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Effects of Eight Weeks of Integrated Neuromuscular Training on Static and Dynamic Balance, Flexibility, and Landing Errors in Male Football Players Aged 18–20 Years

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ABSTRACT

Football requires neuromuscular control, postural stability, flexibility, and safe jump-landing mechanics. Deficits in these components may impair performance and contribute to hazardous lower-limb movement patterns. This randomized controlled study examined the effects of eight weeks of integrated neuromuscular training on static and dynamic balance, flexibility, and landing errors in male football players aged 18–20 years. Methods: Thirty male football players were randomly allocated to an integrated neuromuscular training group or an active control group (n = 15 per group). The experimental group completed a progressive multicomponent program three times weekly for eight weeks, including balance, strength, plyometric, core-stability, landing-technique, and reactive-agility exercises. The control group continued usual football training. Dynamic balance, static balance, flexibility, and landing quality were assessed before and after the intervention. Analysis of covariance was used with baseline values entered as covariates. Results: After the intervention, the experimental group showed significantly greater improvements in static balance, dynamic balance, flexibility, and landing quality than the control group ($p < .001$). Large effects were observed for dynamic balance (partial $\eta^2 = .656$) and landing errors (partial $\eta^2 = .492$). The experimental group showed an adjusted 35.9-cm improvement in dynamic balance and a 1.55-error reduction in Landing Error Scoring System scores, corresponding to an approximate 27.6% reduction in landing errors. Exploratory mediation analysis suggested that improved dynamic balance statistically explained part of the reduction in landing errors. Conclusion: Eight weeks of integrated neuromuscular training improved postural control, flexibility, and landing mechanics in young male football players. The program may be used as a structured warm-up strategy in football settings, although larger trials with injury follow-up are required.

Keywords: *neuromuscular training; dynamic balance; static balance; flexibility; Landing Error Scoring System; football players; postural control*

1. Introduction

Football is a multidimensional intermittent sport in which technical execution, tactical decision-making, and repeated high-intensity physical actions are continuously integrated under rapidly changing environmental constraints. During a typical match or training session, players must accelerate, decelerate, jump, land, sprint, cut, turn, kick, and respond to opponents while maintaining body control and movement efficiency. These actions are essential for performance, but they also impose considerable mechanical and neuromuscular demands on the lower extremities. In particular, young football players are frequently exposed to movement situations that require rapid force absorption, dynamic postural control, coordinated lower-limb alignment, and efficient transition from eccentric braking to concentric propulsion. Therefore, modern football conditioning should not be limited to improving strength, speed, and endurance; it should also target the neuromuscular mechanisms that allow players to control movement quality during sport-specific tasks. Recent advances in athlete monitoring, wearable sensing, and performance profiling have further emphasized that athletic capacity is not merely a function of force magnitude, but also of timing, coordination, movement precision, and the ability to regulate neuromuscular responses under task constraints (1, 2).

Neuromuscular control refers to the coordinated interaction among sensory input, central processing, motor planning, muscle activation, joint stabilization, and postural regulation. In football, this system is challenged during both anticipated and unanticipated actions, especially when players perform landing, cutting, defensive pressing, dribbling, or kicking under temporal pressure. Effective neuromuscular control enables the athlete to maintain the center of mass within a safe and efficient relationship to the base of support, regulate joint stiffness, preserve lower-limb alignment, and distribute forces across the hip, knee, and ankle. Conversely, deficits in neuromuscular control may result in poor trunk positioning, excessive knee valgus, reduced hip and knee flexion, asymmetrical loading, impaired balance, delayed muscle activation, and inefficient landing mechanics. These deficits are particularly important because they may reduce performance quality and increase exposure to hazardous lower-limb movement patterns during common football actions (3, 4).

Lower-limb injuries, especially those involving the knee, remain a major concern in football and other pivoting sports. Non-contact anterior cruciate ligament injury mechanisms are frequently associated with rapid deceleration, landing, side-cutting, or change-of-direction tasks in which the athlete fails to control frontal-plane knee motion, trunk displacement, or lower-limb loading. Biomechanical evidence indicates that neuromuscular control deficits and valgus loading patterns can predict elevated anterior cruciate ligament injury risk, highlighting the clinical relevance of screening and modifying movement mechanics (4). Moreover, the consequences of joint injury are not limited to the acute period of tissue damage. Ligament injury can disrupt proprioceptive function, alter muscle activation, impair postural regulation, and produce long-term neuromuscular adaptations that may complicate rehabilitation and return to sport (3). Knee joint injury is also recognized as a contributing factor to early degenerative changes, including osteoarthritis in young adults, underscoring the importance of preventive approaches that target movement quality before injury occurs (5).

Balance is one of the central components of neuromuscular function in football. Static balance reflects the ability to maintain postural stability during relatively fixed positions, whereas dynamic balance refers to the capacity to control the center of mass during movement, reach, perturbation, or changing support conditions. Football players rely heavily on both dimensions: they stabilize on one limb while passing or shooting, recover balance after contact, land from aerial duels, and control body orientation during cutting and dribbling. Dynamic balance is especially relevant because many football actions involve unilateral support, multidirectional reaching, and rapid changes in momentum. Evidence from neuromuscular training research suggests that structured programs can improve dynamic balance in young athletes, as demonstrated through performance on tests such as the Star Excursion Balance Test and related postural-control assessments (6, 7). In adolescent male soccer players, proprioceptive training has also been shown to enhance balance, strength, agility, and dribbling, indicating that balance-oriented training may transfer to both motor control and sport-specific performance capacities (8).

Flexibility is another important physical quality that may interact with neuromuscular control and movement mechanics. Adequate range of motion in the lower extremity and lumbopelvic region allows athletes to achieve mechanically favorable positions during kicking, sprinting, landing, and change-of-direction movements. Restricted flexibility may limit hip and knee flexion, alter pelvic positioning, increase compensatory movement strategies, and reduce the athlete's ability to absorb force safely. In soccer players, proprioceptive neuromuscular facilitation stretching has been shown to improve range of motion and kicking-related performance, supporting the relevance of flexibility development in football conditioning (9). Although flexibility alone cannot explain injury risk or performance quality, it may provide a necessary movement capacity that supports more efficient postural control, landing strategy, and technical execution.

