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Standing Versus Floor-Based Trunk Stability Training: Effects on Landing and Cutting Movement Quality in Youth Male Football Players

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Abstract

This study compared the effects of a 5-week standing single-leg trunk-stability programme, a conventional floor-based trunk-stability programme, and active general conditioning on landing and cutting movement quality in early-adolescent male football players. In this exploratory three-arm randomised trial, 31 early-adolescent male football players were allocated to a standing single-leg trunk-stability programme (n = 11), a conventional floor-based trunk-stability programme (n = 12), or an active general-conditioning control programme (n = 8). Participants completed two supervised 15 min sessions per week. Co-primary outcomes were the Landing Error Scoring System (LESS) and bilateral mean Cutting Movement Assessment Score (CMAS); secondary outcomes were change-of-direction (COD) time and accelerometer-derived lumbopelvic stability. Baseline-adjusted ANCOVA showed significant group effects for LESS ($F(2.27) = 17.02$, $p < 0.001$, $\eta p^2 = 0.53$) and CMAS ($F(2.26) = 10.45$, $p < 0.001$, $\eta p^2 = 0.45$). The standing single-leg group showed lower baseline-adjusted LESS and bilateral CMASs than both comparison groups in the primary analyses. The LESS finding remained robust after adjustment for age, whereas the CMAS pairwise contrasts were attenuated in the age-adjusted ANCOVA; however, the complementary age-adjusted side-specific analysis continued to support a group effect for CMAS. No clear between-group differences were observed for COD time or lumbopelvic acceleration. These exploratory findings support a task-specific effect of the standing single-leg programme on observable landing and cutting movement quality, although the CMAS result should be interpreted cautiously because the pairwise contrasts were attenuated after adjustment for chronological age.

Keywords: trunk stability; youth football; landing; cutting; change of direction; LESS; CMAS; neuromuscular training

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1. Introduction

Dynamic sporting actions such as landing, deceleration, and change of direction (COD) require coordinated control of the trunk, pelvis, and lower limbs while forces are rapidly

absorbed and redirected [1,2]. Prospective evidence has associated impaired trunk neuromuscular control with subsequent knee and ligament injury, suggesting that trunk control may be relevant to these movement strategies [3]. However, whether trunk-focused training translates into meaningful changes in sport-specific movement patterns remains uncertain. Recent systematic reviews and meta-analyses indicate that trunk muscle training can improve balance, trunk endurance, and selected performance outcomes, although the magnitude of these effects varies across outcomes, populations, and training approaches [4–6].

In youth football, repeated accelerations, decelerations, jumps, and COD place substantial demands on neuromuscular control and contribute to a considerable lower-limb injury burden [7]. Although multicomponent exercise-based injury prevention programmes can reduce injury incidence in youth football, the specific contribution and optimal design of trunk-focused training remain unclear [8].

Conventional trunk-stability programmes used in football commonly include floor-based exercises such as bridge, plank, and bird-dog variations [9,10]. These exercises provide a controlled stimulus to the trunk musculature but challenge postural control mainly in prone, supine, lateral, or quadruped positions. Exercise difficulty can be systematically progressed by increasing lever length, reducing the base of support, alternating the supporting limb, or incorporating controlled limb movements [11–13]. In contrast, many football actions require control of the trunk and pelvis in standing, frequently under unilateral support, multiplanar loading, and rapid force production. Because training adaptations may be task specific, transfer may be more evident when the training and assessment tasks share similar postural and mechanical demands [14]. Previous research comparing predominantly standing and unilateral core-stability training with conventional floor-based programmes in youth male football players has shown potential benefits for sprint and COD performance [15]. However, it remains unclear whether increasing the task specificity and dynamic perturbation demands of trunk stability training can also improve movement quality during landing and cutting.

Field-based two-dimensional screening tools provide a practical means of evaluating movement quality during landing and cutting tasks. The Landing Error Scoring System (LESS) quantifies observable landing mechanics and has demonstrated good reliability and acceptable validity in football populations, although evidence supporting its prognostic value for future injury remains inconsistent [16–18]. The Cutting Movement Assessment Score (CMAS) similarly evaluates observable cutting characteristics associated with multiplanar lower-limb loading [19]. However, it remains unclear whether a multicomponent trunk-stability programme combining upright single-leg support, controlled movements, elastic perturbations, and small submaximal jumping actions can produce greater improvements in landing and cutting movement quality than conventional floor-based trunk-stability training.

