

RESEARCH ARTICLE

Effects of combined resistance-plyometric training on explosive power, lactic acid tolerance and race performance in competitive male 110-meter hurdlers

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The 110-meter hurdles require rapid force production, reactive lower limb strength, high anaerobic power, and technically efficient hurdle clearance. Although resistance and plyometric training are widely used to develop these qualities, evidence regarding an integrated program in competitive hurdlers remains limited. This study examined whether an 8-week combined resistance-plyometric program would improve explosive power, anaerobic performance, blood lactate response, hurdle clearance kinematics, and race performance more than routine training. Thirty (30) competitive male 110-meter hurdlers with mean age of 22.3 ± 1.8 years were randomly allocated to an experimental group (EG) ($n = 15$) or a control group (CG) ($n = 15$). The EG completed two resistance and two plyometric sessions each week, whereas the CG continued its established strength and conditioning program. Countermovement jump (CMJ), depth-jump reactive strength index (DJ-RSI), 30-second Wingate performance, blood lactate concentration, 110-meter hurdles race time, and hurdle clearance kinematics were assessed before and after the intervention. Compared with CG, EG showed greater improvements in CMJ height (9.7% vs. 2.1%), DJ-RSI (14.3% vs. 3.2%), Wingate peak power (7.8% vs. 1.9%), mean power (6.3% vs. 1.7%), fatigue index (-8.0% vs. -2.1%), and peak blood lactate (10.6% vs. 2.8%) ($P < 0.05$). Race time improved from 15.44 ± 0.48 to 15.07 ± 0.45 seconds in EG and from 15.47 ± 0.47 to 15.39 ± 0.46 seconds in CG. EG demonstrated a $2.40 \pm 1.42\%$ improvement, corresponding to an absolute reduction of 0.37 seconds, whereas CG improved by $0.52 \pm 1.23\%$, corresponding to an absolute reduction of 0.08 seconds. EG also displayed more favorable take-off distance, landing distance, clearance height, and pre-hurdle contact time. An 8-week combined resistance-plyometric program produced greater improvements in explosive power, anaerobic performance, blood lactate response, hurdle clearance technique, and race performance than routine training. The findings supported the use of integrated strength-power programming during the preparatory period for competitive male hurdlers.

Keywords: resistance training; plyometric training; reactive strength; anaerobic power; blood lactate; hurdle performance.

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Introduction

The 110-meter hurdles is a technically demanding sprint event that requires athletes to

accelerate rapidly, preserve horizontal velocity between barriers, and execute repeated hurdle clearances with minimal loss of momentum. Performance depends on the interaction of lower

limb force production, reactive strength, sprint mechanics, and precise take-off and landing positions [1, 2]. Because the event is completed at near-maximal intensity, even small changes in contact time, clearance trajectory, or power maintenance can materially influence race outcome.

Resistance training is a central component of preparation for sprint and power athletes because maximal strength provides a mechanical foundation for acceleration and rapid force development [3]. Conventional loading strategies can improve muscular strength and power [4]. However, hurdle performance also requires the athlete to express force within very short ground-contact periods and under event-specific technical constraints [5]. Consequently, strength gains are most useful when they are transferred to rapid and coordinated movement. Plyometric training targets the stretch-shortening cycle and is commonly used to improve reactive strength, rate of force development, and sprint-jump performance [6, 7]. Evidence syntheses indicate that plyometric jump training can enhance lower limb power when training dose, progression, and athlete level are appropriately considered [8]. Combining resistance and plyometric methods may therefore provide complementary adaptations as that resistance exercise develops force capacity, whereas plyometric exercise improves the speed and efficiency with which the force is expressed. Despite this rationale, controlled evidence in competitive 110-meter hurdlers remains limited. Much of the available literatures have examined general sprint or jump outcomes, while fewer studies have simultaneously evaluated explosive power, anaerobic power maintenance, post-exercise blood lactate response, hurdle clearance kinematics, and actual race performance. This gap is important because improvements in general physical capacity do not necessarily transfer to the technical demands of hurdling.

