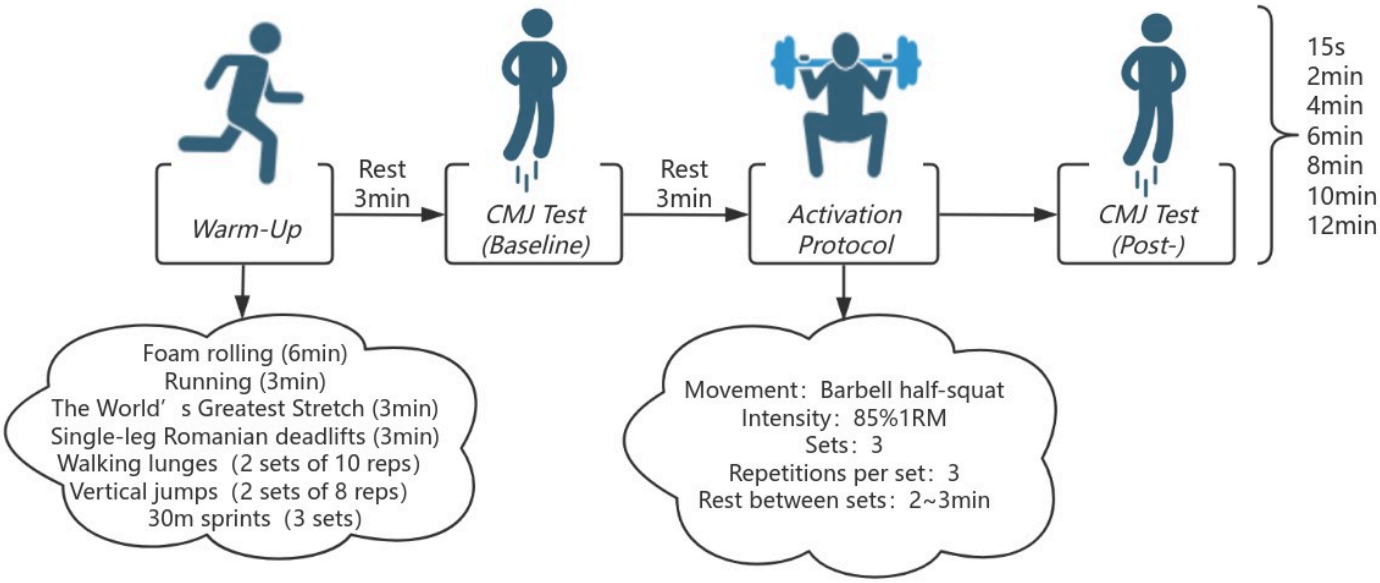


Figure 1

Experimental flow chart

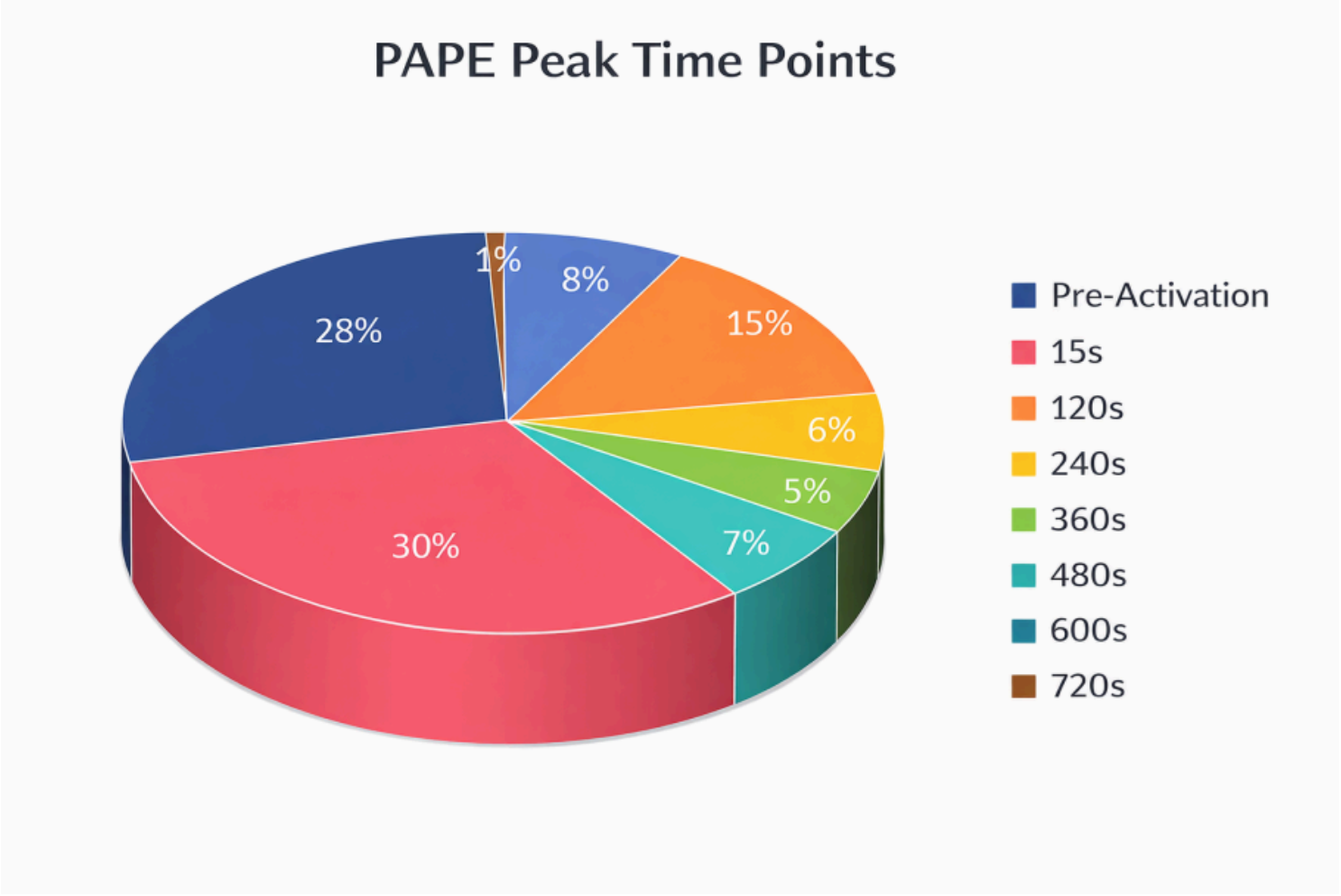


Figure 2