Landing mechanics represent a particularly important expression of neuromuscular control because landing requires rapid eccentric force absorption, trunk stabilization, coordinated hip-knee-ankle flexion, and control of frontal- and transverse-plane motion. Poor landing mechanics may include stiff landings, limited knee flexion, medial knee displacement, asymmetrical foot contact, poor trunk control, and inadequate shock attenuation. The Landing Error Scoring System is frequently used to identify observable landing errors and provides a practical method for assessing movement quality during jump-landing tasks. Injury prevention programs have been shown to modify landing biomechanics over time, suggesting that repeated exposure to technique-focused training can improve the way athletes absorb and redirect forces during dynamic tasks (10). Similarly, sustained improvements in dynamic balance and landing mechanics have been reported after neuromuscular training in female basketball players, indicating that targeted exercise programs can produce meaningful changes in both postural and landing outcomes (11).

Integrated neuromuscular training has emerged as a comprehensive approach for improving movement competence, reducing injury risk factors, and enhancing athletic performance. Unlike isolated training methods that focus on a single physical attribute, integrated neuromuscular training combines balance, strength, plyometric, core-stability, agility, proprioceptive, and technique-oriented exercises within a progressive training structure. This multicomponent approach is particularly appropriate for youth and young adult athletes because sport performance requires the simultaneous integration of force production, joint control, coordination, and task-specific movement execution. Integrative training models for children and adolescents have been recommended as effective strategies for reducing sports-related injuries while enhancing athletic performance capacities (12). Further, integrative neuromuscular training strategies have been specifically proposed for youth athletes because they address fundamental movement quality, postural control, strength, plyometric competency, and landing mechanics in a developmentally appropriate manner (13).

The preventive value of neuromuscular training is supported by systematic reviews and meta-analyses in youth sport and female athlete populations. Neuromuscular training strategies have demonstrated beneficial effects in reducing sport-related injury risk, particularly when programs include multiple components such as strength, balance, plyometrics, agility, and feedback-based technique training (14). In female athletes, anterior cruciate ligament injury prevention training has been associated with reductions in injury incidence and improvements in selected athletic performance tests, supporting the concept that injury prevention and performance enhancement are not mutually exclusive outcomes (15). Reviews focused on soccer have also emphasized that prevention programs aiming to modify neuromuscular and biomechanical risk factors may reduce non-contact anterior cruciate ligament injuries, especially when exercises are implemented consistently and integrated into regular training environments (16). However, the effectiveness of such programs depends on appropriate exercise selection, progressive overload, technical supervision, compliance, and sport-specific relevance.

The role of compliance is particularly important in neuromuscular training. Even well-designed programs may fail to produce meaningful outcomes if athletes do not complete the exercises consistently or if the training stimulus is insufficiently supervised. Research examining trunk and hip integrative neuromuscular training has shown that compliance influences strength-related adaptations, indicating that the dose and fidelity of training implementation are important determinants of program success (17). This is highly relevant in football settings, where training time is limited and coaches must balance physical preparation with tactical and technical work. Warm-up-based neuromuscular programs are therefore attractive because they can be implemented before routine practice without requiring a separate conditioning session. The FIFA 11+ program and related structured warm-up models have received attention because they combine practical feasibility with evidence-informed injury prevention and performance objectives. For example, neuromuscular warm-up exercises may enhance muscle pre-activation before football participation, which could improve readiness for high-load actions (18). In adolescent soccer players, FIFA 11+ warm-up training has also been shown to affect kinematics and proprioception, supporting the potential of structured warm-up interventions to modify neuromuscular and biomechanical factors relevant to injury risk (19).

Although most neuromuscular training research has focused on football and other field sports, recent studies suggest that structured warm-up and integrative training concepts may have broader relevance across athletic populations. For example, comparison of the FIFA 11+ warm-up with conventional warm-up in cyclists has indicated that structured neuromuscular warm-up models may enhance performance-related variables and mitigate injury risk even outside traditional football contexts (20). Similarly, a systematic review and meta-analysis comparing integrative neuromuscular training with traditional physical fitness training in young athletes has shown that integrative approaches can improve physical performance outcomes, reinforcing the idea that coordinated multicomponent training may be superior to narrowly focused conditioning for developing athletic movement capacity (21). These findings align with the broader shift in sports science toward training approaches that integrate strength, coordination, balance, mobility, cognitive demand, and technical movement execution.

In football, movement quality also interacts with technical skill. Kicking, passing, dribbling, and shooting require precise neuromuscular coordination, trunk-pelvis control, hip mobility, balance, and timing of force transfer through the kinetic chain. Recent work on neuro-muscular control strategies in penalty kicks has highlighted the role of neuromuscular regulation in soccer-specific technical execution, suggesting that interventions targeting motor control may have implications beyond injury prevention alone (22). Pilates-based exercise interventions have also been investigated in soccer, with attention to physical and technical performance outcomes, further indicating that training modalities emphasizing trunk control, flexibility, alignment, and coordinated movement may support football performance (23). Therefore, an integrated neuromuscular training program that improves balance, flexibility, and landing mechanics may provide dual benefits: reducing hazardous movement patterns and supporting performance-related movement efficiency.

Plyometric training is a key component of many integrated neuromuscular programs because it trains the athlete to absorb, store, and rapidly produce force through the stretch-shortening cycle. However, plyometrics must be introduced with attention to movement quality, landing technique, and progressive loading. In rehabilitation and athletic training contexts, plyometric exercise has been recognized for its physiological and clinical applications, particularly when used to develop explosive capacity and neuromuscular control in athletes (24). When combined with strength, balance, agility, and feedback-based technique instruction, plyometric tasks may help athletes improve lower-limb alignment, increase joint flexion during landing, reduce excessive valgus motion, and develop safer deceleration strategies. This integrated structure is especially relevant for football players, whose sport requires repeated cycles of jumping, landing, braking, and re-accelerating under unpredictable match conditions.

