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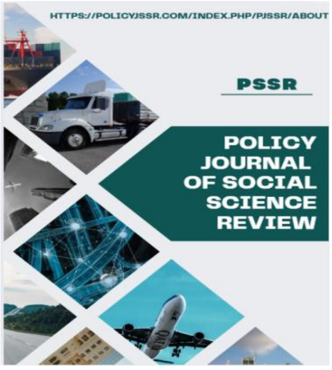

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ACUTE AND CHRONIC EFFECTS OF PLYOMETRIC TRAINING ON NEUROMUSCULAR PERFORMANCE IN UNIVERSITY-LEVEL MALE FOOTBALL PLAYERS

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ABSTRACT

Background: Plyometric training is widely regarded as an effective modality for enhancing explosive athletic performance; however, evidence comparing its immediate (acute) and long-term (chronic) effects within a controlled experimental framework remains limited, particularly for university-level football populations in developing countries.**Objective:** To examine the acute and chronic effects of an 8-week plyometric training program on neuromuscular performance in male university football players. **Methods:** A randomized controlled design with a 2 × 3 (Group × Time) mixed factorial structure was employed. Thirty male university footballers (age: 21.3 ± 1.9 years) were randomly allocated to an experimental group (EG; n = 15), which completed a structured 8-week plyometric program alongside regular football training, or a control group (CG; n = 15), which continued standard training only. Performance was assessed at three time points: baseline (T_0), immediately following the first plyometric session (T_1), and 48 hours after program completion (T_2). Outcome measures included the Standing Broad Jump (SBJ), 10-m Sprint Test, Illinois Agility Test, Y-Balance Test (anterior reach), and 10–5 Repeated Jump Test. Mixed-design ANOVA with Bonferroni post-hoc corrections and partial eta-squared (η^2p) effect sizes were employed for statistical analysis. **Results:** At T_0, the EG exhibited a transient decline across all performance variables, indicative of acute neuromuscular fatigue. By T_2, however, the EG demonstrated significant improvements in explosive power (SBJ: +8.97%), sprint acceleration (10-m: −6.19%), agility (Illinois: −7.19%), and dynamic balance (Y-Balance: up to +9.5%), with all Group × Time interactions significant at $p < .001$ and large effect sizes (η^2p = .54–.74). The CG showed no meaningful change across any time point. **Conclusion:** An initial acute decrement gives way to substantial chronic neuromuscular gains following 8 weeks of plyometric training. These findings support the systematic integration of

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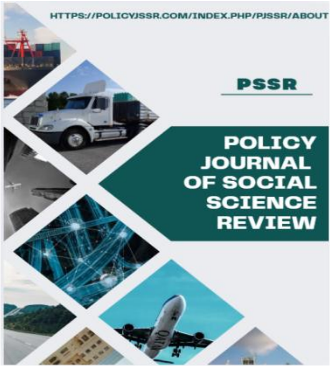

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plyometric training into university football conditioning programs to optimize athletic performance.

Keywords: *plyometric training; neuromuscular performance; explosive power; agility; football; stretch-shortening cycle*

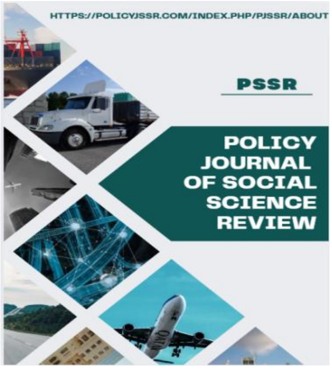
1. Introduction

Football is a high-intensity intermittent sport characterized by repeated explosive actions, including maximal sprints, rapid directional changes, jumping, and physical confrontations. These demands place considerable stress on the neuromuscular system, requiring athletes to sustain high levels of explosive power, sprint acceleration, agility, and dynamic stability across match play (Silva et al., 2026; Santos et al., 2026). Accordingly, the physical preparation of football players must prioritize training methods that enhance these specific capacities.