The purpose of this randomized controlled study was to determine the effects of an 8-week combined resistance-plyometric program on

lower limb explosive power, Wingate anaerobic performance, blood lactate response, 110-meter hurdles race time, and hurdle clearance kinematics in competitive male hurdlers. Pre- and post-intervention testing was used to compare the integrated program with the athletes' established training routine. By linking laboratory, biomechanical, and competition-specific outcomes, the study provided practically relevant evidence for strength and conditioning programs in competitive hurdling.

Materials and methods

Participant selection and characteristics

Thirty (30) competitive male athletes specializing in the 110-meter hurdles were recruited from Lincoln University College, Petaling Jaya, Selangor Darul Ehsan, Malaysia. Their personal best performance times ranged from 14.20 to 16.24 seconds. The inclusion eligibility required at least 5 years of competitive hurdling experience, no lower extremity injury during the previous 6 months, and prior experience with resistance and plyometric training. Athletes were excluded if they were unable to complete the full testing battery or if an injury prevented participation in the intervention. Participants were randomly allocated by a computer-generated random number sequence to the experimental group (EG) and control group (CG) with 15 athletes in each group. Allocation was performed by a researcher who was not involved in training supervision or outcome assessment. Baseline characteristics were comparable between EG and CG for age of 22.5 ± 1.7 vs. 22.1 ± 1.9 years old, height of 185.3 ± 4.2 vs. 184.8 ± 4.5 cm, body mass of 77.8 ± 3.6 vs. 78.2 ± 3.8 kg, body fat of $8.7 \pm 1.2\%$ vs. $8.9 \pm 1.3\%$, and 110-meter hurdles personal best of 15.31 ± 0.46 vs. 15.35 ± 0.44 seconds. All participants provided written informed consent before enrollment. The protocol of this study was approved by the Institutional Review Board of Lincoln University College (Petaling Jaya, Selangor Darul Ehsan, Malaysia) with the approval number of LUC/DVCECA/26022026/023.

Experimental design

The study used a randomized, parallel-group, pre- and post-test design and lasted 10 weeks including one (1) week pre-intervention assessment, eight (8) weeks training intervention, and one (1) week post-intervention assessment. The assessment battery was distributed across three testing days with at least 48 hours between sessions. Pre- and post-intervention tests were conducted under the same procedures and environmental conditions at the same time of day for each athlete with ± 1 hour and by the same experienced assessors to reduce circadian and measurement variation. The study was conducted during the preparatory period rather than the main competition season. The participants in both groups maintained their usual 110-meter hurdles technical sessions. Training volume and frequency were matched as closely as practical, whereas the principal between-group difference was the organization and content of the strength-power program. All sessions were supervised by qualified strength and conditioning specialists. Participants were instructed to maintain their habitual diet, avoid new nutritional supplements, and refrain from additional strength or plyometric training throughout the study period.

Training interventions

(1) Experimental group (EG) protocol

EG completed a periodized program comprising four sessions each week, which included two resistance training sessions and two plyometric training sessions with a minimum of 48 hours between sessions that emphasized the same muscle groups. Each session began with a standardized 15 minute warmup consisting of light jogging, dynamic mobility, and movement preparation exercises specific to the planned training content. Resistance training included back squats, Romanian deadlifts, bench presses, weighted lunges, pull-ups, and trunk-strengthening exercises. Training intensity ranged from 70% to 85% of one-repetition maximum (1RM) defined as the greatest load that could be lifted once with correct technique. Primary exercises were performed for 3 - 5 sets

of 4 - 6 repetitions, and supplementary exercises were performed for 2 - 3 sets of 8 - 12 repetitions. Loads increased progressively while prescribed repetition ranges and technical quality were maintained. Bilateral and unilateral lower limb exercises were included to address the force demands of sprinting and hurdling. Plyometric sessions included depth jumps, hurdle hops, bounding, and hurdle specific reactive drills. Depth-jump heights progressed from 30 to 75 cm across the intervention, and exercises were completed for 4 - 6 sets of 6 - 10 repetitions. Rest intervals were 2 - 3 minutes between sets with approximately 5 - 7 seconds between individual plyometric repetitions to preserve movement quality and maximal intent. Exercise complexity and intensity increased gradually followed by a reduction in volume during the final week to limit residual fatigue before post-intervention testing. Each session ended with light aerobic activity and static stretching.