Male football players aged 18–20 years represent an important population for neuromuscular training research. This age range is a transitional period between late adolescence and senior competition, during which players often experience increased training intensity, higher match demands, greater physical contact, and more competitive selection pressures. Although many athletes in this age group have developed substantial strength, speed, and technical skill, their ability to consistently coordinate these capacities during complex movement tasks may still be variable. Furthermore, most injury-prevention literature has historically emphasized female athletes or adolescent populations, leaving fewer studies that specifically evaluate young adult male football players. The available evidence supports the general efficacy of neuromuscular and integrative training, but there remains a need for controlled studies examining whether an eight-week integrated neuromuscular program can simultaneously improve static balance, dynamic balance, flexibility, and landing mechanics in male football players aged 18–20 years.

Accordingly, the present study aimed to examine the effects of eight weeks of integrated neuromuscular training on static balance, dynamic balance, flexibility, and landing errors in male football players aged 18–20 years.

2. Methods and Materials

2.1. Study Design

A two-group, parallel, randomized controlled design with pretest and posttest assessments was used. The study process included one week of familiarization and baseline testing, eight weeks of training intervention, and one week of final testing. Posttest assessments were performed 48–72 hours after the last training session using the same order, environmental conditions, and instructions as the pretest.

2.2. Participants

Thirty-four male football players from a competitive football academy were initially randomized to the experimental or control condition. Four players withdrew because of minor injuries sustained during regular football competition and unrelated to the intervention. Thus, 30 players completed the study and were included in the final analysis, with 15 participants in each group. The final sample had a mean age of 18.97 ± 0.66 years, mean height of 1.78 ± 0.06 m, and mean body mass of 73.3 ± 5.0 kg.

2.2.1. Eligibility Criteria

Inclusion criteria were male sex, age between 18 and 20 years, at least three years of organized football training and competition, and active participation in regional league competition. Exclusion criteria were any lower-limb musculoskeletal injury during the previous six months that limited performance, neurological or cardiovascular disorders, and participation in additional strength or conditioning programs outside the team schedule. During the study, absence from more than 20% of training sessions, injury or illness affecting testing, or failure to complete posttest assessments led to exclusion.

2.2.2. Randomization and Blinding

Before allocation, players were stratified according to playing position to reduce the possible effect of position-related physical differences. Within each stratum, participants were randomly assigned to the integrated neuromuscular training group or the active control group. Landing videos were coded before analysis, and the assessor scoring the videos was blinded to group allocation.

2.2.3. Sample Size

Sample size was estimated using G*Power 3.1.9.7 for a pretest-posttest two-group design. Assuming a medium effect size of 0.25, alpha of .05, and power of .80, the minimum required sample was 28 participants. Thirty-four players were enrolled to allow for potential attrition.

2.3. Familiarization and Testing Procedures

One week before baseline assessment, participants completed a 60-minute familiarization session. The procedures for balance, flexibility, and jump-landing tests were explained and practiced. Participants were asked to avoid strenuous activity for 48 hours before testing and to avoid caffeine and alcohol for 24 hours. Before testing, all participants completed a standardized warm-up consisting of light aerobic activity and dynamic lower-limb movements.

2.4. Intervention

The integrated neuromuscular training group performed the intervention for eight weeks, three sessions per week, for a total of 24 sessions. Each session lasted approximately 30 minutes and replaced the usual team warm-up. Players then continued their regular technical and tactical football training.

The program included balance, core-stability, strength, plyometric, landing-control, unilateral and bilateral movement, and reactive-agility exercises. Training progression was achieved by increasing movement complexity, reducing the base of support, progressing from bilateral to unilateral tasks, increasing speed, adding external resistance, and increasing cognitive and reactive demands.

The intervention was delivered in three phases. Weeks 1–2 emphasized fundamental movement competency, static stability, lower-limb alignment, and double-leg landing technique. Weeks 3–5 introduced greater intensity and complexity through resistance exercises, dynamic plyometrics, single-leg landing, goblet squats, multidirectional movement, and dynamic balance tasks. Weeks 6–8 emphasized transfer to faster football-specific tasks, including change of direction, reactive agility, multidirectional jumping and landing, and movement responses to visual or verbal cues. Coaches and researchers provided feedback on trunk control, knee alignment, and landing mechanics throughout the program.

The active control group continued usual football training, including technical and tactical practice, small-sided games, general physical preparation, and conventional warm-up activities. No structured progressive neuromuscular, landing-control, or balance program was added for the control group. Participants in both groups were asked not to participate in supplementary training outside the assigned team program.

2.5. *Outcome Measures*

2.5.1. *Anthropometry*

Standing height was measured with a wall-mounted stadiometer to the nearest 0.1 cm. Body mass was measured with a digital scale to the nearest 0.1 kg while participants wore light sports clothing and no shoes. Body mass index was calculated as body mass divided by height squared.

2.5.2. *Dynamic Balance*

Dynamic balance was assessed with the Y-Balance Test. Participants stood on one limb and reached as far as possible in the anterior, posteromedial, and posterolateral directions with the free limb. Reach distances were normalized to lower-limb length, and a composite score was calculated. A trial was repeated if the participant lost balance, moved the stance foot, used the reach indicator for support, or failed to return under control.

2.5.3. *Static Balance*

Static balance was assessed with the Stork Balance Stand Test. Participants stood on the dominant limb, placed both hands on the hips, positioned the non-stance foot against the medial knee of the stance limb, and raised the heel of the stance foot. Timing stopped if hand position changed, the stance foot moved, the non-stance foot lost contact, or the heel touched the floor. The best of three trials was recorded in seconds.