Pie chart showing the percentage distribution of PAPE peak time points

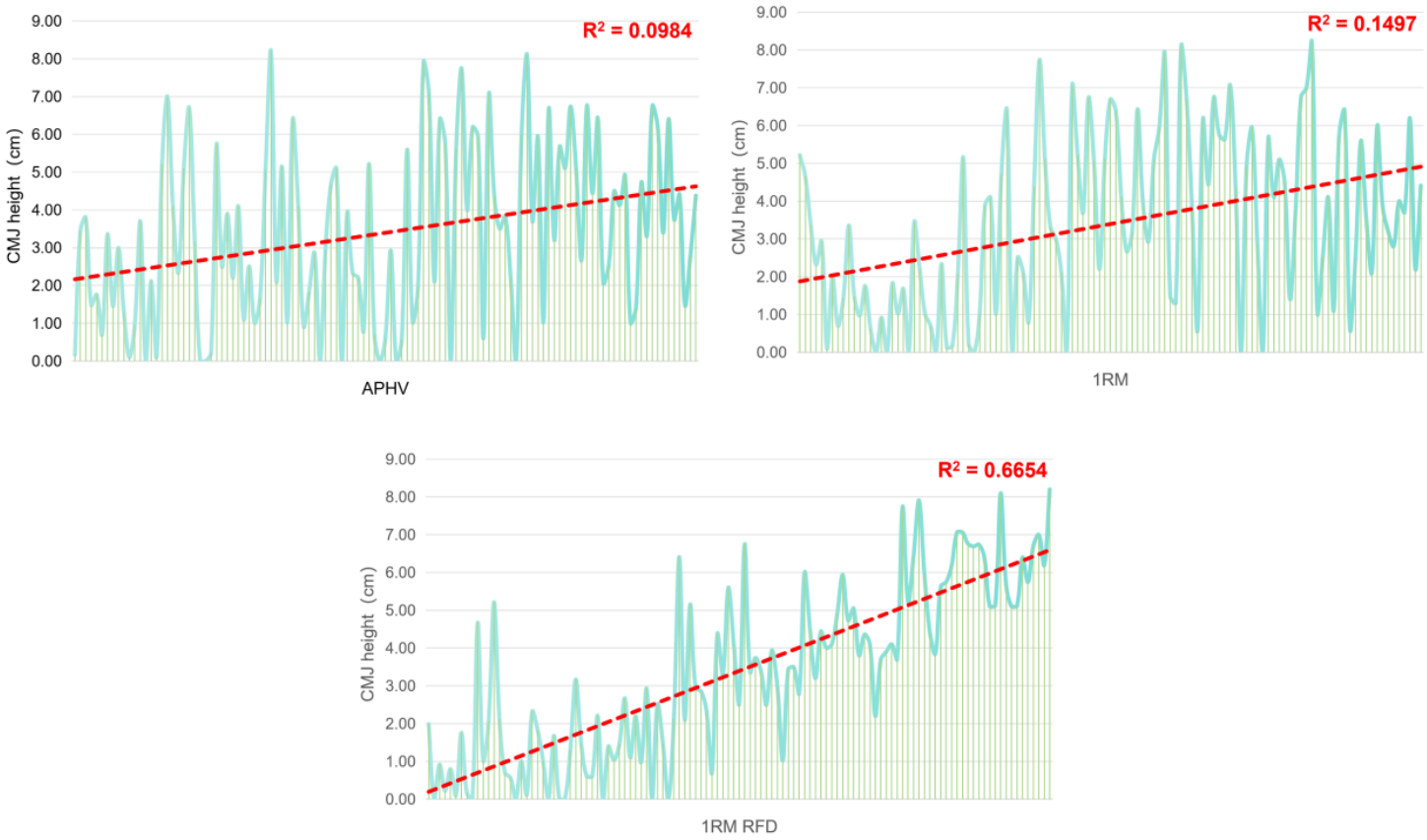


Figure 3

Trend of Key Predictors Influencing Lower-Limb PAPE