

# Effects of an eight-week neuromuscular training program on performance variables in female university football players

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## Abstract

**Background and Study Aim** Football performance depends on the integration of speed, strength, agility, and balance, all of which contribute to efficient movement and injury prevention. Neuromuscular training (NMT) is widely used to improve these attributes by combining strength, plyometric, balance, and coordination exercises within a structured program. Although various training methods are applied in football conditioning, their relative effectiveness in enhancing multiple performance domains simultaneously remains a matter of practical interest. The aim of this study was to examine the effects of an eight-week NMT program on sprint performance, explosive power, change-of-direction (COD) ability, and dynamic balance in female university football players.

**Material and Methods** A total of 41 athletes were initially screened. Thirty-four athletes aged 20–24 years met the inclusion criteria and were randomly assigned to either an experimental group (EXP,  $n = 17$ ) or a control group (CON,  $n = 17$ ). The EXP group completed structured NMT sessions three times per week alongside regular football training. The CON group continued standard practice without additional training. Pre- and post-intervention tests included the 50-m sprint, standing broad jump, 505 COD test, and Y-Balance Test. Statistical analyses included paired t-tests, ANCOVA, and repeated measures ANOVA. Effect sizes were calculated using Cohen's  $d_z$  and partial eta squared.

**Results** The EXP group showed significant within-group improvements across all outcomes ( $p < .001$ , Cohen's  $d_z = 1.07–1.24$ ). The CON group demonstrated no meaningful changes. Between-group comparisons showed significant differences for all performance variables (all  $p < .01$ ), with large effect sizes ( $\eta^2 p = 0.28–0.35$ ). Correlation analysis revealed strong associations between improvements in dynamic balance, COD, and sprint performance ( $r = -0.56$  to  $+0.62$ ,  $p < .01$ ). Sensitivity analyses confirmed that the findings remained robust after excluding low adherence and outlier cases.

**Conclusions** An eight-week NMT program led to significant improvements in speed, power, agility, and balance among female university football players. The results highlight the effectiveness of integrated neuromuscular interventions in enhancing multidimensional performance characteristics in this population.

**Keywords:** physical education, sports performance, agility training, dynamic balance, plyometric exercise, women's football.

## Introduction

Football continues to evolve as a physically demanding and tactically complex sport, requiring players to cope with frequent, high-speed movements in multiple directions. Sprinting, cutting, jumping, and sudden changes in pace occur repeatedly throughout a match, alternating with brief periods of lower activity [1, 2]. To perform effectively, athletes must develop physical qualities that support efficient movement and reduce fatigue during play. Speed, power, agility, directional control,

and balance all contribute directly to performance outcomes and help reduce the likelihood of injury [3, 4].

Neuromuscular training (NMT) offers a structured way to improve multiple physical capacities by combining strength exercises with plyometrics, balance work, agility drills, and sprint tasks. Unlike isolated methods that focus on a single skill, NMT develops coordination between different movement systems to improve performance and reduce injury risk [5, 6]. It targets neural processes such as motor-unit recruitment, reflex control, and movement coordination, which are especially important for explosive and reactive actions in football [7, 8]. Even short training periods can lead to measurable gains

in power, sprinting form, directional speed, and balance control [9–11]. In recent years, NMT has received more attention in women’s football due to its practical value in improving movement and lowering injury risk. For example, Roso-Moliner et al. (2023) reported that a 10-week program improved sprinting, agility, and jumping performance, while also reducing side-to-side differences in lower limbs among female players [12].

Female athletes represent a group in which neuromuscular factors have specific practical importance. Studies show that women may be more prone to certain movement-related injuries, including anterior cruciate ligament (ACL) rupture. This is partly linked to differences in landing technique, joint stability, and neuromuscular control [13, 14]. Programs that improve postural control, balance, and muscle response to sudden forces are therefore especially relevant for this population. Although more women are now involved in football, most training research still focuses on male athletes [15, 16]. Shifting attention to female players helps strengthen both applied practice and the evidence base in sports science.

One of the main advantages of neuromuscular training (NMT) is that it targets several aspects of athletic performance at the same time. In contrast, traditional training often focuses on a single capacity. For example, resistance training is used to build strength, and sprint drills are applied to improve speed. However, these approaches may overlook the coordination required for effective multidirectional movements. Research indicates that NMT can lead to broader improvements by combining explosive exercises with tasks that challenge balance and movement control [17]. Plyometric exercises support the stretch-shortening cycle and improve reactive strength. Sprint drills develop both horizontal and vertical force production. COD training builds braking ability and re-acceleration. Balance tasks improve sensorimotor control. These components work together to build a movement base that supports performance and may help reduce injury risk [18, 19].