2.5.4. *Flexibility*

Flexibility of the posterior thigh and lumbopelvic region was assessed using the sit-and-reach test. Participants sat without shoes, kept the knees fully extended, and reached forward smoothly without bouncing. The best of three trials was recorded to the nearest 0.5 cm.

2.5.5. *Landing Mechanics*

Landing mechanics were assessed using the Landing Error Scoring System (LESS). Participants performed three standardized drop-jump trials from a 30-cm box, landed at a distance equal to approximately 50% of body height, and immediately performed a maximal vertical jump. Frontal and sagittal recordings were obtained with two cameras at 60 Hz. A blinded assessor scored the 17-item LESS, with higher scores indicating more observable landing errors and poorer landing quality. Intra-rater reliability was confirmed before the main analysis, with an intraclass correlation coefficient greater than 0.90.

2.6. *Statistical Analysis*

Data were analyzed with IBM SPSS Statistics version 28. Quantitative variables are presented as mean ± standard deviation. Data were screened for missing values, outliers, and entry errors. Normality of standardized residuals was examined with the Shapiro-Wilk test, and homogeneity of variance was examined with Levene's test. One-way analysis of covariance was used to compare posttest values between groups, with the corresponding baseline value entered as a covariate. Linearity between covariates and dependent variables and homogeneity of regression slopes were checked before analysis. Partial eta squared was used to quantify intervention effects, with .01, .06, and .14

interpreted as small, medium, and large effects. Cohen's d was also calculated for baseline between-group differences. Statistical significance was set at $p < .05$. An exploratory bootstrap mediation analysis with 5,000 resamples was used to examine whether change in dynamic balance statistically mediated the association between group allocation and change in LESS score. The indirect effect was considered statistically significant when the 95% bootstrap confidence interval did not include zero.

3. Findings and Results

No missing data were observed among participants who completed all phases of the study. Standardized residuals were normally distributed, and Levene's test supported homogeneity of variance for the analyzed variables. Of the 34 randomized players, 30 completed the intervention and both assessment sessions. Four participants withdrew because of minor injuries from usual football competition; these injuries were not related to the intervention. Baseline comparisons between completers and non-completers showed no statistically significant differences in age, body mass index, or baseline aerobic capacity (all $p > .40$).

Baseline demographic and biomechanical characteristics are shown in Table 1. Before the intervention, the experimental and control groups did not differ significantly in age, body mass, training experience, or LESS score (all $p > .05$). Cohen's d values ranged from 0.10 to 0.40, indicating small to moderate baseline differences.

Table 1

Baseline Demographic and Biomechanical Characteristics of Participants

Variable	Control group (n = 15)	Experimental group (n = 15)	p value	Cohen d
Age, years	18.93 ± 0.70	19.00 ± 0.65	.78	0.10
Body mass, kg	72.9 ± 5.6	73.8 ± 4.5	.62	0.18
Training experience, years	4.7 ± 1.1	5.2 ± 1.2	.29	0.40
LESS score, errors	5.67 ± 0.98	5.33 ± 0.98	.34	0.34

Note. Values are mean ± standard deviation. p values are based on independent-samples t tests. LESS = Landing Error Scoring System.

After controlling for pretest values, analysis of covariance showed significant between-group differences in dynamic balance and landing quality. In the Y-Balance Test, the integrated neuromuscular training group performed significantly better than the control group at posttest, $F(1, 27) = 51.60$, $p < .001$, partial $\eta^2 = .656$. The adjusted between-group difference was +35.9 cm in favor of the experimental group, with a 95% confidence interval from 25.7 to 46.1 cm.

The intervention also had a significant effect on LESS score, $F(1, 27) = 26.17$, $p < .001$, partial $\eta^2 = .492$. The adjusted posttest LESS score was 1.55 errors lower in the experimental group than in the control group, with a 95% confidence interval from -2.16 to -0.94 errors. Because lower LESS scores indicate fewer landing errors, this result reflects improved landing quality. The reduction corresponded to approximately 27.6% fewer landing errors in the experimental group.

Sensitivity analysis using nonparametric rank-based ANCOVA produced results consistent with the parametric ANCOVA. Between-group differences in dynamic balance and LESS score remained statistically significant, with $p < .001$ for both outcomes.

The exploratory mediation analysis indicated a statistically significant indirect effect of the intervention on LESS score through change in dynamic balance. The point estimate for the indirect effect was -0.91, with a 95% bootstrap confidence interval from -1.48 to -0.45. Because the interval did not include zero, the indirect effect was considered significant. The model suggested that approximately 62% of the association between the intervention and change in LESS score was statistically explained by change in dynamic balance. This mediation result should be interpreted cautiously because of the modest sample size and the exploratory design.

Table 2

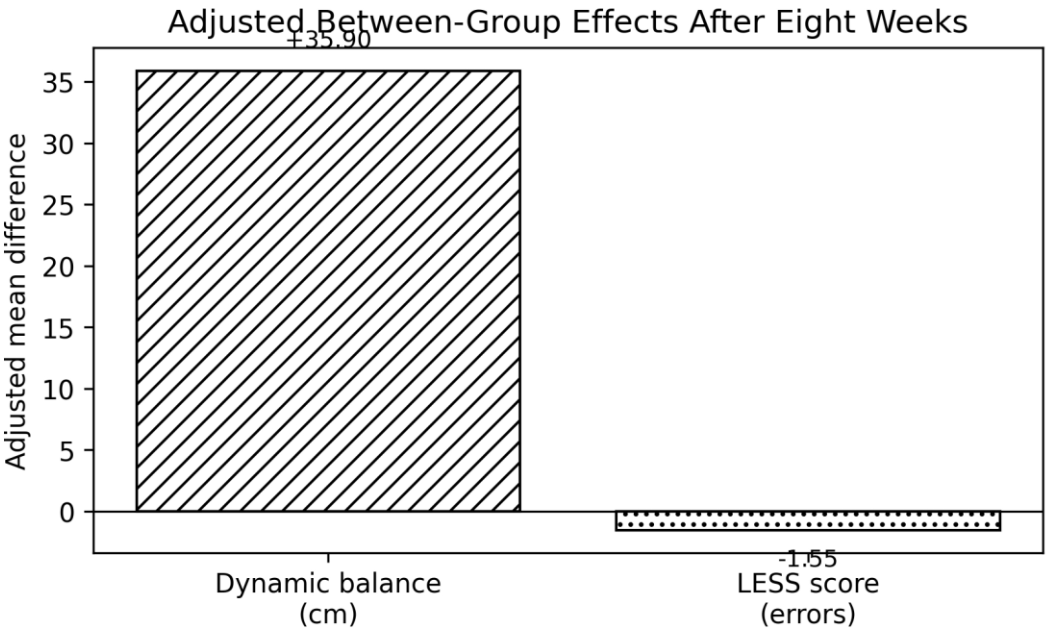
ANCOVA Results for Posttest Outcomes After Controlling for Baseline Values