(2) Control group (CG) protocol

CG continued its established strength and conditioning program, which consisted of 2 - 3 resistance training sessions and 1 - 2 conventional plyometric sessions each week in addition to regular hurdle specific technical training. Resistance exercises were similar to those used by EG, but the loading scheme emphasized 3 - 4 sets of 8 - 10 repetitions at 65 - 80% 1RM. Conventional jump exercises were completed for 3 - 4 sets of 10 - 12 repetitions. Session frequency, supervision, and overall workload were managed to approximate those of EG, while the integrated sequencing, higher load resistance work, progressive depth jumps, and hurdle specific plyometric content were not applied.

Assessment procedures

(1) Anthropometric and body-composition assessment

Stature was measured to the nearest 0.1 cm with a calibrated stadiometer, and body mass was measured to the nearest 0.1 kg with a precision electronic scale. Participants wore minimal clothing and no footwear. Lean mass and bodyfat

percentage were assessed by using Discovery Wi system dual-energy X-ray absorptiometry (Hologic, Inc., Marlborough, MA, USA). The same certified technician performed all scans according to the manufacturer's positioning and analysis procedures. Participants maintained normal hydration and avoided strenuous exercise for 24 hours before scanning.

(2) Lower-limb power assessment

Lower-limb explosive power was assessed by the countermovement jump (CMJ) and depth-jump reactive strength index (DJ-RSI) tests. For CMJ, participants performed three maximal vertical jumps with their hands on their hips to eliminate arm swing. From an upright position, each athlete used a self-selected countermovement depth and immediately extended the hips, knees, and ankles to jump vertically. Jump height was measured using an AMTI OR6-7 force platform (Advanced Mechanical Technology, Inc., Watertown, MA, USA). The best of three valid attempts was used with 2 minutes of recovery between attempts. The system estimated jump height measurement error was ± 0.5 cm. For DJ-RSI, athletes performed depth jumps from 30, 45, and 60 cm boxes onto the same AMTI force platform. They stepped from the box, landed bilaterally, and immediately executed a maximal vertical jump while minimizing ground contact time. DJ-RSI was calculated as jump height divided by ground contact time. Three trials were performed at each height, and the best valid value was retained. Trials with a visible technical error were repeated after 2 minutes of recovery. Temporal resolution was approximately ± 4 ms.

(3) Anaerobic capacity and blood lactate assessment

Anaerobic power and capacity were assessed using a 30 second Wingate test on a Monark 894E cycle ergometer (Monark Exercise AB, Vansbro, Sweden). After a 5 minute warmup at 50 watts (W) of external mechanical power that included two 5 second accelerations, participants completed a maximal 30 second sprint against a resistance equal to 7.5% of body mass. Standardized verbal encouragement was

provided. Peak power, mean power, and fatigue index were calculated from power values sampled at 50 hertz (Hz), meaning that the system recorded 50 data points per second. Power was expressed in watts per kilogram (W/kg), where W was watts and division by body mass permitted comparison among athletes of different sizes. Fatigue index represented the percentage decline from peak to minimum power during the test. Blood lactate concentration was measured using a Lactate Pro 2 LT-1730 analyzer (ARKRAY, Inc., Kyoto, Japan) following manufacturer's instructions. Capillary blood was obtained from the fingertip at rest immediately after the Wingate test and at 3, 5, and 7 minutes of recovery. The highest post-exercise concentration was defined as peak blood lactate. The same trained technician collected all samples using standardized procedures.

(4) Event-specific performance assessment

Participants completed a full 110-meter hurdles race under simulated competition conditions after a standardized competition warmup. Hurdles were positioned in accordance with International Association of Athletics Federations (IAAF) (now World Athletics) regulations. Athletes wore sprint spikes and ran on a standard synthetic track. Race time was recorded to 0.01 seconds with a TCI dual-beam photoelectric timing system (Brower Timing Systems, Draper, UT, USA) synchronized with the starting signal. Environmental conditions were standardized as closely as possible with 20 - 24°C and wind speed < 2 m/s, and repeated timing checks yielded a measurement standard deviation within ± 0.03 seconds.

