RESEARCH ARTICLE

International Journal of
PHYSICAL EDUCATION, FITNESS AND SPORTS

DOI: 10.54392/ijpefs2619

Neuromuscular Adaptations to a 12-Week Periodized Speed, Agility, and Quickness Training Program in Female Collegiate Athletes

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DOI: https://doi.org/10.54392/ijpefs2619
Received: 01-01-2026; Revised: 23-02-2026; Accepted: 04-03-2026; Published: 10-03-2026

Abstract: An athlete needs to perform well in his/her game, so motor skills like speed, agility, and explosive power are very essential fitness components. Although programs of training are frequently employed to enhance these aspects, and although structured training methods are frequently used to improve these attributes, there is still inadequate information on how well they work for female collegiate athletes. The purpose of this study was to investigate the effect of a training intervention program on selected motor skills linear speed, multidirectional agility, and lower body explosive power in female college athletes. Total thirty healthy female university students aged 20.4 ± 1.8 years participated in a single-group pre-post experimental study. Motor skill performance was measured using a 50 m sprint test (speed), Three Cones Test, Zig-zag Test, and the Illinois Agility Test (agility), and vertical jump tests such as the countermovement jump, the countermovement jump with arm swing, and squat jump (explosive power). Pre-post changes were analyzed using paired sample t-tests, and the effect size was calculated using Cohen's d. The results showed significant improvements in sprint and agility performance ($p = 0.003$), with moderate to large effect sizes ($d = 0.63$-0.78). However, no significant improvements were found in vertical jump performance ($p \geq 0.05$), indicating minimal changes in lower body explosive power. The organized training protocol improved female collegiate athletes' linear speed and multidirectional agility but had limited impact on increasing lower-body explosive power.

Keywords: Speed, Agility, Quickness, SAQ Training, Female Collegiate Athletes, Sprint Performance, Change-of-Direction Speed, Explosive Power, Neuromuscular Adaptation

1. Introduction

The complex phenomenon of sport performance includes strength, power, speed, agility, balance, and coordination, all of which are commonly referred to as motor skills and are crucial for successful participation in sports (Chen *et al.,* 2025). For collegiate athletes, particularly women, motor skill optimization is crucial to enhancing athletic performance and reducing injury risk (Hughes *et al.,* 2023). As opposed to physical activity, training entails periodization, specificity, and methodical progression that aid in neuromuscular adaptation and enable athletes to exhibit quantifiable gains in motor skills unique to their sport (Mujika et al. 2018) . When compared to male athletes, female collegiate athletes are a unique group due to physiological, hormonal, and neuromuscular characteristics affecting training adaptation (Hughes *et al.,* 2023). Present investigation highlights the significance of sex-specific training factors: following particular training treatments, female athletes may exhibit distinct changes in strength, sprinting, and balance training. Also, playing collegiate sports is linked to higher physical demands that require well-developed motor abilities, such as continuous anaerobic activity, change-of-direction exercises, repetitive sprinting, and jumping (Lin *et al.,* 2025). The Complex training, integrative neuromuscular training (INT), and plyometric therapies have gained popularity in recent sports science literature due to their multiple impact on motor performance outcomes. It has been proved that within 8 weeks, complex training which blends high-intensity strength and power exercises—significantly enhances female athletes' lower-body strength, power, and change-of-direction ability (Mujika *et al.,* 2018). The integration of strength, balance, agility, and coordination components in INT programs has also improved sprint, jump, balance, and agility performance in athletic populations. (Deng *et al.*, 2022). In female team-sport athletes, plyometric training also shows potential as a powerful technique for enhancing explosive performance traits like countermovement jump height and change-of-direction speed. Plyometric interventions of sufficient duration and volume e.g., ≥9 weeks or longer sessions demonstrate the efficacy of systematic, recurrent neuromuscular challenges for female athletes (Lin *et al.,* 2025). Interventions of sufficient duration and volume, usually extending over a period of several weeks, seem to be most effective, as repeated neuromuscular stimulation increases lower limb power output and reactive strength qualities critical for explosive movement. Other complementary approaches, such as speed, agility, and quickness (SAQ) training, also provide moderate gains in lower limb power and short sprint performance, thus underscoring the importance of comprehensive neuromuscular programming (Koral *et al.,* 2021). Taken together, these results underscore the importance of incorporating structured plyometric and SAQ training programs to maximize explosive and multidirectional performance qualities in team sport athletes, including females. Specific principles of strength and speed training highlight the need for modalities tailored to sprint and power performance. Findings indicate that strength training protocols specifically designed for sprint and power activities may lead to greater improvements in short to moderate sprint distances (0-40 m) than traditional strength training (Hughes *et al.,* 2023). Training effects are affected by the training program design, duration, frequency, and individual differences among participants, including age, sport-specificity, and training experience. Longer duration training protocols with greater frequency seem to promote more reliable improvements in key motor skills, thereby supporting the dose-response relationship between training volume and performance adaptations (Chen *et al.,* 2025). Despite previous interventions incorporating SAQ and plyometric training, which have shown improvements in sprint and agility performance among female athletes, there is a lack of research on comprehensive, periodized training programs specifically targeting female collegiate athletes, especially in South Asia. Hence, the purpose of this study is to assess the impact of a 12-week training program on motor performance among female collegiate athletes.