Dependent variable	Adjusted mean difference (95% CI)	F	p value	Partial η²	Effect size
Dynamic balance, cm	+35.9 [25.7, 46.1]	51.60	< .001	.656	Large
LESS score, errors	-1.55 [-2.16, -0.94]	26.17	< .001	.492	Large

Note. Positive values for dynamic balance indicate better performance in the experimental group. Negative values for LESS indicate fewer landing errors in the experimental group. Degrees of freedom for both ANCOVA models were 1 and 27.

Figure 1

Adjusted between-group effects after the intervention. The positive value for dynamic balance indicates better performance in the experimental group, whereas the negative value for LESS indicates fewer landing errors.



4. Discussion and Conclusion

The present study examined the effects of eight weeks of integrated neuromuscular training on static balance, dynamic balance, flexibility, and landing errors in male football players aged 18–20 years. The findings demonstrated that the experimental group, which completed a progressive multicomponent neuromuscular program three sessions per week, achieved significantly greater post-intervention improvements than the active control group across all measured outcomes. After controlling for baseline values, the intervention produced a large effect on dynamic balance, with the experimental group showing an adjusted 35.9-cm advantage over the control group. The intervention also produced a large effect on landing mechanics, with an adjusted 1.55-error reduction in Landing Error Scoring System scores, corresponding to an approximate 27.6% decrease in observable landing errors. Static balance and flexibility also improved significantly in the experimental group, indicating that the intervention influenced both postural-control capacity and movement-related functional mobility. Collectively, these results support the hypothesis that integrated neuromuscular training can improve movement quality in young male football players and suggest that structured warm-up-based programs may be effective for enhancing key neuromuscular capacities required for football performance and lower-limb movement safety.

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The significant improvement in dynamic balance is one of the most important findings of this study. Dynamic balance requires continuous regulation of the center of mass over a changing base of support and depends on the coordinated integration of proprioceptive, vestibular, visual, and motor-control mechanisms. In football, dynamic balance is required during kicking, passing, cutting, dribbling, landing, shielding, and rapid changes of direction. The large improvement observed in the experimental group can be explained by the repeated exposure of participants to unilateral stance, multidirectional reaching, core-stability tasks, progressive lower-limb strengthening, reactive-agility drills, and balance exercises under increasing coordinative demands. These training components likely enhanced sensorimotor integration, anticipatory postural adjustment, hip-knee-ankle coordination, and the ability to stabilize the body during unilateral loading. This interpretation is consistent with evidence showing that neuromuscular training improves performance on dynamic balance tests in young female athletes (6), and with findings that proprioceptive training enhances balance, strength, agility, and dribbling performance in adolescent male soccer players (8). The present findings also align with research showing time-dependent postural-control adaptations following neuromuscular training in youth athletes, suggesting that structured exposure to balance and coordination tasks can generate measurable improvements in postural regulation (7).

The improvement in static balance further supports the effectiveness of the intervention in enhancing postural-control mechanisms. Although static balance is less complex than dynamic football-specific actions, single-leg stance control remains highly relevant to football because players frequently stabilize on one limb while executing technical skills or responding to perturbations. The improvement in static balance may reflect enhanced proprioceptive feedback, improved ankle and hip strategy coordination, greater trunk control, and better regulation of postural sway. Previous evidence has emphasized that ligament injury and neuromuscular impairment can disrupt joint-position sense and motor control, particularly around the knee joint (3). Therefore, improving static balance may be clinically meaningful because it indicates more efficient sensory-motor regulation during controlled single-limb support. From a training perspective, the progression from bilateral to unilateral tasks and from stable to more challenging movement contexts likely provided sufficient stimulus for improving postural stability. This is consistent with integrative neuromuscular training models that emphasize balance, core stability, and movement competency as foundational components for reducing sport-related injury risk and improving athletic performance in young athletes (12, 13).

The reduction in landing errors is a particularly important result because landing mechanics represent a dynamic expression of neuromuscular control under rapid force absorption. The Landing Error Scoring System identifies observable movement faults such as inadequate hip and knee flexion, poor trunk position, medial knee displacement, asymmetry, poor foot placement, and limited control during jump-landing tasks. The 1.55-error reduction in the experimental group indicates that players demonstrated fewer visible landing faults after the intervention. This improvement may be attributed to the inclusion of plyometric exercises, landing-technique instruction, lower-limb alignment feedback, core-stability exercises, and progressive unilateral and bilateral jumping tasks. These components may have improved eccentric control, joint flexion strategy, force attenuation, trunk stabilization, and frontal-plane knee control. The present results are consistent with previous evidence showing that injury prevention programs can improve landing biomechanics over time (10), and with findings that neuromuscular training can produce sustained improvements in both dynamic balance and landing mechanics (11). They also support the biomechanical premise that neuromuscular control and valgus loading are central factors in lower-limb injury risk, particularly in relation to anterior cruciate ligament loading mechanisms (4).