(5) Kinematic analysis of hurdle clearance technique

Two HERO9 Black high-speed cameras (GoPro, Inc., San Mateo, CA, USA) recorded the third and seventh hurdle clearances at 240 frames per second. Cameras were placed perpendicular to the running direction at 10 m distance from the lane to minimize parallax. A 1 m calibration scale was positioned within the capture volume. The

Table 1. Lower limb explosive power alterations (mean $\pm$ SD).

Measure	Group	Pre-intervention	Post-intervention	Percent change
CMJ height (cm)	EG	58.3 $\pm$ 3.7	63.9 $\pm$ 3.9***	9.7 $\pm$ 1.8
	CG	57.9 $\pm$ 3.8	59.1 $\pm$ 3.7	2.1 $\pm$ 1.2
DJ-RSI (60 cm)	EG	2.45 $\pm$ 0.22	2.80 $\pm$ 0.24***	14.3 $\pm$ 2.5
	CG	2.43 $\pm$ 0.23	2.51 $\pm$ 0.22	3.2 $\pm$ 1.4

Note: *** $P < 0.001$ compared to pre-intervention values.

resulting temporal resolution was 4.17 ms per frame, and the minimum measurable spatial resolution was approximately 1 cm. Video analysis was performed with Kinovea version 0.9.5 (<https://www.kinovea.org>). Before the primary analysis, intra-rater and inter-rater reliability were evaluated. Intraclass correlation coefficient (ICC) values exceeded 0.90 for all variables. The same experienced biomechanist then measured take-off distance, landing distance, clearance height, lead and trail leg angles, and ground contact time immediately before and after clearance. Take-off and landing distances were defined as the horizontal distance between the relevant foot contact and the hurdle, clearance height as the vertical distance between the estimated center of mass and hurdle bar, and contact time as the interval from initial foot contact to toe-off.

Statistical analysis

Statistical analyses were conducted using SPSS version 26.0 (IBM, Armonk, NY, USA). Data were reported as mean $\pm$ standard deviation (SD). Normality was assessed with the Shapiro-Wilk test, and homogeneity of variance was examined with Levene's test. A 2×2 repeated measures analysis of variance (group $\times$ time) was used for each outcome. Significant interaction or main effects were followed by Bonferroni-adjusted comparisons. Partial eta squared (η^2p) was interpreted as small (0.01 - 0.05), medium (0.06 - 0.13), or large (≥ 0.14) [9]. Percentage change from pre- to post-intervention was calculated for each participant, and independent samples *t*-tests compared percentage changes between groups. Statistical significance was set at $P < 0.05$.

Results

Protocol adherence and injury incidence

All 30 athletes completed the study, producing a 100% retention rate. Mean attendance across prescribed sessions was $96.5 \pm 2.3\%$ and was comparable between groups. No injury requiring missed training or withdrawal occurred. Mild transient muscle soreness was reported most often during the initial weeks but did not prevent participation.

Baseline and anthropometric outcomes

EG and CG were comparable at baseline for age, stature, body mass, body-fat percentage, and 110-meter hurdles personal best time of 15.31 ± 0.46 vs. 15.35 ± 0.44 seconds, respectively ($P > 0.05$). Body mass and body composition remained stable during the intervention. EG showed a small, non-significant reduction in body fat as $-0.3 \pm 0.2\%$ and increase in lean mass as 0.4 ± 0.3 kg, whereas CG showed similarly small changes in body fat of $-0.2 \pm 0.2\%$ and lean mass of 0.3 ± 0.2 kg ($P > 0.05$).