1.1 Objective

The main objective of this research was to investigate the impact of a 12-week structured and periodized training program on the designated motor skills namely, linear sprinting speed, multidirectional agility, and lower body explosive power for female college-level athletes. Additionally, the objective was to assess the extent of performance changes and if the training-related modifications were task-specific among the various motor skill domains.

1.2 limitation

The design of the study was a single-group pre-post experimental design to evaluate the impact of the structured training program on motor performance. While this design is effective in measuring the improvement of subjects within their own group, the lack of a control group is a major limitation of this design. Also time and financial support is a limiting factor of the study.

1.3 Significance of the Study

This investigation is important to strength and conditioning professionals, coaches, and sports scientists working with female athletes, especially in the South Asian collegiate setting, where there is a lack of sufficient research. This study, analysing a structured multidimensional training program that combines resistance training, cardiovascular training, and speed-agility drills, offers region-specific empirical evidence. The results of this study improve the understanding of training-related adaptations between different performance tasks. Moreover, the results of this study support evidence-based program design, especially in terms of agility and sprint performance, while underlining the relevance of specific plyometric training to improve vertical explosive power.

2. Materials and Methods

2.1 Study Design

The study used a single-group pretest-posttest pre-experimental design ($O_1 \rightarrow X \rightarrow O_2$) to investigate the effect of a 12-week structured training program.

The pre-test (O_1) was done before the implementation of the intervention, while the post-test (O_2) was done using the same method to determine the effect of the intervention on certain motor skills. This design allowed the researcher to determine the effect of the intervention on performance changes over time. However, the lack of a control group and randomization affects the internal validity of the research. The theoretical and inferential bases of this design have been explained in detail in Experimental and Quasi-Experimental Designs for Research by Campbell and Julian (2015).

2.2 Participants

Thirty healthy female collegiate athletes of mean age 20.4 ± 1.8 years; height 158.2 ± 4.8 cm; body mass 52.6 ± 4.4 kg voluntarily participated in the study. All participants had 2–4 years of sports experience, including volleyball, kabaddi, and cricket, with participation at intercollegiate or district level competitions. Participants had not engaged in any other systematic sports training during the 12 weeks intervention programme and before 6 months of the intervention. The participants represented diverse sport backgrounds, the limited number within each discipline did not permit subgroup analyses; therefore, generalization to specific sports was made with caution. Written informed consent was obtained from all participants.

2.3 Inclusion and Exclusion Criteria

Participants were eligible if they were apparently healthy female collegiate athletes aged 18-23 years old, had at least 2-4 years of regular participation in organized sports such as cricket, volleyball, or basketball, and had not taken part in structured speed, agility, or power-specific training during 12 weeks and previous six months.

Exclusion criteria included: (a) a history of lower-limb musculoskeletal injury within the previous six months; (b) any medical condition that precludes maximal physical exertion; (c) associated participation in another structured training program; and (d) the attendance of less than 80% of the scheduled training sessions.