Among evidence-based conditioning approaches, plyometric training has received considerable empirical support for its ability to improve neuromuscular performance in team sport athletes (Zheng et al., 2025; Selmi et al., 2026). Grounded in the mechanics of the stretch-shortening cycle (SSC), plyometric exercises involve a rapid eccentric muscle action immediately followed by a concentric contraction, facilitating greater force output through elastic energy storage and enhanced neural activation (Oulmas & Haddadi, 2026; McGarrigal et al., 2025). The resulting improvements in motor unit recruitment, firing frequency, and intramuscular coordination are particularly relevant to football-specific performance tasks.

Despite this breadth of evidence, most published studies examine either the acute or chronic effects of plyometric training in isolation, often focusing on elite populations or single performance outcomes. Comparatively little research has simultaneously evaluated both immediate neuromuscular responses and long-term adaptations within the same experimental framework, especially in university-level athletes from developing countries where scientific training practices remain underutilized (Arauzo et al., 2025). Acute effects, including transient performance enhancement through post-activation performance enhancement (PAPE) and temporary decrements from fatigue, carry direct implications for warm-up design and training periodization. Chronic adaptations, accumulated over several weeks of systematic overload, inform long-term conditioning strategy.

The present study was therefore designed to address this gap by simultaneously examining acute (T_0) and chronic (T_2) neuromuscular responses to an 8-week plyometric intervention in male university football players at the University of the Punjab, Lahore, using a randomized controlled design. It was hypothesized that (H_2) acute plyometric loading would produce a transient decline in performance; (H_3) the 8-



Policy Journal of Social Science Review

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week program would significantly improve all neuromuscular performance indicators relative to the control group; and (H_3) chronic adaptations at T_1 would significantly exceed acute responses at T_2.

2. Methods

2.1 Study Design

A randomized controlled trial employing a 2 (Group: Experimental vs. Control) × 3 (Time: T_0, T_1, T_2) mixed factorial design was used. Ethical approval was obtained from the institutional review board of the University of the Punjab, and written informed consent was collected from all participants prior to data collection. The study was conducted in accordance with the Declaration of Helsinki.

2.2 Participants

Thirty male university football players (mean age: 21.3 ± 1.9 years; mean BMI: 23.1 ± 2.1 kg/m²) were recruited from the Punjab University Football Club. Inclusion criteria required a minimum of two years of competitive football experience, active participation in at least three training sessions per week, and freedom from musculoskeletal injury during the study period. Participants currently enrolled in external strength or plyometric programs were excluded. Using a random number allocation procedure, participants were equally divided into the Experimental Group (EG; n = 15) and Control Group (CG; n = 15). Independent samples t-tests confirmed no significant baseline differences between groups across all demographic and anthropometric variables (all $p > .05$).

2.3 Intervention

The EG completed structured 8-week plyometric training program in addition to regular football training. The program was delivered three sessions per week and incorporated progressive plyometric loading: early weeks focused on bilateral jumps and box exercises, transitioning to unilateral hops, lateral bounds, and reactive drop jumps in later weeks. Session duration ranged from 40 to 60 minutes, including warm-up and cool-down. Training volume and intensity were progressively overloaded across the intervention to support systematic neuromuscular adaptation (Manikandan et al., 2026). The CG continued their standard football training schedule without any supplementary plyometric component throughout the 8-week period.

2.4 Outcome Measures

Neuromuscular performance was assessed across five validated field-based tests at three time points: T_0 (pre-intervention baseline), T_1 (immediately following the first plyometric session; EG only; equivalent rest-day assessment for CG), and T_2 (48 hours after the final training session). All assessments were conducted under standardized environmental conditions and testing order.

Explosive lower-limb power was measured via the Standing Broad Jump (SBJ; cm), recorded as the best of three trials (Council of Europe, 1988). Sprint acceleration was

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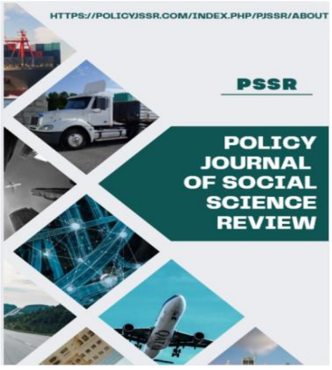

Policy Journal of Social Science Review

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assessed using the 10-m Sprint Test (seconds), timed with electronic gates (Little & Williams, 2005). Change-of-direction speed was evaluated with the Illinois Agility Test (seconds; Hachana et al., 2014). Dynamic balance and neuromuscular stability were quantified via the Y-Balance Test anterior reach as a percentage of dominant and non-dominant limb length (Plisky et al., 2009). Reactive strength was evaluated using the 10–5 Repeated Jump Test, scored on a 1–5 scale. For sprint and agility measures, lower values indicate superior performance.