Sprint performance is an important element in football. Players often cover short bursts of high-speed running to gain position or reach the ball ahead of an opponent [20, 21]. Improving this ability depends not only on muscle power but also on neuromechanical control. Specifically, athletes must direct force horizontally and reduce braking during ground contact. Neuromuscular training (NMT) targets these qualities through resisted sprints, bounding exercises, and sprint technique drills. These methods have been associated with improvements in acceleration and maximum speed [22, 23].

Explosive power is also essential. It is often assessed through jumping tests and contributes to

both sprinting and aerial actions. Studies report that the plyometric elements of NMT improve vertical and horizontal jump performance. This is achieved by increasing stretch-shortening cycle (SSC) efficiency and tendon stiffness [24, 25].

Change-of-direction (COD) ability depends on eccentric braking strength, control of the trunk and pelvis, and quick transitions from stopping to starting again [26, 27]. COD drills used in neuromuscular training (NMT) help athletes develop these skills. Dynamic balance, although sometimes overlooked, also contributes to movement efficiency and injury prevention. Training that includes core and balance exercises has been shown to improve postural stability [28, 29, 30].

Research shows that neuromuscular programs combining different types of exercises can lead to gains in sprinting, agility, balance, and jump performance. These effects have been observed in athletes across a wide age range [31, 32, 33]. However, female university players are still studied less often than youth or elite professionals [15, 16].

Analysis of research findings has shown that neuromuscular training (NMT) improves several components of athletic performance, including sprinting, agility, jumping, and balance. Researchers emphasize that these adaptations are particularly important in sports requiring rapid, multidirectional actions such as football. Authors also highlight the role of structured and integrative programs that combine strength, coordination, and control-oriented exercises. Although NMT has been widely studied among youth and mixed athlete groups, comparatively fewer investigations have focused on female university players. Existing studies confirm that neuromuscular interventions enhance speed, agility, balance, and jump performance across age categories [31, 32, 33]. However, questions remain about how female athletes respond to different training loads, progressions, and program designs within football contexts. This ongoing uncertainty limits the practical use of targeted interventions in university-level settings, where female athletes train intensively but often lack the professional support available to elite players. To explore this issue, the present study examined the effects of an eight-week NMT program on sprint performance, explosive power, change-of-direction ability, and dynamic balance in female university football players.

## Materials and Methods

### *Participants of the Study*

Forty-one female athletes initially volunteered to participate in the study. Seven were excluded due to medical conditions that made participation unsafe. The final sample consisted of thirty-four university-level female football players aged 20 to 24 years

(mean  $\pm$  SD = 21.8  $\pm$  1.3 years). All participants had at least three years of structured training experience and were actively involved in competitive university football. Demographic and baseline characteristics of the participants are summarized in Table 1.

**Table 1.** Demographic characteristics of participants (n = 34)

Variable	Experimental Group (n = 17)	Control Group (n = 17)	p-value
Age (years)	21.7 $\pm$ 1.4	21.9 $\pm$ 1.2	.68
Height (cm)	162.8 $\pm$ 5.7	163.5 $\pm$ 6.1	.74
Body mass (kg)	58.2 $\pm$ 6.4	57.6 $\pm$ 6.1	.82
Playing experience (years)	5.4 $\pm$ 1.2	5.3 $\pm$ 1.1	.79

Note. Values are presented as mean  $\pm$  standard deviation. Independent samples t-tests showed no significant differences between groups (all  $p > .05$ ), indicating that baseline characteristics were comparable.

Athletes were recruited from local university sports programs and agreed to take part voluntarily after receiving detailed information about the study procedures. Inclusion criteria required participants to be in good health, free of injury during the previous six months, and not involved in any additional structured resistance or plyometric training. Exclusion criteria included recent musculoskeletal injury, neurological disorders, or absence from more than 10 percent of scheduled sessions.

Participants were randomly assigned to either an experimental group (EXP, n = 17), which completed the neuromuscular training program, or a control group (CON, n = 17), which continued regular football training without any additional intervention. Randomization was performed using a computerized random number generator.

All participants provided written informed consent prior to the start of the study. Ethical approval was obtained from the Institutional Human Ethics Committee and the procedures followed the principles outlined in the Declaration of Helsinki.

The recruitment, allocation, and follow-up process for all participants is outlined in the CONSORT flow diagram. This includes the number of athletes assessed for eligibility, reasons for exclusion, and group assignment, as well as adherence and retention throughout the study. An overview of the participant flow is shown in Figure 1.

#### Procedures

##### Intervention Design

This study used a randomized controlled trial (RCT) design with pre- and post-test assessments

conducted over an 8-week period. Thirty-four female football players were randomly assigned to either an experimental group (EXP, n = 17), which completed an additional neuromuscular training (NMT) program, or a control group (CON, n = 17), which continued with regular football training.