2.4 Variables and Test

All tests were completed in a single testing session on an indoor, non-slip surface in standardized environmental conditions. A standardized 15-minute warm-up, consisting of light aerobic exercise, dynamic stretching, and 2-3 submaximal practice trials of each test, was completed for all participants. To reduce the confounding influence of inter-test fatigue, the test battery was presented in the following fixed order: (1) 50m sprint, (2) agility tests (Three Cones, Zig-zag, Illinois), and (3) vertical jump tests (countermovement jump, countermovement jump with arm swing, squat jump). A minimum of 10 minutes of passive recovery was inserted between test categories. The best of two trials was used for analysis for all performance tests, with the exception of vertical jumps, for which the highest of three attempts was recorded. Timing was measured to the nearest 0.01 seconds using electronic timing gates for sprint and agility tests; jump height was measured to the nearest 0.1. All electronic timing gates and touch mats were calibrated according to the manufacturer's guidelines before every testing session. The same primary investigator conducted all performance tests to ensure inter-rater reliability. Testing took place indoors between 8:00-11:00 AM, with controlled environmental conditions (temperature of 24-26°C).

2.4.1 Speed Assessment

The 50m sprint test was employed to evaluate acceleration and sprinting speed. The test was initiated with the dominant foot placed behind the start line and in a stationary standing start position. When the auditory "Go" signal was given, the participants sprinted maximally for 50m. The timer was stopped once the torso crossed the finish line. Two trials were completed with a minimum 5-minute rest break in between (Hasrudin, *et al.,* 2023).

2.4.2 Agility Assessments

Three validated agility tests were conducted. The Three Cones Test (L-drill) involved the movement through an L-shaped course with cones placed 5 yards (4.57 m) apart, including forward sprint, backpedal, side shuffle, and figure-eight patterns; timing started with initial movement and ended with torso re-crossing the start/finish line (Mann *et al.,* 2016). The Zig-zag Test involved four cones arranged in a zig-zag pattern over a total distance of 20m, with cones staggered alternately 100 cm to the left and right of a central meridian at 5m intervals; participants sprinted through the course without moving cones (Metaxas *et al* 2005). The Illinois Agility Test involved participants starting in a prone position, quickly moving to their feet, and completing a 10m × 5m course by weaving through four cones placed centrally and two end turns; timing started with a signal and ended with torso crossing the finish line (Getchell, 1979; Markovic *et al.,* 2004).

2.4.3 Lower-Body Explosive Power Assessment

Three vertical jump tests were conducted with chalk and wall method. The Countermovement Jump (CMJ) involved subjects standing with hands placed firmly on hips, performing a rapid downward countermovement to a self-selected depth, and immediately jumping maximally without preparatory pause; arm swing was not allowed of the CMJ jump (Markovic *et al.,* 2004). The Countermovement Jump with Arm Swing (CMJa) allowed subjects to swing their arms freely, with subjects starting from an elbow-flexed position with arms forward and performing vigorous downward and upward arm swings during the countermovement phase (Heishman *et al.,* 2020). The Squat Jump (SJ) involved isolating concentric power, with subjects lowering themselves to a half-squat position (about 90° knee flexion, hands on hips), holding stationary posture for 3-5 seconds to allow elastic energy to recover, and then jumping maximally on command without preparatory countermovement (Markovic *et al.,* 2004). For all vertical jump tests, three attempts were taken with 60-second recovery between trials, and the highest jump was retained.

2.5 Training Intervention

The 12-week structured training program was periodized into six 2-week mesocycles with progressively increasing volume and intensity (Table 1). Sessions were conducted six days weekly.