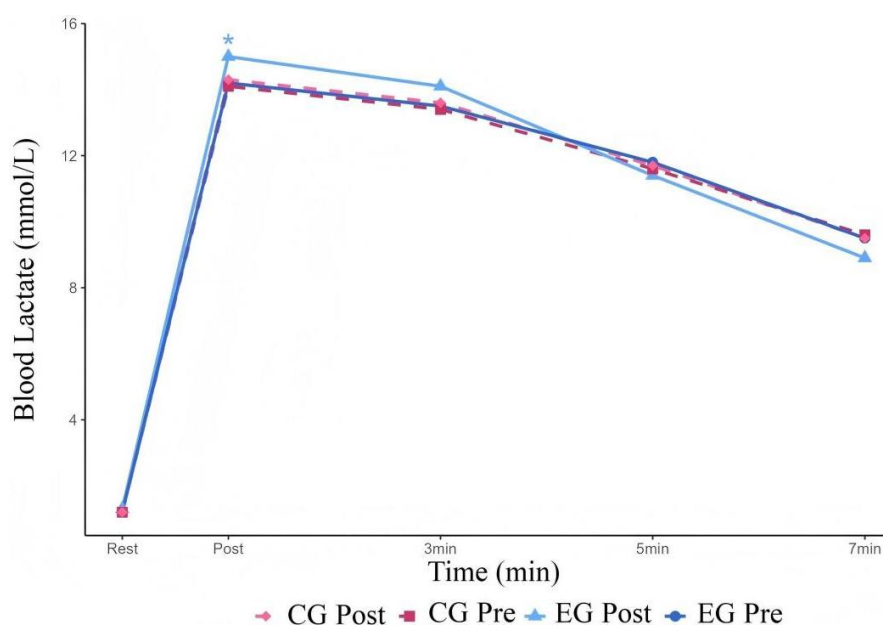
Lower limb explosive power

Pre- and post-intervention explosive power outcomes showed that CMJ height increased from 58.3 ± 3.7 to 63.9 ± 3.9 cm in EG with the increase of $9.7 \pm 1.8\%$ and from 57.9 ± 3.8 to 59.1 ± 3.7 cm in CG with the increase of $2.1 \pm 1.2\%$. DJ-RSI increased from 2.45 ± 0.22 to 2.80 ± 0.24 in EG with the increase of $14.3 \pm 2.5\%$ and from 2.43 ± 0.23 to 2.51 ± 0.22 in CG with the increase of $3.2 \pm 1.4\%$. Within-group improvements in EG were significant ($P < 0.001$), and the group-by-time interactions favored EG for CMJ height ($F(1, 28) = 12.75$, $P < 0.05$, $\eta^2p = 0.31$) and DJ-RSI ($F(1, 28) = 15.42$, $P < 0.05$, $\eta^2p = 0.35$) (Table 1).

Table 2. Anaerobic power and blood lactate alterations (mean $\pm$ SD).

Measure	Group	Pre-intervention	Post-intervention	Percent change
Peak power (W/kg)	EG	12.8 $\pm$ 0.7	13.8 $\pm$ 0.8**	7.8 $\pm$ 1.6
	CG	12.7 $\pm$ 0.8	12.9 $\pm$ 0.7	1.9 $\pm$ 1.1
Mean power (W/kg)	EG	9.6 $\pm$ 0.5	10.2 $\pm$ 0.6**	6.3 $\pm$ 1.4
	CG	9.5 $\pm$ 0.6	9.7 $\pm$ 0.5	1.7 $\pm$ 1.0
Fatigue index (%)	EG	52.3 $\pm$ 3.8	48.1 $\pm$ 3.5**	-8.0 $\pm$ 2.1
	CG	52.6 $\pm$ 3.7	51.5 $\pm$ 3.6	-2.1 $\pm$ 1.3
Peak lactate (mmol/L)	EG	14.2 $\pm$ 1.3	15.7 $\pm$ 1.4**	10.6 $\pm$ 2.3
	CG	14.1 $\pm$ 1.4	14.5 $\pm$ 1.3	2.8 $\pm$ 1.5

Note: ** $P < 0.01$ compared to pre-intervention values.