Performance tests were conducted at baseline and after the intervention. These included the 50-meter sprint, standing broad jump, 505 change-of-direction (COD) test, and the Y-Balance Test. All testing was carried out under standardized conditions.

EXP group training sessions were held three times per week (75 minutes per session on Monday, Wednesday, and Friday). Each session followed a structured format that included a warm-up, a progressive neuromuscular training block, and a cool-down. The program was delivered either on the university football field or in an indoor hall, depending on weather conditions. All sessions were supervised by certified strength and conditioning specialists, maintaining a coach-to-athlete ratio of 1:8.

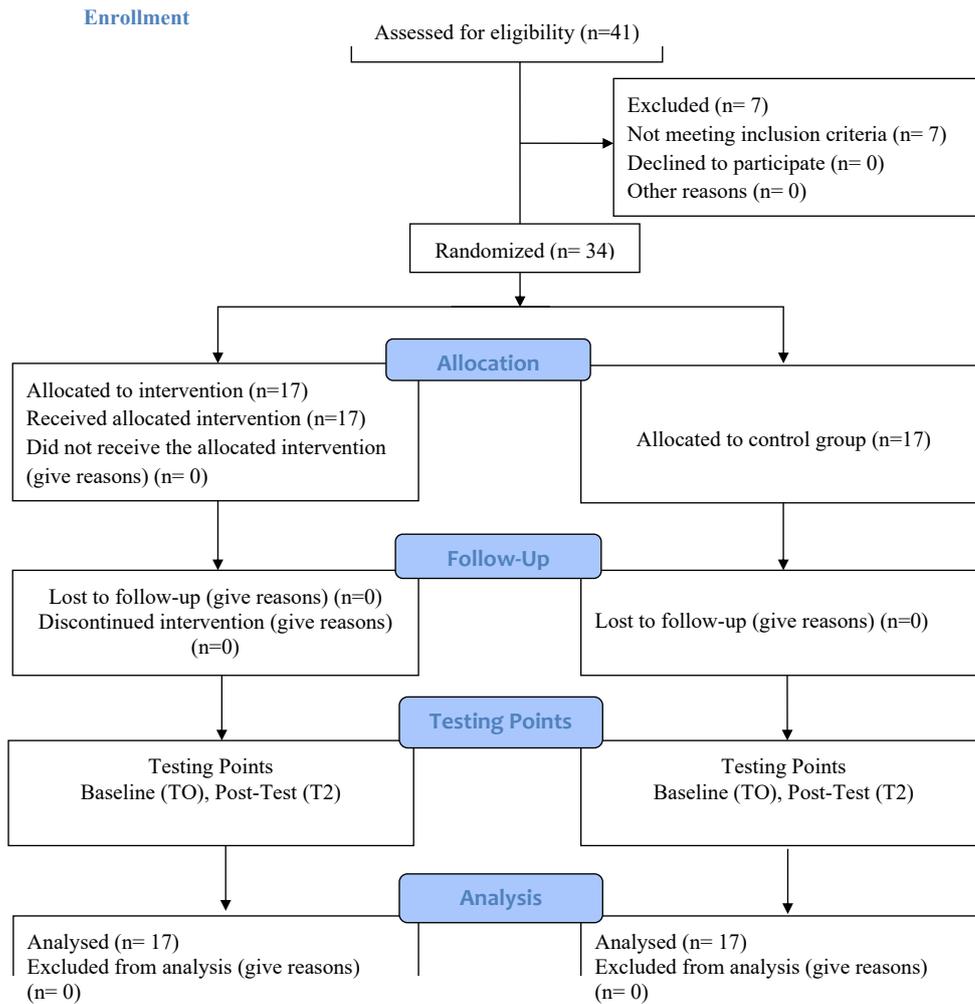
Training intensity progressed over time. In weeks 1 to 2, intensity was set at 40 to 50 percent of maximum effort and increased to 70 to 80 percent by weeks 7 to 8. Sets, repetitions, and rest intervals were controlled and adjusted according to progression (Table 2).

The intervention included football-specific drills, such as sprint technique work, plyometric exercises, COD tasks, and balance activities. These components are directly related to functional demands in football. Importantly, the NMT program was integrated into the athletes' existing football training routines. This approach ensured ecological validity by reflecting real-world competitive training conditions.

The CON group continued with regular football training and did not receive any additional neuromuscular input. Both groups were instructed to maintain their usual dietary habits and daily routines throughout the study period.

##### Training fidelity and intensity monitoring:

To ensure reproducibility, session fidelity was monitored through attendance logs and coach supervision checklists. Exercise intensity was prescribed using the Borg CR-10 Rate of To support reproducibility, training fidelity was monitored using attendance logs and weekly coach supervision checklists. Exercise intensity was regulated with the Borg CR-10 Rate of Perceived Exertion (RPE) scale, progressing from RPE 4 to 8 (light to very hard). For resisted sprints, the load was set at approximately 10 percent of each athlete's body mass. Plyometric drills were performed with ground contact times kept below 0.25 seconds. Coaches monitored adherence weekly, and average session compliance exceeded 90 percent.