Therefore, the purpose of this study was to compare the effects of a 5-week standing single-leg trunk stability programme, a conventional floor-based trunk stability programme, and an active general-conditioning control programme in early-adolescent male football players. The co-primary outcomes were landing movement quality, assessed using the LESS [16,17], and cutting movement quality, assessed using the bilateral mean CMAS [19,20]. Secondary outcomes were COD time and accelerometer-derived lumbopelvic stability during single-leg front-bridge and bird-dog stability tests, which have been previously used to assess lumbopelvic stability in field settings [21]. We hypothesised that the standing single-leg programme would produce greater improvements in LESS and CMASs than the floor-based and active control programmes because its combination of upright unilateral support, controlled hip movements, elastic perturbations, and small submaximal jumping actions would provide training demands more closely resembling those involved in landing and COD tasks. We further hypothesised that the

standing single-leg programme would produce greater improvements in COD time, whereas changes in accelerometer-derived lumbopelvic stability during the floor-based tests would be greater following the floor-based programme because of the greater similarity between the training and assessment tasks.

2. Methods

2.1. Study Design

A three-arm, parallel-group, randomised pre-post intervention study was conducted during the competitive season to compare two trunk stability programmes with an active control condition in youth male football players.

The intervention lasted 5 weeks and comprised two supervised 15 min sessions per week (10 planned sessions), conducted in addition to the players' regular football training. Testing was performed under the same experimental conditions, at the same time and immediately before and after the intervention using the same field-based procedures. Participants were allocated to a standing single-leg trunk stability group, a conventional floor-based trunk stability group, or an active control group. Landing movement quality assessed with the LESS and cutting movement quality assessed with the CMAS were considered the co-primary outcomes. COD time and accelerometer-derived lumbopelvic stability during the single-leg front-bridge and bird-dog stability tests were secondary outcomes.

Randomisation was conducted separately within each of the two participating teams, with players from each team allocated to the three intervention groups. Within each team, participants were randomly assigned using a sequence generated in Microsoft Excel (Microsoft Corporation, Redmond, WA, USA). Randomisation was not stratified by age. No formal allocation-concealment procedure was used; group assignments were revealed after completion of the baseline assessments. Because of the nature of the exercise interventions, participants and instructors could not be blinded to group allocation. Video-based LESS and CMAS assessments were scored by one evaluator, a graduate in Sport and Exercise Sciences who had received prior training in the application of both scoring systems. The evaluator was not blinded to group allocation or assessment occasion.

No formal a priori sample-size calculation was performed. The sample size was determined by the number of eligible players available from the two participating teams. Accordingly, the study should be considered exploratory, and the precision of the estimated intervention effects should be interpreted cautiously.

2.2. Participants

Thirty-one youth male football players (age, 12.8 ± 0.7 years; body mass, 46.8 ± 10.1 kg; height, 155.6 ± 9.4 cm) participated in the study. Players were recruited from two under-14 teams competing in the second regional league in Alicante, Spain. Both teams trained twice per week during the competitive season and participated regularly in official competition. Based on the Participant Classification Framework proposed by McKay et al. [22], the sample was classified as Tier 2 (Trained/Developmental). The intervention was delivered as a 15 min block added to each of the players' two regular weekly team-training sessions over the 5-week study period.

Eligibility criteria were: (1) age 12–14 years; (2) regular participation in team training and competition; (3) no regular participation in an additional trunk-focused exercise programme; (4) no physical limitations, no injury or health problems preventing full participation in testing or training; (5) no musculoskeletal injuries during the preceding 6 months; and (6) no ligament injury during the preceding 12 months. A self-reported medical and injury history covering the preceding year was obtained before enrolment. For inclusion in

the final analysis, participants were required to complete the pre- and post-intervention assessments and attend at least 8 of the 10 planned intervention sessions (≥80% adherence).

The study was conducted in accordance with the Declaration of Helsinki and was approved by the institutional ethics committee (approval code DCD.CJR.230630). Written informed consent was obtained from a parent or legal guardian, and assent was obtained from each player before participation.

2.3. Testing Procedures

Pre- and post-intervention assessments were conducted on the players' usual training field. Tests were administered in the following fixed order: bird-dog stability test, single-leg front-bridge stability test, LESS, and CMAS. Testing took place during the teams' usual evening training period, between approximately 18:00 and 20:00 h, on the same outdoor artificial-turf pitch. Players wore their usual football training kit and football boots. Environmental conditions were not formally recorded. A 3 min recovery interval was provided between repeated trials of the same test and 5 min between consecutive tests. The same test order, surface, footwear requirements, time-of-day window, and standardised instructions were used at both assessment occasions.