Progression and Load Monitoring: Progression of intensity was facilitated in a variety of ways: (a) resistance training intensity was progressed from 60-65% to 80-85% of estimated one-repetition maximum (1RM) in weeks 1-2 to 11-12, respectively; (b) strength training volume was progressed in a descending order (3x10-12 to 5x6-8); (c) cardiovascular training type was progressed from steady-state running to interval training, tempo runs, fartlek, and high-intensity interval training, respectively; (d) speed/agility drills were progressed from basic stride exercises to resisted sprints and complex multi-directional patterns. All training sessions were supervised by certified strength and conditioning specialists and research assistants trained in standardized coaching procedures. Participant compliance was recorded by daily attendance sheets; participants with >20% absence of total training sessions (≥15 sessions) were excluded from final analysis. Mean attendance over the 12-week training period was 91.4% (range: 82-100%). Training loads were progressively increased across mesocycles by varying resistance, number of repetitions, sets, duration, and exercise complexity, thereby ensuring that progressive overload principles were strictly followed throughout the training period. Internal validity was further ensured by strict adherence to pre-specified exercise parameters and supervision by certified strength and conditioning specialists.

External validity, conversely, was bolstered by selecting exercises and drills that closely mirrored the physiological demands and movement patterns inherent in collegiate athletics, thereby maximizing the ecological relevance of the findings (Ibrahim *et al.,* 2020). This comprehensive approach ensured that the training adaptations observed were directly applicable to enhancing athletic performance in real-world competitive scenarios.

2.6 Statistical Power and Sample Size

All statistical analyses were conducted using SPSS software version 26.0 (IBM Corp., Armonk, NY, USA). The results are expressed as mean ± standard deviation. Normality of the difference scores was verified by the Kolmogorov-Smirnov test ($p > 0.05$). Paired sample t-tests were used to compare pre- and post-training differences, with a significance level of $\alpha = 0.05$ (two-tailed). Effect sizes were calculated using Cohen's d and classified as small (0.20-0.49), medium (0.50-0.79), or large (≥0.80). An a priori power calculation (G*Power version 3.1) was performed for a paired sample t-test with $\alpha = 0.05$, power = 0.80, and a medium effect size ($d = 0.50$). The minimum sample size required was 27 participants. The present study's final sample ($N = 30$) exceeded this requirement, providing sufficient power to detect moderate training-related effects. Yet, smaller effect sizes may have necessitated a larger sample size to provide adequate statistical sensitivity.

3. Results

Descriptive statistics, pre-post comparisons, and effect sizes for all motor ability measures are presented in Table 2. The Kolmogorov–Smirnov test confirmed that difference scores for all variables were normally distributed ($p = 0.104–0.140$), supporting the appropriateness of parametric testing.

Table 1. Twelve-Week Periodized Training Protocol

Week	Focus	Strength Training (Mon/Wed/Fri)	Cardio/Endurance (Tue/Thu)	Speed/Drills (Sat)	Daily Total Duration
1–2	Foundational strength & volume	Squats: 3×10–12, Push-ups: 3×12–15, Planks: 3×30–45s, Lunges: 3×10–12/leg	Steady run: 20–30 min easy pace	Sprint drills: 4–5×50m strides	1 hour 30 minutes
3–4	Introduce weights & intervals	Deadlifts: 3×10–12, Bench press: 3×10–12, Core twists: 3×15–20/side, Step-ups: 3×10–12/leg	Interval run: 4–5× (2 min hard / 2 min easy)	Stair sprints: 4–5×20s uphill	1 hour 45 minutes
5–6	Build power & tempo	Power cleans: 4×8–10, Overhead press: 4×10–12, Russian twists: 4×15–20/side, Bulgarian split squats: 4×8–10/leg	Tempo run: 30–35 min (10–15 min @ threshold)	Agility ladder drills: 6–7 sets	2 hours
7–8	Plyometrics & peak strength	Box jumps: 4×8–10, Pull-ups: 4×max to max+1, Leg raises: 4×12–15, Calf raises: 4×15–20	Fartlek run: 40–45 min varied pace	100m sprints: 6–7× with full recovery	2 hours 15 minutes
9–10	Sharpen speed & power	Explosive squats: 5×6–8, Dips: 5×10–12, Bicycle crunches: 5×20–25/side, Single-leg deadlifts: 5×8–10/leg	High-intensity intervals: 6–7× (1 min max / 3 min easy)	200m repeats: 4–5× with walk recovery	2 hours 20 minutes
11–12	Maximize performance & final taper	Plyo push-ups: 5×8–10, Rows: 5×10–12, Plank variations: 5×45–60s, Pistol squats: 5×6–8/leg (assisted if needed)	Pyramid intervals: build to max effort → reduced volume in week 12	400m repeats: 3–4× with full recovery	2 hours 30 minutes