**Figure 1.** Blood lactate response curves pre- and post-intervention.

Anaerobic power and blood lactate response

Wingate and blood lactate outcomes demonstrated that peak power increased from 12.8 $\pm$ 0.7 to 13.8 $\pm$ 0.8 W/kg in EG with 7.8 $\pm$ 1.6% increase and from 12.7 $\pm$ 0.8 to 12.9 $\pm$ 0.7 W/kg in CG with 1.9 $\pm$ 1.1% increase. Mean power increased from 9.6 $\pm$ 0.5 to 10.2 $\pm$ 0.6 W/kg in EG with 6.3 $\pm$ 1.4% increase and from 9.5 $\pm$ 0.6 to 9.7 $\pm$ 0.5 W/kg in CG with 1.7 $\pm$ 1.0% increase. Fatigue index decreased from 52.3 $\pm$ 3.8% to 48.1 $\pm$ 3.5% in EG with -8.0 $\pm$ 2.1% decrease and from 52.6 $\pm$ 3.7% to 51.5 $\pm$ 3.6% in CG with -2.1 $\pm$ 1.3% decrease. Peak blood lactate increased from 14.2 $\pm$ 1.3 to 15.7 $\pm$ 1.4 mmol/L in EG with an increase

of 10.6 $\pm$ 2.3% and from 14.1 $\pm$ 1.4 to 14.5 $\pm$ 1.3 mmol/L in CG with an increase of 2.8 $\pm$ 1.5%. Within-group changes in EG were significant for all outcomes ($P < 0.01$). Significant group-by-time interactions were observed for peak power, mean power, fatigue index, and peak blood lactate (all $P < 0.05$) with η^2p values ranging from 0.27 to 0.33 (Table 2). The blood lactate time course at rest, immediately after exercise, and during 3, 5, and 7 minute recovery demonstrated a higher immediate peak followed by a progressive decline during recovery in the post-intervention EG (Figure 1).

Table 3. Alterations in kinematic parameters of hurdle clearance (mean $\pm$ SD).

Parameter	Hurdle	Group	Pre-intervention	Post-intervention	Percent change
Take-off distance (m)	3rd	EG	2.05 $\pm$ 0.08	2.12 $\pm$ 0.07**	3.4 $\pm$ 0.9
		CG	2.04 $\pm$ 0.09	2.06 $\pm$ 0.08	1.0 $\pm$ 0.7
	7th	EG	2.08 $\pm$ 0.09	2.16 $\pm$ 0.08**	3.8 $\pm$ 1.0
		CG	2.07 $\pm$ 0.08	2.09 $\pm$ 0.09	1.1 $\pm$ 0.8
Landing distance (m)	3rd	EG	1.28 $\pm$ 0.06	1.22 $\pm$ 0.05**	-4.7 $\pm$ 1.1
		CG	1.29 $\pm$ 0.07	1.27 $\pm$ 0.06	-1.4 $\pm$ 0.9
	7th	EG	1.26 $\pm$ 0.07	1.19 $\pm$ 0.05**	-5.5 $\pm$ 1.2
		CG	1.27 $\pm$ 0.06	1.25 $\pm$ 0.06	-1.6 $\pm$ 0.8
Clearance height (cm)	3rd	EG	32.4 $\pm$ 2.3	30.1 $\pm$ 2.1**	-7.1 $\pm$ 1.5
		CG	32.6 $\pm$ 2.4	31.9 $\pm$ 2.3	-2.2 $\pm$ 1.1
	7th	EG	33.1 $\pm$ 2.5	30.5 $\pm$ 2.2**	-7.8 $\pm$ 1.6
		CG	32.9 $\pm$ 2.3	32.1 $\pm$ 2.4	-2.4 $\pm$ 1.2
Contact time pre-hurdle (s)	3rd	EG	0.112 $\pm$ 0.008	0.103 $\pm$ 0.007**	-8.0 $\pm$ 1.7
		CG	0.113 $\pm$ 0.009	0.110 $\pm$ 0.008	-2.7 $\pm$ 1.3
	7th	EG	0.110 $\pm$ 0.008	0.100 $\pm$ 0.006**	-9.1 $\pm$ 1.8
		CG	0.111 $\pm$ 0.008	0.108 $\pm$ 0.007	-2.9 $\pm$ 1.2

Note: ** $P < 0.01$ compared to pre-intervention values.