The improvement in landing quality should be interpreted as evidence of favorable modification of injury-related movement characteristics rather than direct evidence of injury reduction. Non-contact knee injuries, especially anterior cruciate ligament injuries, are multifactorial and may occur during landing, cutting, or deceleration when poor trunk control, excessive knee valgus, inadequate hip control, or insufficient knee flexion are present. Theoretical and empirical literature has emphasized that prevention programs should aim to modify these neuromuscular and biomechanical risk factors in football players (16). Systematic reviews have also reported that neuromuscular training programs can reduce injury risk in youth sport and improve injury-related movement outcomes when programs are implemented with adequate frequency, progression, and supervision (14). Similarly, evidence from female athlete populations indicates that anterior cruciate ligament injury prevention training can reduce injury incidence and improve selected performance outcomes (15). However, because the present study assessed landing errors rather than prospective injury incidence, the results indicate improvement in movement quality and potential reduction of hazardous mechanics, but they do not establish a direct preventive effect on actual injury occurrence.

The significant improvement in flexibility observed in the experimental group suggests that integrated neuromuscular training may also enhance functional range of motion. Although the intervention was not designed as a traditional flexibility-only program, it included squats, lunges, landing tasks, dynamic movements, multidirectional actions, and controlled movement through progressively larger ranges. These exercises may have improved stretch tolerance, posterior-chain mobility, lumbopelvic control, and the ability to assume more mechanically favorable positions during landing and cutting. The finding is consistent with research showing that proprioceptive neuromuscular facilitation stretching improves range of motion and kicking speed in young male soccer players (9). The present results extend this concept by suggesting that flexibility can improve within a multicomponent neuromuscular program even when flexibility is trained through dynamic, functional, and sport-relevant movement patterns rather than isolated stretching alone. Improved flexibility may also support landing mechanics by allowing greater hip and knee flexion, improved trunk positioning, and more efficient force absorption.

The observed improvements may also be explained by the integrated nature of the intervention. Rather than training balance, flexibility, strength, plyometrics, and landing technique separately, the program combined these components into a progressive sequence that reflected the demands of football. This design likely promoted transfer from basic movement control to more complex sport-specific tasks. Plyometric exercises may have improved stretch-shortening cycle efficiency and eccentric-concentric transition capacity, while strength and core-stability exercises may have enhanced proximal control and lower-limb alignment. Balance and proprioceptive drills likely improved sensory-motor regulation, whereas reactive-agility tasks increased the ecological relevance of the program by requiring players to control movement in response to external cues. This interpretation is consistent with the clinical and physiological rationale for plyometric exercise in athlete rehabilitation and performance contexts (24), and with contemporary models of integrative neuromuscular training that emphasize simultaneous development of movement quality, postural control, strength, and performance capacity (12, 13). It also aligns with meta-analytic evidence indicating that integrative neuromuscular training may be superior to traditional physical fitness training for improving physical performance outcomes in young athletes (21).

The exploratory mediation analysis suggested that improvement in dynamic balance statistically explained part of the reduction in landing errors. This finding is theoretically plausible because both dynamic balance and landing quality depend on control of the center of mass, trunk stability, lower-limb alignment, proprioceptive feedback, and rapid neuromuscular responses. Athletes who improve their ability to stabilize during unilateral and multidirectional tasks may also become better able to control body position during jump-landing tasks. This relationship is consistent with the broader understanding that neuromuscular function is not a single isolated capacity but a coordinated system linking sensory input, postural control, muscle activation timing, and movement execution (1, 3). However, the mediation result should be interpreted cautiously because the sample size was modest and the mediator and outcome were assessed across the same intervention period. Nevertheless, the finding provides a useful hypothesis for future studies: dynamic balance may be one mechanism through which integrated neuromuscular training improves landing mechanics in young football players.

The present results also align with evidence supporting structured warm-up programs in football. Warm-up-based neuromuscular interventions are practical because they can replace conventional warm-ups and be embedded into regular team training without requiring extensive additional time. Previous research has shown that neuromuscular warm-up exercises may improve muscle pre-activation before football participation (18), while the FIFA 11+ program has been shown to affect kinematics and proprioception in adolescent soccer players (19). The current study supports this approach by showing that a 30-minute integrated neuromuscular program performed three times weekly for eight weeks improved dynamic balance and landing mechanics in male football players aged 18–20 years. Similar principles have also been extended beyond football; for example, comparison of the FIFA 11+ warm-up with conventional warm-up in cyclists suggests that structured neuromuscular warm-ups may enhance performance and reduce injury-related risk factors in other athletic populations (20). These findings collectively reinforce the practical value of replacing non-specific warm-ups with structured neuromuscular routines that target movement quality.

In addition to injury-related outcomes, the findings may have implications for performance. Football performance depends on the ability to coordinate strength, balance, flexibility, technical skill, and rapid motor responses. Improved dynamic balance may support dribbling, kicking stability, directional changes, and body control during opponent pressure. Improved landing mechanics may also enhance the efficiency of jumping, aerial duels, and repeated explosive actions. Recent research has increasingly emphasized that neuromuscular regulation contributes to technical execution in football, including kicking performance and motor-control strategies (22). Pilates-based interventions in soccer have similarly highlighted the relevance of trunk control, flexibility, and coordinated movement for physical and technical performance (23). Broader performance profiling in action sports also supports the importance of integrating physiological, physical, and neuromuscular characteristics when designing athlete development programs (2). Therefore, the benefits observed in this study should not be viewed only from an injury-prevention perspective; they may also reflect improvements in the movement foundation required for efficient football performance.

Another important consideration is the role of training adherence and implementation quality. Neuromuscular training effects depend not only on the content of the program but also on compliance, supervision, progression, and feedback. Previous research has shown that compliance influences adaptations to trunk and hip integrative neuromuscular training, particularly in relation to hip abductor strength (17). In the present study, the intervention was delivered three times per week and incorporated progressive overload, technical feedback, and football-specific complexity, which likely increased the likelihood of meaningful adaptation. The findings therefore support the idea that neuromuscular programs should not be applied as informal or unsupervised exercise collections; instead, they should be structured, progressive, and monitored to ensure correct landing technique, appropriate knee alignment, trunk control, and adequate exercise intensity.