3.1 Sprint and Agility Performance

There were marked improvements in all the running-related tasks. The mean 50m sprint time reduced from 10.22 ± 0.61 s to 9.81 ± 0.58 s, with a mean difference of 0.41 s (4.0%); $t(29) = 4.12$, $p = 0.001$, Cohen's $d = 0.75$ (medium-to-large effect size). The Three Cones Test took less time to complete, with a mean time reducing from 11.55 ± 0.72 s to 10.98 ± 0.69 s (Δ = 0.57 s, 4.9%); $t(29) = 3.87$, $p = 0.002$, $d = 0.71$ (medium effect size). The Zig-zag Test also showed improved performance, with the mean time reducing from 8.30 ± 0.53 s to 7.92 ± 0.50 s (Δ = 0.38 s, 4.6%); $t(29) = 3.45$, $p = 0.003$, $d = 0.63$ (medium effect size). The Illinois Agility Test showed the largest improvement in magnitude, with mean times reducing from 20.80 ± 0.98 s to 19.95 ± 0.94 s (Δ = 0.85 s, 4.1%)

3.2 Lower-Body Explosive Power

In contrast to the significant enhancements observed in sprint and agility performance, the three vertical jump measures did not exhibit any statistically significant improvements following the intervention. Countermovement Jump height increased marginally from 24.40 ± 3.2 cm to 24.95 ± 3.4 cm (Δ = 0.55 cm, 2.3%); $t(29) = 1.21$, $p = 0.234$, $d = 0.22$ (small effect).

Countermovement Jump with Arm Swing rose from 27.60 ± 3.5 cm to 28.20 ± 3.7 cm (Δ = 0.60 cm, 2.2%); $t(29) = 1.38$, $p = 0.178$, $d = 0.25$ (small effect). Squat Jump exhibited minimal change, increasing from 23.80 ± 3.0 cm to 24.10 ± 3.2 cm (Δ = 0.30 cm, 1.3%); $t(29) = 0.94$, $p = 0.354$, $d = 0.17$ (small effect).

Table 2. Descriptive Statistics and Pre-Post Comparisons of Motor Abilities

Variable	Pre-test Mean	Post-test Mean	t(29) value	Kolmogorov–Smirnov Test	p-value	Cohen's d
50 m Dash (s)	10.22	9.81	4.12	0.118 (NS)	0.001*	0.75
Three Cones Test (s)	11.55	10.98	3.87	0.104	0.002*	0.71
Zig-zag Test (s)	8.30	7.92	3.45	0.121	0.003*	0.63
Illinois Agility Test (s)	20.80	19.95	4.26	0.109	0.001*	0.78
Countermovement Jump (cm)	24.40	24.95	1.21	0.132	0.234	0.22
CMJ with Arm Swing (cm)	27.60	28.20	1.38	0.126	0.178	0.25
Squat Jump (cm)	23.80	24.10	0.94	0.140	0.354	0.17

Note: K-S = Kolmogorov–Smirnov test of normality for difference scores; $p < 0.05$; effect size interpretation: d = 0.20–0.49 (small), 0.50–0.79 (medium), ≥0.80 (large).

Taken together, these findings suggest that the 12-week intervention led to practical, statistically significant results in linear sprint performance and multidirectional agility, as evidenced by the consistent presence of moderate to large effect sizes. In contrast, the training protocol resulted in trivial changes in vertical jump ability, as evidenced by effect sizes that were below the threshold level for small practical significance.

4. Discussion

The present study demonstrated significant improvements in sprint and agility performance following the 12-week structured training protocol, whereas vertical jump performance did not show statistically significant enhancement. While the positive adaptations in sprint and change-of-direction ability are consistent with contemporary neuromuscular training literature, further interpretation is warranted regarding the non-significant jump outcomes.