2.5 Statistical Analysis

Data were analyzed using SPSS Version 26.0. Descriptive statistics (mean, standard deviation, 95% confidence intervals) were computed for all variables. A 2 × 3 mixed-design ANOVA was used to examine Group × Time interaction effects. Where significant interactions emerged, Bonferroni-corrected post-hoc pairwise comparisons were applied within each group across time points. Effect sizes were calculated using partial eta-squared (η^2p), interpreted as small (.01), medium (.06), and large (.14) per Cohen (1988). Statistical significance was set at $\alpha = .05$.

3. Results

3.1 Participant Characteristics

Both groups were statistically equivalent at baseline across all demographic, anthropometric, and baseline performance measures (Table 1). This confirmed group comparability prior to intervention, supporting the internal validity of subsequent between-group comparisons.

Table 1: Baseline Demographic and Anthropometric Characteristics by Group (N = 30)

Variable	EG M	EG SD	CG M	CG SD	t28	p
Age (years)	21.1	1.8	21.5	2.0	0.61	.54
Body mass (kg)	70.2	6.6	70.6	7.1	0.17	.87
Stature (cm)	174.4	5.2	174.8	5.7	0.21	.84
BMI (kg/m²)	23.0	2.0	23.2	2.2	0.27	.79
Dominant limb (cm)	88.5	4.1	88.9	4.3	0.28	.78
Football exp. (years)	4.5	1.7	4.7	1.9	0.32	.75
Weekly sessions (n)	3.9	0.6	3.8	0.7	0.43	.67

Note. EG = Experimental Group; CG = Control Group; M = mean; SD = standard deviation. No significant between-group differences were observed (all $p > .05$).

3.2 Neuromuscular Performance Outcomes

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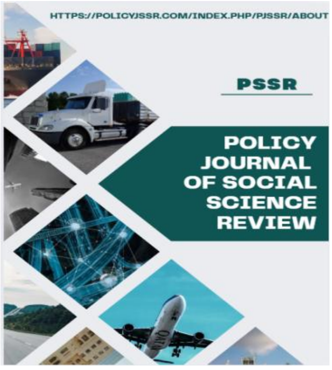

Policy Journal of Social Science Review

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Table 2 presents group means, mixed ANOVA statistics, and effect sizes for all six performance variables across the three time points. Across the EG, a consistent biphasic pattern was observed: a transient performance decline at T_0 , followed by substantial improvement at T_2. The CG exhibited no significant change at any time point.

Table: Group Means and Mixed ANOVA Results for Neuromuscular Performance Variables across T_0 , T_1, and T_2.

Variable	Experimental Group (n = 15)			Control Group (n = 15)			F(2,56)	η²p	p
	T_0	T_1	T_2	T_0	T_1	T_2			
SBJ (cm)	187.4	181.6	204.2	186.8	185.1	188.3	39.7	.73	<.001
10-m Sprint (s)	1.94	1.99	1.82	1.95	1.97	1.94	33.2	.67	<.001
Illinois Agility (s)	16.84	17.32	15.63	16.91	17.15	16.78	36.8	.70	<.001
Y-Bal Dom. (%)	68.4	65.2	74.8	68.1	67.3	68.6	28.4	.61	<.001
Y-Bal Non-Dom. (%)	67.1	63.8	73.2	66.8	65.9	67.4	25.1	.59	<.001
10-5 RJ (score)	3.12	2.68	4.04	3.09	2.97	3.14	21.4	.54	<.001

Note. SBJ = Standing Broad Jump; Y-Bal Dom. = Y-Balance dominant limb; Y-Bal Non-Dom. = Y-Balance non-dominant limb; 10-5 RJ = 10-5 Repeated Jump Test. For sprint and agility tests, lower values indicate better performance. η²p values represent Group × Time interaction effect sizes. All interactions significant at $p < .001$.