**Figure 1.** CONSORT flow diagram of participants

The control group maintained their standard football schedule, which included 3 to 4 weekly team sessions lasting 90 to 100 minutes. These sessions consisted of tactical drills, small-sided games, and aerobic conditioning. However, no structured plyometric or neuromuscular elements were included. Training loads for both groups were tracked using the session-RPE method ( $RPE \times duration$ ) to confirm comparability of total workload exposure.

The training protocol shown in Table 2 followed a three-phase format: warm-up, main neuromuscular block, and cool-down. Intensity and complexity increased progressively across the eight weeks. Exercise intensity was prescribed using the Borg CR-10 RPE scale, beginning with RPE 4–5 in weeks 1–2 and reaching RPE 7–8 in weeks 7–8. Load progression was tailored using supervised feedback and individual monitoring. Athlete adherence exceeded 90 percent, verified through attendance records, coach oversight, and weekly video reviews. Rest intervals were standardized and enforced by coaching staff. The control group maintained regular football training of similar volume and duration but without any additional neuromuscular elements.

Four outcome variables were assessed in this study:

1. *Sprint Speed.* Measured using the 50-meter dash test. Time was recorded to the nearest 0.01 seconds using electronic timing gates (Brower Timing Systems, Draper, UT, USA) [34].
2. *Explosive Power.* Assessed with the Standing Broad Jump (SBJ) test. Distance (in meters) was measured from the take-off line to the nearest point of heel contact using a calibrated measuring tape [35].
3. *Change-of-Direction (COD) Speed.* Evaluated using the 505 COD test. Timing gates were placed at 5 and 10 meters. Athletes completed two trials per leg, and the best time was used for analysis [36].
4. *Dynamic Balance.* Measured using the Y-Balance Test – Lower Quarter (YBT-LQ). Reach distances (in centimeters) were recorded in the anterior, posteromedial, and posterolateral directions. Scores were normalized to leg length, and a composite score was calculated [37].

All tests used in the study have demonstrated acceptable reliability in previous research

**Table 2.** Eight-Week Neuromuscular Training Protocol for the Experimental Group

Week	Frequency & Session Length	Structure	Key Exercises	Sets × Reps	Intensity Prescription	Rest
1–2	3 sessions/week (Mon, Wed, Fri); 75 min	Warm-up (15 min): light jogging, mobility, dynamic stretching. Main block (50 min): introductory plyometrics, sprint mechanics, balance and core control drills. Cool-down (10 min): static stretching, breathing.	Squat jumps, lateral bounds, front planks, Y-balance reach	2 × 8	RPE 4–5 (≈ 50% max effort)	45 s
3–4	3 sessions/week; 75 min	Progressive overload phase I with horizontal propulsion and short sprints.	Box jumps, resisted sprints (10–20 m, 10% body mass), single-leg hops, shuttle runs	3 × 10	RPE 5–6 (≈ 60% max), moderate velocity	60 s
5–6	3 sessions/week; 75 min	Progressive overload phase II with increased volume and eccentric focus.	Depth jumps (0.45 m), 30 m sprints, 505 COD drills, unstable-surface balance tasks	4 × 12	RPE 6–7 (≈ 70% max), contact time < 0.25 s	75 s
7–8	3 sessions/week; 75 min	Performance integration with reactive stimuli and ball drills.	Bounding, repeated sprints (10–40 m), advanced COD with ball, single-leg box jumps (0.3 m)	5 × 14	RPE 7–8 (≈ 80% max), near-max velocity	90 s

Note. RPE = Borg CR-10 Rate of Perceived Exertion; COD = change-of-direction; s = seconds; m = meters.

(intraclass correlation coefficient, ICC = 0.80–0.95). A familiarization session was conducted one week prior to baseline testing to minimize learning effects.

#### Statistical Analysis

All analyses were performed using IBM SPSS Statistics (Version 26). Data normality was assessed with the Shapiro–Wilk test. Descriptive statistics are reported as mean ± standard deviation for all variables. Within-group (pre-to-post) changes were evaluated using paired-samples t-tests. Between-group differences were analysed using analysis of covariance (ANCOVA), with baseline values included as covariates. Effect sizes were calculated as Cohen’s *d* for within-group comparisons and Hedges’ *g* (with correction for small sample size) for between-group comparisons. Ninety-five percent confidence intervals (95% CIs) were reported for all mean changes and group differences. Two sensitivity analyses were performed: (a) excluding participants with adherence below 90 percent, and (b) removing extreme outliers defined as values more than three standard deviations from the group mean. In both cases, the results remained consistent with the main findings. Statistical significance was set at  $p < .05$ .