The improvements in sprint and agility are likely attributable to enhanced horizontal force production and intermuscular coordination. Recent evidence suggests that acceleration performance is predominantly influenced by the athlete's ability to apply horizontal ground reaction forces effectively (Morin *et al.,* 2015). Structured speed and agility training has been shown to enhance rate of force development and motor unit recruitment patterns, particularly in female team-sport athletes (Ramirez-Campillo *et al.,* 2022). Furthermore, multidirectional drills may improve neuromechanical efficiency and braking–propulsive transitions, thereby enhancing agility performance (Jarosław Domaradzki *et al.,* 2021). The present findings therefore align with contemporary research emphasizing the efficacy of targeted SAQ-based protocols in improving linear and multidirectional speed.

In contrast, the absence of significant improvements in vertical jump performance may be explained by the principle of force-vector specificity. According to the force-vector theory, training adaptations are direction-specific; exercises emphasizing horizontal force application preferentially improve sprint acceleration, whereas vertically oriented exercises (e.g., plyometrics, loaded jumps) are more strongly associated with improvements in vertical jump height (Morin & Samozino, 2016). The current training protocol primarily emphasized horizontal acceleration and change-of-direction drills, which may not have provided sufficient vertical loading stimulus to elicit substantial improvements in countermovement jump performance.

Additionally, neuromuscular adaptation timelines may have influenced the jump results. Improvements in sprint and agility can occur relatively early through neural adaptations such as improved motor coordination and firing frequency. However, significant increases in vertical power often require longer durations or higher-intensity plyometric stimuli to enhance musculotendinous stiffness and stretch–shortening cycle efficiency (Cormie *et al.,* 2021; Markovic & Mikulic, 2023). Therefore, the 12-week intervention may have been sufficient for neuromotor refinements affecting speed but insufficient for structural adaptations required to meaningfully elevate jump height.

Several limitations should be acknowledged. The absence of a control group restricts causal inference, as external training exposure or seasonal adaptation cannot be entirely excluded. Moreover, although participants were female collegiate athletes, more detailed sport-specific stratification would enhance generalizability and allow examination of sport-dependent responsiveness to training.

Future research should incorporate randomized controlled designs to strengthen internal validity. Comparative studies across different sport types (e.g., volleyball, athletics, and team invasion sports) are recommended to determine whether training responsiveness varies according to sport-specific demands. Additionally, integrating structured plyometric components or vertically oriented resistance exercises may clarify whether combining horizontal and vertical force stimuli produces broader motor performance adaptations. Long-term follow-up assessments extending beyond 12 weeks would also help determine whether vertical power adaptations emerge with prolonged exposure. Finally, incorporating biomechanical profiling methods, such as force–velocity analysis, could provide deeper insight into the mechanistic basis of adaptation in female athletes. The structured training protocol effectively enhanced sprint and agility performance in female collegiate athletes. However, the specificity of force application and neuromuscular adaptation timelines likely explain the absence of significant vertical jump improvements. Future controlled and longitudinal investigations incorporating plyometric elements and sport-specific comparisons are necessary to optimize motor development strategies in female athletic populations.

5. Conclusion

This study shows that female collegiate cricket players' linear sprint performance and multidirectional agility are greatly improved by a 12-week organized training program that includes progressive strength training, aerobic conditioning, and speed-agility-quickness drills. Effect sizes ranging from moderate to large suggest significant real-world gains in motor skills associated with speed. However, as a consequence of the force-vector specificity, small plyometric volume, and a short training period, the intervention did not considerably increase lower-body explosive power. Despite methodological limitations, including the absence of a control group, the findings provide preliminary evidence supporting targeted neuromuscular training for improving sport-specific performance in Indian female collegiate athletes. Future randomized controlled trials with larger samples are warranted.

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Acknowledgments

The authors sincerely thank all participants and research assistants for their cooperation and contribution to the successful completion of the study.

Ethics Approval and Consent to Participate

The study protocol was approved by The University of Burdwan Institutional Ethics Committee (IEC/BU/2025/9) on 15 January 2025, and all procedures conformed to the ethical standards of the Declaration of Helsinki. Written informed consent was obtained from all participants prior to enrollment; for participants under 18 years of age, additional written consent was obtained from a parent or legal guardian.

Funding Source

This study received no external funding.

Author Contribution Statement

All the authors equally contributed and approved the final version of the work.

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