Event-specific performance: 110-meter hurdles race time

A significant group-by-time interaction was observed for 110-meter hurdles performance with $F(1, 28) = 14.93$, $P < 0.001$, $\eta^2p = 0.35$. Race time in EG decreased from 15.44 ± 0.48 seconds at baseline to 15.07 ± 0.45 seconds after the intervention, representing an improvement of $2.40 \pm 1.42\%$ and an absolute reduction of 0.37 ± 0.22 seconds. In comparison, race time in CG decreased from 15.47 ± 0.47 to 15.39 ± 0.46 seconds, corresponding to an improvement of $0.52 \pm 1.23\%$ and an absolute reduction of 0.08 ± 0.19 seconds.

Hurdle clearance kinematics

Kinematic outcomes demonstrated that, at the third hurdle, EG take-off distance increased from 2.05 ± 0.08 to 2.12 ± 0.07 m with an increase of $3.4 \pm 0.9\%$, while landing distance decreased from 1.28 ± 0.06 to 1.22 ± 0.05 m with a $-4.7 \pm 1.1\%$ decrease, clearance height decreased from 32.4 ± 2.3 to 30.1 ± 2.1 cm with a $-7.1 \pm 1.5\%$ decrease, and pre-hurdle contact time decreased from 0.112 ± 0.008 to 0.103 ± 0.007 seconds with a decrease of $-8.0 \pm 1.7\%$. At the seventh hurdle,

EG take-off distance increased from 2.08 ± 0.09 to 2.16 ± 0.08 m, a $3.8 \pm 1.0\%$ increase. Landing distance decreased from 1.26 ± 0.07 to 1.19 ± 0.05 m, a $-5.5 \pm 1.2\%$ decrease. Clearance height decreased from 33.1 ± 2.5 to 30.5 ± 2.2 cm, a $-7.8 \pm 1.6\%$ decrease. The pre-hurdle contact time decreased from 0.110 ± 0.008 to 0.100 ± 0.006 seconds, a $-9.1 \pm 1.8\%$ decrease. The corresponding CG changes were smaller. All EG pre- and post-test differences were significant ($P < 0.01$), and group-by-time interactions were significant for the measured kinematic variables ($P < 0.05$ and $\eta^2p = 0.25 - 0.31$) (Table 3).

Discussion

This randomized study examined whether integrating progressive resistance and plyometric training would provide broader performance benefits than routine training in competitive male 110-meter hurdlers. The combined program was associated with superior changes in lower limb explosive power, anaerobic power maintenance, post-exercise blood lactate response, race time, and several technical

features of hurdle clearance. The convergence of laboratory, kinematic, and event specific outcomes supported the practical relevance of combining strength and reactive power stimuli during the preparatory period.

Lower-limb explosive power

The greater improvements in CMJ and DJ-RSI were consistent with research showing that combined strength and plyometric training enhanced jump and sprint related performance [8, 10, 11]. CMJ performance reflected the capacity to generate substantial impulse during a relatively unconstrained movement, whereas DJ-RSI emphasized rapid force production during a short stretch shortening cycle. Improvements in both measures indicated that the program developed complementary aspects of lower limb power rather than a single isolated quality. For hurdlers, this adaptation was relevant because take-off and inter-hurdle sprinting required force to be expressed rapidly, while horizontal velocity was maintained [1, 12]. The marked improvement in reactive strength was also compatible with stronger relationships between jump performance and maximal-speed sprint variables [13]. Resistance exercise likely increased the available force capacity [3], while progressive depth jumps and hurdle specific plyometrics might have improved neural activation, coordination, and stretch shortening cycle efficiency [7].