The long-term significance of improving landing mechanics and postural control is also important. Lower-limb injuries can have consequences that extend beyond temporary absence from sport. Joint injuries may produce persistent neuromuscular deficits, altered loading patterns, and increased risk of future joint degeneration (3, 5). Therefore, interventions that improve movement quality in young athletes may contribute to both immediate performance readiness and longer-term musculoskeletal health. The present study adds to the evidence base by focusing on male football players aged 18–20 years, a group that is often exposed to high training and competition demands but is less frequently studied than adolescent or female athlete populations in anterior cruciate ligament prevention research. The findings suggest that even in young male players, who may already possess relatively developed physical capacities, an eight-week integrated neuromuscular program can produce meaningful improvements in balance, flexibility, and landing quality.

Several limitations should be considered when interpreting the findings of this study. First, the sample size was relatively small and included only male football players aged 18–20 years from a limited competitive context; therefore, the results should be generalized cautiously to female athletes, younger adolescents, elite senior players, recreational players, and athletes from other sports. Second, the intervention lasted eight weeks, and no follow-up assessment was included, so the durability of the improvements remains unknown. Third, although landing mechanics were assessed using a standardized method, the testing environment did not fully reproduce match-specific fatigue, opponent pressure, tactical decision-making, or unpredictable contact situations. Fourth, the study evaluated movement-quality indicators rather than actual injury incidence, so the findings cannot directly establish that the intervention reduced injury rates. Finally, the exploratory mediation analysis should be interpreted with caution because the sample size was modest and causal temporal ordering between dynamic balance improvement and landing-error reduction cannot be confirmed.

Future studies should replicate these findings using larger, multicenter samples and should include both male and female football players across different age groups and competitive levels. Researchers should also examine whether the improvements in balance, flexibility, and landing mechanics are retained after several months and whether booster sessions are needed to maintain training adaptations. Future trials should incorporate prospective injury surveillance to determine whether improvements in Landing Error Scoring System scores and balance tests translate into meaningful reductions in lower-limb injury incidence. It would also be valuable to assess movement quality under more ecologically valid conditions, including fatigue, reactive decision-making, opponent pressure, and sport-specific cutting or landing tasks. In addition, future research should compare different durations, frequencies, and components of integrated neuromuscular training to identify the minimum effective dose and the most influential exercise elements for improving postural control and landing mechanics.

Coaches, strength and conditioning specialists, and rehabilitation professionals can consider incorporating integrated neuromuscular training into the warm-up structure of young football players. A practical program should include balance tasks, unilateral and bilateral strength exercises, core-stability drills, plyometric progressions, landing-technique practice, multidirectional agility, and reactive movement tasks. Technical feedback should emphasize soft landings, adequate hip and knee flexion, trunk control, symmetrical foot contact, and avoidance of excessive medial knee displacement. The program should be progressive, beginning with fundamental movement control and advancing toward faster, more complex, and football-specific tasks. Because implementation quality is essential, coaches should supervise movement execution closely rather than treating the program as a routine warm-up without correction. Applied consistently, this type of training may help improve balance, flexibility, landing quality, and movement efficiency in young football players.

Authors' Contributions

All authors contributed substantially to the study and to manuscript development, and all approved the final version.

Declaration

The authors declare that artificial intelligence tools were used only to assist with language editing, translation, and improvement of the manuscript's readability. All conceptualization, study design, data collection, data analysis, interpretation of findings, and final approval of the manuscript were performed by the authors. The authors take full responsibility for the accuracy, integrity, and originality of the content.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

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Declaration of Interest

The authors report no conflict of interest.

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Ethics Considerations

The study placed a high emphasis on ethical considerations. Informed consent obtained from all participants, ensuring they are fully aware of the nature of the study and their role in it. Confidentiality strictly maintained, with data anonymized to protect individual privacy. The study adhered to the ethical guidelines for research with human subjects as outlined in the Declaration of Helsinki.