## Results

All 34 participants completed the 8-week intervention, and full datasets were available for analysis. No adverse events were reported during

the study. At baseline, the experimental and control groups were statistically comparable in terms of age, body mass, height, and training experience (all  $p > .05$ ; Table 1). Attendance in the experimental group was high, with participants completing over 90 percent of the scheduled training sessions. Normality testing confirmed that all variables were normally distributed, allowing the use of parametric statistical procedures. The intervention led to marked improvements across all performance outcomes in the experimental group. In contrast, only minimal changes were observed in the control group.

Results of the Shapiro–Wilk test (all  $p > .05$ ) indicated no significant departures from normality, confirming that parametric analyses were appropriate for all variables presented in Table 3.

The effects of the 8-week intervention within each group are summarized in Table 4, which presents pre- and post-test means, *t*-values, *p*-values, effect sizes, and confidence intervals for all performance variables.

The results presented in Table 4 show that the experimental group achieved statistically significant improvements across all performance outcomes following the 8-week neuromuscular training program ( $p < .001$  for all tests). The largest gains were observed in sprint time and standing broad jump distance, both showing large effect sizes ( $dz > 1.15$ ), indicating substantial enhancement in linear speed and explosive power. Similarly, change-of-

**Table 3.** Shapiro-Wilk normality test results for study variables (n = 34)

Variable	Group	Pre-test (p-value)	Post-test (p-value)
50-m Sprint (s)	Experimental	0.231	0.188
	Control	0.274	0.301
Standing Broad Jump (m)	Experimental	0.162	0.205
	Control	0.243	0.198
505 COD Test (s)	Experimental	0.211	0.174
	Control	0.229	0.256
Y-Balance Composite (%)	Experimental	0.184	0.193
	Control	0.209	0.247

**Table 4.** Within-group Pre–Post Changes (Paired t-tests, Cohen’s dz, 95% CI)

Variable	Group	Pre-test (M ± SD)	Post-test (M ± SD)	t(16)	p-value	Cohen’s dz	95% CI for Δ
50-m Sprint (s)	Experimental	7.42 ± 0.41	7.02 ± 0.38	5.12	<.001	1.24	[-0.54, -0.28]
	Control	7.45 ± 0.39	7.41 ± 0.42	1.02	.319	0.24	[-0.11, 0.04]
Standing Broad Jump (m)	Experimental	1.92 ± 0.18	2.07 ± 0.16	4.88	<.001	1.18	[0.09, 0.21]
	Control	1.93 ± 0.17	1.94 ± 0.18	0.58	.571	0.14	[-0.02, 0.05]
505 COD Test (s)	Experimental	2.48 ± 0.12	2.34 ± 0.11	4.39	<.001	1.07	[-0.20, -0.07]
	Control	2.47 ± 0.13	2.46 ± 0.12	0.41	.687	0.10	[-0.04, 0.03]
Y-Balance Composite (%)	Experimental	93.4 ± 3.2	97.8 ± 2.9	4.62	<.001	1.12	[2.1, 6.7]
	Control	93.6 ± 3.3	93.9 ± 3.5	0.77	.450	0.19	[-0.5, 1.1]

Note. Within-group effect sizes in the experimental group ranged from dz = 1.07 to 1.24, indicating large and practically meaningful improvements across all tested variables.

**Table 5.** ANCOVA Results with Partial Eta Squared

Variable	F-value	p-value	Partial η <sup>2</sup>
50-m Sprint	14.62	0.001	0.35
Standing Broad Jump	12.35	0.002	0.32
505 COD Test	10.87	0.003	0.29
Y-Balance Composite	11.24	0.002	0.30

Note. ANCOVA revealed significant between-group differences for all performance outcomes ( $F = 10.87–14.62$ ,  $p < .01$ ), with large effect sizes (partial  $\eta^2 = 0.29–0.35$ ), indicating that the experimental group demonstrated greater improvements than the control group after adjusting for baseline values.

direction speed and dynamic balance also improved significantly, reflecting enhanced neuromuscular control. In contrast, the control group did not exhibit statistically significant changes in any of the measured variables ( $p > .05$ ), suggesting that regular football training alone was insufficient to elicit comparable adaptations over the same period.

The results of the ANCOVA analysis, which compared post-intervention outcomes between

groups while adjusting for baseline values, are summarized in Table 5. As shown in Table 5, the experimental group achieved significantly better post-intervention results across all measured domains compared to the control group. These differences remained significant after adjusting for pre-test scores, confirming the specific effect of the neuromuscular training program. The largest between-group differences were observed in sprint

performance and standing broad jump, with partial eta squared values exceeding 0.30, indicating large effects. Overall, the data support the conclusion that structured neuromuscular training provided superior benefits compared to routine football practice alone.