Anaerobic power and blood lactate response

EG exhibited a more favorable Wingate profile characterized by higher peak and mean power together with a lower fatigue index. Although cycling differed from sprint hurdling, these outcomes indicated an enhanced general ability to generate and sustain high power during short duration maximal exercise. Such adaptations were relevant to the 110-meter hurdles because a decline in power late in the race could disrupt inter-hurdle rhythm and technical accuracy [5]. The resistance component provided progressive overload across relatively high intensities, a stimulus known to produce load specific neuromuscular adaptations [14]. The repeated

maximal intent of plyometric exercises might have complemented this effect by increasing rapid motor unit recruitment. The higher post-exercise blood lactate concentration should not be interpreted in isolation as improved clearance, rather, when considered together with the reduced fatigue index and improved race performance, it was compatible with a greater capacity to sustain power despite substantial glycolytic demand. This interpretation was relevant because high intensity hurdling relied meaningfully on anaerobic glycolysis [1]. The Wingate test remained a general rather than hurdle specific measure. Accordingly, the observed changes should be understood as physiological adaptations that might support performance, not as a direct representation of the metabolic demands of hurdle running. The event specific race and kinematic findings provided stronger evidence that these general adaptations transferred to hurdling.

Event specific performance

The improvement in 110-meter hurdles race time was the most practically important finding. Performance gains were difficult to obtain in well-trained athletes over a short intervention, and even modest changes could be meaningful in sprint events [15]. The present pattern was compatible with evidence that gains in power, sprint related stiffness, and jump performance could contribute to faster locomotion when the training stimulus was appropriately matched to the athlete [2, 16, 17]. The integrated program addressed several determinants of hurdle performance at the same time including force capacity, reactive strength, anaerobic power maintenance, and technical execution. This multidimensional approach was consistent with biomechanical models showing that hurdle success depended on the coordination of approach velocity, take-off position, clearance trajectory, and rapid return to sprinting [18]. The transfer to race performance therefore appeared to reflect the combined effect of physical and technical adaptations rather than a single mechanism.

Hurdle clearance kinematics

The kinematic findings provided a plausible technical pathway for the observed race improvement. Proprioceptive and coordination oriented training had been proposed as a means of refining the hurdle step [19]. In the present study, longer take-off distance combined with shorter landing distance and lower clearance height indicated a flatter and more economical flight path. This configuration could help preserve horizontal velocity by limiting unnecessary vertical displacement [2, 20]. The shorter pre-hurdle contact time was also consistent with improved reactive strength. Rapid force production immediately before take-off was essential for maintaining approach velocity and establishing an efficient clearance trajectory [5]. Because depth jumps and hurdle hops imposed short ground contacts and rapid eccentric-to-concentric transitions, the plyometric component offered a direct training stimulus for this technical demand [6]. Similar adaptations at the third and seventh hurdles suggested that the program influenced both early race execution and technique under accumulating fatigue.

Strengths, limitations, and practical implications

A strength of this study was the combined use of laboratory power tests, post-exercise blood lactate sampling, electronic race timing, and high speed kinematic analysis within a randomized design. The intervention was supervised, adherence was high, and testing conditions were standardized. These features strengthened the internal consistency of the findings. Several limitations should be considered. The sample was small and restricted to competitive male hurdlers, which limited generalization to female athletes, youth athletes, or different competitive levels. The 8-week duration did not establish the persistence of the adaptations, and the Wingate test did not reproduce hurdle specific movement. Coaches and assessors could not be fully blinded to group assignment. Future studies should include larger samples, direct sprint hurdle metabolic assessment, longer follow up, and comparison of different sequencing strategies for

resistance and plyometric work. For practice, the findings supported two weekly progressive resistance sessions and two weekly plyometric sessions, separated by adequate recovery, during the preparatory phase. The program should preserve technical quality, progress depth jump exposure cautiously, and reduce volume before performance testing or competition.

Conclusion

An 8-week combined resistance-plyometric program was more effective than routine training for improving explosive power, anaerobic performance, post-exercise blood lactate response, hurdle-clearance mechanics, and 110-meter hurdles race performance in competitive male athletes. The parallel improvements in physical and technical outcomes indicated that integrated strength-power programming could facilitate transfer from general neuromuscular adaptation to event-specific performance when training volume, progression, and recovery were carefully controlled.

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