References

1. Köklü Ö. Wearable Sensor Assessment Of Neuromuscular Latency: Revealing The Strength-Timing Trade-Off In Female Soccer. 2026. [DOI]
2. Liang W, Hou Y, Liu C, Ma S, Zong Y, Yan X. Physiological And Physical Characteristics Of Bmx Freestyle Athletes: A Preliminary Review. Frontiers in Physiology. 2025;16. [PMID: 40917805] [PMCID: PMC12408523] [DOI]
3. Ageberg E. Consequences Of A Ligament Injury On Neuromuscular Function And Relevance To Rehabilitation: Using The Anterior Cruciate Ligament-Injured Knee As A Model. Journal of Electromyography and Kinesiology. 2002;12(3):205-12. [PMID: 12086815] [DOI]
4. Hewett TE, Myer GD, Ford KR, Heidt RS, Colosimo AJ, Mclean SG, et al. Biomechanical Measures Of Neuromuscular Control And Valgus Loading Of The Knee Predict Anterior Cruciate Ligament Injury Risk In Female Athletes. The American Journal of Sports Medicine. 2005;33(4):492-501. [PMID: 15722287] [DOI]
5. Roos EM. Joint Injury Causes Knee Osteoarthritis In Young Adults. Current Opinion in Rheumatology. 2005;17(2):195-200. [PMID: 15711235] [DOI]
6. Filipa A, Byrnes R, Paterno MV, Myer GD, Hewett TE. Neuromuscular Training Improves Performance On The Star Excursion Balance Test In Young Female Athletes. Journal of Orthopaedic & Sports Physical Therapy. 2010;40(9):551-8. [PMID: 20710094] [PMCID: PMC3439814] [DOI]
7. Zech A, Klahn P, Hoeft J, Zu Eulenburg C, Steib S. Time Course And Dimensions Of Postural Control Changes Following Neuromuscular Training In Youth Field Hockey Athletes. European Journal of Applied Physiology. 2014;114(2):395-403. [PMID: 24318788] [DOI]
8. Gidu DV, Badau D, Stoica M, Aron A, Focan G, Monea D, et al. The Effects Of Proprioceptive Training On Balance, Strength, Agility And Dribbling In Adolescent Male Soccer Players. International Journal of Environmental Research and Public Health. 2022;19(4):2028. [PMID: 35206215] [PMCID: PMC8871985] [DOI]
9. Akbulut T, Agopyan A. Effects Of An Eight-Week Proprioceptive Neuromuscular Facilitation Stretching Program On Kicking Speed And Range Of Motion In Young Male Soccer Players. Journal of strength and conditioning research. 2015;29(12):3412-23. [PMID: 26020709] [DOI]
10. Distefano LJ, Marshall SW, Padua DA, Peck KY, Beutler AI, De La Motte SJ, et al. The Effects Of An Injury Prevention Program On Landing Biomechanics Over Time. The American Journal of Sports Medicine. 2016;44(3):767-76. [PMID: 26792707] [PMCID: PMC9718103] [DOI]
11. Pfile KR, Gribble PA, Buskirk GE, Meserth SM, Pietrosimone BG. Sustained Improvements In Dynamic Balance And Landing Mechanics After A 6-Week Neuromuscular Training Program In College Women'S Basketball Players. Journal of Sport Rehabilitation. 2016;25(3):233-40. [PMID: 26355913] [DOI]
12. Myer GD, Faigenbaum AD, Chu DA, Falkel J, Ford KR, Best TM, et al. Integrative Training For Children And Adolescents: Techniques And Practices For Reducing Sports-Related Injuries And Enhancing Athletic Performance. The Physician and Sportsmedicine. 2011;39(1):74-84. [PMID: 21378489] [DOI]
13. Fort-Vanmeerhaeghe A, Romero-Rodriguez D, Lloyd RS, Kushner A, Myer GD. Integrative Neuromuscular Training In Youth Athletes. Part Ii: Strategies To Prevent Injuries And Improve Performance. Strength and Conditioning Journal. 2016;38(4):9-27. [DOI]
14. Emery CA, Roy TO, Whittaker JL, Nettel-Aguirre A, Van Mechelen W. Neuromuscular Training Injury Prevention Strategies In Youth Sport: A Systematic Review And Meta-Analysis. British Journal of Sports Medicine. 2015;49(13):865-70. [PMID: 26084526] [DOI]
15. Noyes FR, Barber-Westin SD. Anterior Cruciate Ligament Injury Prevention Training In Female Athletes: A Systematic Review Of Injury Reduction And Results Of Athletic Performance Tests. Sports Health. 2012;4(1):36-46. [PMID: 23016067] [PMCID: PMC3435901] [DOI]
16. Alentorn-Geli E, Myer GD, Silvers HJ, Samitier G, Romero D, Lázaro-Haro C, et al. Prevention Of Non-Contact Anterior Cruciate Ligament Injuries In Soccer Players. Part 2: A Review Of Prevention Programs Aimed To Modify Risk Factors And To Reduce Injury Rates. Knee Surgery, Sports Traumatology, Arthroscopy. 2009;17(8):859-79. [PMID: 19506834] [DOI]
17. Sugimoto D, Myer GD, Bush HM, Hewett TE. Effects Of Compliance On Trunk And Hip Integrative Neuromuscular Training On Hip Abductor Strength In Female Athletes. Journal of strength and conditioning research. 2014;28(5):1187-94. [PMID: 24751656] [PMCID: PMC4170915] [DOI]
18. De Sire A, Demeco A, Marotta N, Moggio L, Palumbo A, Iona T, et al. Anterior Cruciate Ligament Injury Prevention Exercises: Could A Neuromuscular Warm-Up Improve Muscle Pre-Activation Before A Soccer Game? A Proof-Of-Principle Study On Professional Football Players. Applied Sciences. 2021;11(11):4958. [DOI]
19. Seyedi M, Zarei M, Daneshjoo A, Rajabi R, Shirzad E, Mozafaripour E, et al. Effects Of FIFA 11+ Warm-Up Program On Kinematics And Proprioception In Adolescent Soccer Players: A Parallel-Group Randomized Control Trial. Scientific Reports. 2023;13:5527. [PMID: 37016130] [PMCID: PMC10073194] [DOI]
20. Panchal R, Rizvi MR, Sharma A, Ahmad F, Hasan S, Shaik AR, et al. Comparing The Effectiveness Of The FIFA 11+ Warm-Up And Conventional Warm-Up In Enhancing Cyclist Performance And Mitigating Injury Risk. Scientific Reports. 2025;15(1). [PMID: 40108222] [PMCID: PMC11923219] [DOI]
21. Wan K, Dai Z-H, Ho RS, Tam BT. Comparing The Effects Of Integrative Neuromuscular Training And Traditional Physical Fitness Training On Physical Performance Outcomes In Young Athletes: A Systematic Review And Meta-Analysis. Sports Medicine - Open. 2025;11(1). [PMID: 39921710] [PMCID: PMC11807040] [DOI]
22. Wang H, Zhang H, Li X, Zhu J. The Impact Of Transcranial Direct Current Stimulation On The Neuro-Muscular Control Strategies Of Penalty Kicks In Soccer Players. Frontiers in Sports and Active Living. 2025;7. [PMID: 40959533] [PMCID: PMC12433942] [DOI]
23. Yılmaz O, Kaplan T, Baťalík L. Randomised Controlled Study On The Effects Of Pilates Exercises In Soccer: Comparing Mat And Reformer Methods On Physical And Technical Performance. Plos One. 2025;20(5):e0324129. [PMID: 40397911] [PMCID: PMC12094727] [DOI]
24. Chmielewski TL, Myer GD, Kauffman D, Tillman SM. Plyometric Exercise In The Rehabilitation Of Athletes: Physiological Responses And Clinical Application. Journal of Orthopaedic & Sports Physical Therapy. 2006;36(5):308-19. [PMID: 16715831] [DOI]