The results of the repeated measures ANOVA, testing for Group  $\times$  Time interaction effects across performance outcomes, are summarized in Table 6. As shown in Table 6, repeated measures ANOVA revealed significant Group  $\times$  Time interactions for all performance variables. These findings indicate that the pattern of change over the 8-week period differed substantially between the experimental and control groups. The most pronounced interaction effects were found for sprint speed and standing broad jump, where performance gains in the experimental group were not matched by the control group. Partial eta squared values ranging from 0.28 to 0.34 reflect large effect sizes, reinforcing the conclusion that the neuromuscular training program was responsible for the observed improvements.

Relationships between relative improvements in performance outcomes were examined using Pearson correlation coefficients. The results are presented in Table 7. As shown in Table 7, moderate to large correlations were found between improvements in balance, sprint speed, COD ability, and explosive power. Notably, participants who improved most in dynamic balance also tended to demonstrate faster sprint and COD times. Similarly, gains in jump performance were associated with sprint acceleration. These relationships suggest that different neuromuscular components may develop

in parallel when exposed to integrative training stimuli, supporting the interconnected nature of adaptation within complex athletic tasks.

Sensitivity analyses confirmed the robustness of the findings. Excluding participants with adherence below 90 percent or removing statistical outliers (greater than 3 standard deviations from the group mean) did not alter the overall outcomes. All ANCOVA and repeated measures ANOVA results remained statistically significant ( $p < .01$ ), with large within-group effect sizes (*Cohen's dz* = 1.07–1.24) maintained across all performance variables.

## Discussions

This randomized controlled trial investigated whether an eight-week neuromuscular training (NMT) program could improve key physical performance qualities in female university football players. The intervention combined plyometric exercises, sprint mechanics, change-of-direction (COD) drills, and balance components. The findings show that athletes in the experimental group achieved consistent and statistically significant improvements across all measured domains. These gains were observed in comparison to peers who continued standard football practice. The differences were confirmed through both within-group analyses and baseline-adjusted between-group comparisons. The results support previous evidence that integrated neuromuscular protocols promote rapid improvements across multiple physical capacities in trained populations [11, 17, 38].

Neuromuscular training (NMT) is best understood as a combined stimulus rather than a single training modality. It integrates motor

**Table 6.** Repeated Measures ANOVA (Group  $\times$  Time Interaction)

Variable	F (Group $\times$ Time)	p-value	Partial $\eta^2$
50-m Sprint	13.48	0.001	0.34
Standing Broad Jump	11.92	0.002	0.31
505 COD Test	9.88	0.004	0.28
Y-Balance Composite	10.15	0.003	0.29

Note. Significant Group  $\times$  Time interaction effects ( $p < .01$ ) were observed across all performance variables, indicating that changes over time differed significantly between groups. Large interaction effect sizes (partial  $\eta^2$  = 0.28–0.34) support the differential impact of the intervention.

**Table 7.** Correlation Analysis Between Improvements (%)

Variable Pair	r-value	p-value	Interpretation
% Y-Balance vs. $\Delta\%$ 505 COD Test	-0.56	0.002	Large, inverse
% Y-Balance vs. $\Delta\%$ 50-m Sprint	-0.48	0.006	Moderate, inverse
% 505 COD Test vs. $\Delta\%$ 50-m Sprint	+0.62	<0.001	Large, positive
% Standing Broad Jump vs. $\Delta\%$ 50-m Sprint	-0.44	0.011	Moderate, inverse

Note. Negative correlations indicate that greater improvements in balance and jump performance corresponded to faster (i.e. lower) sprint and COD times. Effect sizes ranged from moderate to large ( $|r|$  = 0.44–0.62, all  $p \leq .011$ ), suggesting meaningful interdependence between neuromuscular adaptations within the NMT program.

control, stretch-shortening cycle (SSC) function, strength and power expression, and movement skills within the same training mesocycle. Systematic reviews and meta-analyses have shown that, when properly progressed and supervised, this integrative approach produces improvements in speed, jump performance, change-of-direction (COD) ability, dynamic balance, and landing mechanics across athletic populations, including female athletes in field sports [5, 15, 31, 39, 40]. During interventions lasting six to ten weeks, early adaptations are typically driven by neural mechanisms. These include enhanced motor-unit recruitment, faster rate coding, improved inter- and intramuscular coordination, and increased pre-activation [8, 24, 38, 40, 41]. With longer exposure, structural adaptations become more pronounced. The present findings were obtained after eight weeks of training with coach supervision and progressive overload. They are consistent with this adaptation timeline and suggest that a single well-designed program can influence several physical capacities simultaneously [6, 11, 17, 39]. These outcomes also support previous studies in women's football. For instance, Roso-Moliner et al. reported improvements in sprinting and change-of-direction ability, along with reduced asymmetries, following a ten-week neuromuscular training program. These findings are comparable to the gains observed in the current study [12].