3.3 Acute Effects (T_0 to T_1)

Within the EG, all performance variables declined significantly from baseline to T_0 (Bonferroni-corrected p values ranging from .011 to .038). The most pronounced decrements occurred in agility (Illinois: 16.84 → 17.32 s; −3%), dynamic balance (Y-Balance dominant: 68.4 → 65.2%; −4.7%), and reactive strength (10–5 RJ: 3.12 → 2.68). No equivalent acute decline was observed in the CG (all pairwise comparisons $p > .05$), confirming that performance decrements were attributable to the plyometric stimulus rather than natural day-to-day variation.

3.4 Chronic Adaptations (T_0 to T_1)

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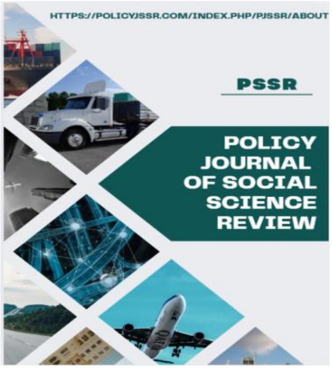

Policy Journal of Social Science Review

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Following the 8-week program, the EG demonstrated significant improvements from baseline across all measures (all Bonferroni-corrected $p < .001$). The largest relative gains were observed for explosive power (SBJ: 187.4 → 204.2 cm; +8.97%), agility (Illinois: 16.84 → 15.63 s; −7.19%), and sprint acceleration (10-m: 1.94 → 1.82 s; −6.19%). Dynamic balance improved substantially for both dominant (68.4 → 74.8%; +9.36%) and non-dominant limbs (67.1 → 73.2%; +9.09%), and reactive strength increased from 3.12 to 4.04 (+29.5%). All Group × Time interactions were large (η^2p = .54–.73, all $p < .001$). The CG showed no significant change from T_1 to T_2 across any variable, confirming that observed EG improvements were attributable specifically to the plyometric intervention.

4. Discussion

This study provides controlled experimental evidence that an 8-week plyometric training program produces substantial neuromuscular performance gains in university-level male football players, and that these chronic adaptations are preceded by a period of acute performance decline following initial plyometric loading. The findings support all three a priori hypotheses and align with contemporary sports science literature on plyometric adaptation.

The acute performance decrements observed at T_0 across all EG variables are consistent with evidence of transient neuromuscular fatigue following high-intensity plyometric loading (Sezen & Sarialioğlu, 2026; Abdelkader & Albosaty, 2026). During initial exposure, depletion of phosphocreatine stores, accumulation of metabolic by-products, and disruption of calcium kinetics collectively impair motor unit efficiency, resulting in measurable reductions in sprint speed, agility, and balance. This pattern aligns with the alarm phase of Selye's General Adaptation Syndrome (GAS) and underscores the importance of scheduling plyometric training sufficiently far from competitive matches during early training phases to avoid impairing match-day performance.

The robust chronic improvements documented at T_2 reflect well-established mechanisms of plyometric adaptation. Enhanced SSC efficiency, characterized by improved elastic energy storage and release in the muscle-tendon unit, is primarily responsible for explosive power and sprint gains (Zheng et al., 2025; Fu et al., 2026). Early neural adaptations, including increased motor unit recruitment, elevated discharge rates, and improved intramuscular coordination, further contribute to performance enhancement preceding morphological changes (Lecce et al., 2026; Santos et al., 2026). The progressive overload applied across the 8-week program enabled systematic super compensation, consistent with established neuromuscular adaptation theory (Manikandan et al., 2026).