Linear sprint performance depends on both neuromuscular and technical factors. These include a stiffer leg spring during ground contact, precise orientation of horizontal and vertical force, coordinated extension at the hip, knee, and ankle joints, and reduced braking impulse during stance [3, 21, 42]. Interventions that combine plyometric training with resisted sprints or acceleration drills often lead to improvements in short-distance sprint ability among athletes in field sports [15, 22, 24, 43, 44]. The changes observed in the present study are consistent with those findings. These improvements can be explained by mechanisms such as enhanced musculotendinous stiffness, improved limb coordination, and shorter ground-contact time. Such adaptations can occur without significant changes in body mass over an eight-week period [7, 8, 25, 40, 41]. Importantly, studies involving female athletes have shown similar relative improvements when training intensity and supervision are scaled appropriately. This suggests that female sex alone is not a limiting factor for neuromuscular adaptation in sprint performance [6, 15, 16, 39].

Standing broad jump performance reflects the efficiency of the stretch-shortening cycle (SSC), the quality of eccentric–concentric coupling, and the coordination of movement from proximal to distal segments. Meta-analyses have shown that

plyometric training improves jump outcomes when exercise progression is applied, landing mechanics are coached, and training volume is adapted to the athlete's experience [24, 43, 44]. In football and similar field sports, exercises such as unilateral hops, bounds, and depth-jump variations are closely related to horizontal propulsion and early-phase acceleration tasks [15, 16, 22, 45]. The improvements observed in this study align with those findings. The current results likely reflect the use of progressively loaded SSC-based exercises that involved both unilateral and bilateral actions. These outcomes are also supported by reports linking improved neuromuscular efficiency to better elastic energy utilization during the amortization phase [7, 8, 40, 41]. Additionally, studies on musculotendinous properties suggest that repeated SSC exposure increases tendon and aponeurotic stiffness *in vivo*. This adaptation enhances force transmission speed and contributes to the observed jump gains over mesocycle training periods [25].

Change-of-direction (COD) ability depends on more than just linear power. It is influenced by braking strength, the direction of force applied through the plant leg, trunk and pelvic stability, and the timing of re-acceleration [1, 2, 4]. COD is distinct from agility, which involves perceptual and decision-making demands. However, both are affected by neuromuscular qualities such as eccentric strength, coordination, and rate of force development [2, 26, 31, 41]. Previous studies show that plyometric and combined-method training programs can improve COD performance. These programs often include unilateral or lateral movements, as well as exercises targeting deceleration control. When delivered for six to ten weeks with proper progression and feedback, such interventions typically produce small to moderate improvements [22, 31, 33]. In the present study, the reduction in COD times following NMT is consistent with these results. Targeted drills may have improved braking mechanics, reduced knee valgus, and supported better trunk alignment. These changes allow for an earlier and more forceful push-off during the plant phase [1, 4, 26]. The inclusion of 505 drills and shuttle-run variations in the later weeks of training likely supported these adaptations through task-specific practice [4, 22, 33].

Dynamic balance improved together with speed and power in this study. Y-Balance Test and similar reach-based assessments are sensitive to changes following interventions that include balance training, proprioceptive stimulation, core stabilization, and lower-limb control. These tests demonstrate acceptable reliability when standardized procedures are followed [29, 30]. Programs that combine neuromuscular and balance-specific elements have been linked to improvements in postural control and movement coordination

across both athletic and general populations [6, 11, 28]. In football players at the youth and university levels, similar neuromuscular interventions have led to parallel gains in balance and jump performance within comparable time frames [10, 11]. The structure of the present program included repeated exposure to single-leg hops, unstable-surface drills, and trunk stabilization tasks. These activities likely contributed to improvements in sensorimotor processing, anticipatory postural responses, and regulation of dynamic stiffness in lower-limb joints [13, 28, 30].

Performance variables such as sprinting, jumping, balance, and change-of-direction (COD) often improve together. These qualities share underlying neuromechanical factors, including motor-unit behavior, musculotendinous stiffness, coordination between body segments, and trunk and pelvic control [7, 8, 38, 41]. Research shows that unilateral balance and trunk stability can predict cutting performance beyond simple strength indicators. Similarly, improvements in COD and short sprint performance often occur together when training targets braking technique and horizontal force application [1, 4, 21, 42]. In this study, stronger gains in balance were associated with better COD and sprint outcomes. This pattern supports the idea that postural control contributes to efficient deceleration and re-acceleration during directional changes [1, 4, 26, 29]. Female athletes have often been underrepresented in strength and power intervention studies. However, current evidence suggests that when training is scaled and supervised appropriately, women show comparable relative improvements [1, 6, 15, 39]. Neuromuscular characteristics that differ by sex, such as frontal-plane control during landings and directional cuts, can be improved through targeted NMT. These changes are reflected in movement quality and markers linked to injury risk within standard training cycles [13, 46]. In women's football, programs that combine plyometrics with sprint and balance work have led to improvements in multiple areas. These include speed, jumping, balance, and COD ability, provided that progression and technical feedback are maintained throughout. The present results are consistent with these findings [15, 16].

This study has several strengths that support the interpretation of its findings. Participants were randomly assigned to groups using concealed sequence generation, which helped reduce selection bias. Testing procedures were matched by time of day, and assessors were blinded to group allocation. These steps helped limit measurement error and increase objectivity in test outcomes [47]. A familiarization session was conducted before baseline testing. This reduced the risk of learning effects in field-based measures that are known to be

sensitive to repeated exposure [48]. The statistical approach followed current guidelines. Data were tested for normality, and both within-group and between-group changes were analyzed. Effect sizes were reported using standardized metrics. These practices are recommended in studies evaluating training interventions [49, 50]. The use of multiple outcome variables such as sprint speed, jumping, change-of-direction, and dynamic balance allowed a more comprehensive assessment of neuromuscular adaptations. Relying on diverse indicators reduces the risk of overinterpreting isolated effects [6, 8, 38]. Finally, correlation analyses were used to examine the relationships between improvements in different domains. This helped clarify how motor qualities may develop together under an integrated training stimulus [2, 4, 26].

The current results across sprinting, horizontal power, change-of-direction speed, and dynamic balance are consistent with existing findings on neuromuscular training. Improvements were observed in domains that depend on stretch-shortening cycle function, braking and re-acceleration capacity, horizontal force direction, and control of trunk and pelvis. The combination of within-group improvements, adjusted between-group differences, and correlations between performance variables suggests that the intervention influenced neuromechanical function on a broad scale. These effects go beyond isolated skill gains and indicate systemic adaptation [7, 24, 38, 40, 42]. Among female university footballers, the results support earlier studies showing that well-structured and supervised neuromuscular training can lead to consistent improvements within short time frames. These adaptations are possible even in already trained athletes [10, 11, 15, 16, 22]. Our findings also agree with broader research on integrated training methods. For example, Choudhary et al. found that complex training improved sprinting, jumping, and change-of-direction performance. This suggests that despite different program structures, both approaches may rely on shared neuromuscular mechanisms [51].

Despite these limitations, the current findings contribute valuable evidence to the growing literature supporting neuromuscular training as a practical and effective method for improving physical performance in female football players. The study specifically targeted university-level athletes, a group that continues to be underrepresented in sports science research despite their increasing involvement in competitive sport. By assessing sprint speed, horizontal power, change-of-direction ability, and dynamic balance within a single training framework, the study provides a multidimensional perspective on functional performance development. Moreover, embedding the program within the athletes' regular

training routine enhances ecological validity and demonstrates the feasibility of implementation in real-world settings. The consistent improvements observed across multiple domains suggest that well-structured neuromuscular training can be a valuable component of performance enhancement strategies in women's football.

#### *Study Limitations*

This study has several limitations that should be considered when interpreting the results. The relatively small sample size limits the generalizability of the findings, although statistical power was sufficient to detect large effects across all measured outcomes. The eight-week duration primarily reflects short-term neuromuscular adaptations and does not provide information about long-term structural changes or retention. Only field-based performance tests were used, without the inclusion of advanced biomechanical or electrophysiological measures such as electromyography or motion analysis. Potential confounding factors such as nutritional intake, sleep quality, and psychological stress were not strictly controlled. Additionally, the study included only female university football players aged 20 to 24 years, which limits the applicability of the results to other age groups or competitive levels. While all participants were post-pubertal, biological maturity was not objectively assessed,

which may be relevant in future studies involving adolescent athletes. Finally, follow-up testing was not conducted, so the sustainability of performance improvements remains unknown.

#### **Conclusions**

Neuromuscular training that combines plyometric, sprint, change-of-direction, and balance exercises within a structured framework can contribute to the development of key athletic capacities in female university football players. When integrated into regular team practice and delivered with appropriate progression and supervision, such training facilitates improvements across multiple movement domains. The observed associations between gains in balance, sprinting, and directional change underscore the interdependence of neuromechanical functions and highlight the relevance of integrated training strategies in applied sport settings.

These findings emphasize the potential of neuromuscular training to enhance physical preparedness in female athletes and support its inclusion in routine football conditioning programs.

#### **Conflict of Interest**

The authors declare no potential conflicts of interest.

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