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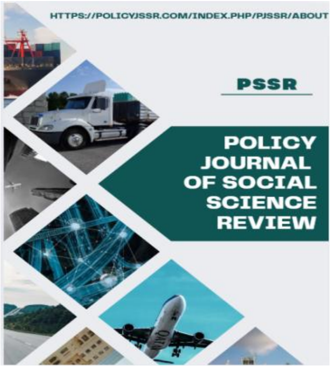

Policy Journal of Social Science Review

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The magnitude of improvements observed is comparable to those reported in recent systematic reviews on plyometric training in adolescent and young adult footballers. Zheng et al. (2025) documented mean improvements of approximately 6–9% in jump and sprint performance following 6–8 week programs, consistent with the 6.19–8.97% improvements recorded here. Improvements in dynamic balance and agility, areas less frequently reported as outcomes in plyometric literature, were particularly pronounced in this study (η^2p = .61–.70), suggesting that the multi-planar and reactive nature of the program effectively targeted neuromuscular stability alongside power.

The absence of any significant performance change in the CG is a critical finding. It confirms that standard football training, conducted at comparable volume and frequency, was insufficient to drive meaningful neuromuscular adaptation over 8 weeks. This reinforces the necessity of supplementary structured plyometric conditioning within university football programs, particularly in South Asian institutional settings where scientific periodization is still developing (Arauzo et al., 2025; Khan et al., 2026).

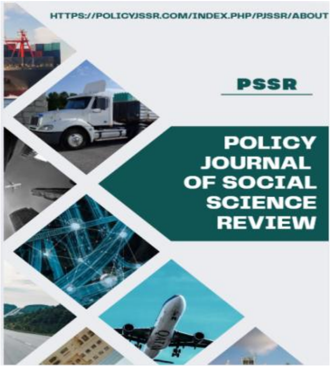
Several limitations warrant acknowledgment. The sample was restricted to male university players at a single institution (N = 30), limiting the generalizability of findings to female athletes, professional cohorts, or other cultural contexts. The absence of a follow-up assessment beyond T_2 precludes conclusions regarding the retention of training adaptations. Furthermore, no hormonal, EMG, or force-plate data were collected, which restricts mechanistic inference beyond field-test performance. Future research should employ larger, more diverse samples, include biochemical and electrophysiological outcome measures, and examine detraining effects over extended post-intervention periods.

5. Conclusion

An 8-week plyometric training program significantly improved explosive power, sprint acceleration, agility, dynamic balance, and reactive strength in male university football players, with large effect sizes across all outcomes. An initial phase of acute neuromuscular fatigue was observed following the first training session, underscoring the need for careful training periodization, particularly around competitive fixtures. The control group's stability across all time points confirms that these adaptations were attributable specifically to the plyometric intervention rather than general training effects. These findings provide robust evidence for the integration of structured plyometric training into university football conditioning programs.

6. Practical Implications

For strength and conditioning coaches, the present findings support the inclusion of plyometric training 2–3 times weekly within structured football conditioning cycles, with progressive overload applied across multi-week blocks. Given the acute fatigue response documented at T_1, initial plyometric sessions should be scheduled at the



Policy Journal of Social Science Review

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beginning of the weekly micro cycle, sufficiently removed from match play, to allow adequate recovery.

For athletes, proper landing mechanics and technique must be prioritized during plyometric execution to minimize injury risk and maximize training stimulus. Athletes should expect a transient performance decrement during early training weeks and maintain consistent participation to realize chronic adaptation benefits.

For institutional sports programs in Pakistan, these findings provide a scientifically grounded rationale for developing structured neuromuscular training curricula within university football programs. Serial use of validated field tests (SBJ, Illinois, and Y-Balance) is recommended for ongoing monitoring of training responses.

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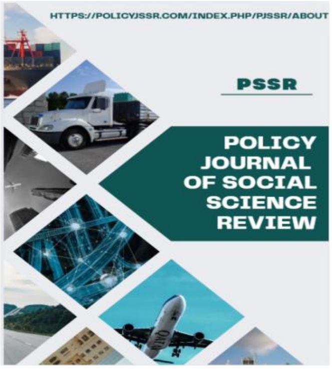

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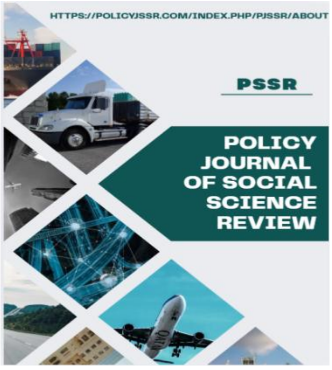

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