Before the bird-dog and single-leg front-bridge tests, participants completed a brief mobility and motor-control routine emphasising a neutral position of the lumbar spine and pelvis. After completing these lumbopelvic stability tests, participants performed a standardised warm-up based on the first running component of the FIFA 11+ programme (running straight ahead, hip out, hip in, circling partner, shoulder contact and quick forwards and backwards) before the LESS and CMAS. This was followed by one submaximal familiarisation trial of each task. For the LESS and accelerometer-based lumbopelvic-control tests, two valid trials were recorded at baseline and their mean was used for analysis, whereas one valid trial was retained at post-intervention. For the CMAS assessment, one valid trial was recorded in each cutting direction (right and left) at each assessment occasion. The same validity criteria and testing instructions were applied at both assessment occasions.

2.3.1. Landing Error Scoring System

Landing movement quality was assessed using the LESS according to the procedures described by Padua et al. [16,17]. Players stood on a 30 cm box positioned at a horizontal distance equivalent to 50% of their body height from a line marking the target landing location. They were instructed to jump forward, land beyond the line with both feet, and immediately perform a maximal vertical jump before landing again. Both hands remained on the iliac crests throughout the task. A trial was considered invalid if the player removed the hands from the iliac crests, failed to land beyond the marked line, did not complete the immediate vertical jump, or stepped on the marked line.

The task was recorded simultaneously in the frontal and sagittal planes. The frontal- and sagittal-plane cameras were positioned 3.45 m from the centre of the landing location at a height of approximately 0.60 m. Recordings were obtained at 240 frames·s^{-1} using an iPhone 15 Pro and an iPhone 13 (Apple Inc., Cupertino, CA, USA). Videos were analysed by the same trained evaluator using Tracker software (version 6.1.6; [23]) following standardised operational rubrics. Recordings could be paused, rewound, and examined frame by frame as required. Initial contact was identified as the first frame in which the foot contacted the ground, whereas maximum knee flexion was identified as the frame showing the greatest knee flexion during the landing phase. Frontal- and sagittal-plane recordings were examined according to the established LESS item-specific criteria. All scoring decisions were made by the same trained evaluator. When classification of an item was uncertain, the relevant sequence and adjacent frames in both views were re-examined before assigning the

final score. The total LESS score was then calculated, with higher scores indicating a greater number of observable landing errors and, therefore, poorer landing movement quality.

2.3.2. Cutting Movement Assessment Score and Change-of-Direction Time

Cutting movement quality was assessed using the Spanish-language adaptation of the CMAS [19,20]. From a stationary start, participants accelerated maximally for 5 m, performed a 90° COD, and completed a 3 m exit sprint. At each assessment occasion, participants completed one valid trial in each direction, first cutting to the right and then to the left. Starting from a stationary position reduced variation attributable to the approach strategy. A trial was considered invalid and was repeated if the player slipped, failed to pass through the timing gates, did not complete the prescribed 90° side-step cut within the marked COD area, or deviated substantially from the prescribed approach or exit path.

COD time was recorded using two pairs of photoelectric timing gates (Witty System, Microgate, Bolzano, Italy; recording precision: 0.01 s), with the first gate positioned 0.50 m beyond the start line and the second 3 m after the COD. The timing gates were positioned at a height of 1.05 m. Two cameras were positioned 5 m from the centre of the COD area at a height of 0.60 m, one in the frontal plane and one in the sagittal plane aligned with the direction of the cut. The same smartphones and recording frequency used for the LESS were employed.

Videos were analysed with Tracker software [23] and scored using the established CMAS criteria. Higher CMASs indicate a greater number of observable COD characteristics associated with potentially greater knee-joint loading. Side-specific CMAS scores and COD times were obtained. The bilateral CMAS outcome was calculated as the mean of the right- and left-side scores, whereas bilateral COD time was calculated as the mean of the two directions.

All LESS and CMAS recordings were scored by the same trained evaluator, who was aware of group allocation and assessment occasion. No study-specific intra-rater reliability assessment was performed.

2.3.3. Accelerometer-Based Lumbopelvic Stability Tests

Lumbopelvic stability was assessed using the single-leg front-bridge stability test and the bird-dog stability test, following previously described field-based protocols [21]. Both tests have been used to quantify lumbopelvic stability through accelerometry during trunk stability tasks. A triaxial accelerometer integrated into an iPhone SE (2021; Apple Inc., Cupertino, CA, USA) was used to quantify pelvic acceleration. The smartphone was secured over the lumbosacral region using a fitted hook-and-loop belt, and acceleration was recorded at 200 Hz using the CoreMaker application. During each 15 s trial, participants were instructed to maintain a neutral lumbar-spine and pelvic position while minimising pelvic oscillation.

The single-leg front-bridge stability test was performed with support on the dominant leg. The bird-dog stability test was performed with the dominant leg and non-dominant arm supporting the body, while the contralateral leg and arm were extended. Leg dominance was defined as the leg preferentially used to kick a ball [24]. The CoreMaker application provided linear acceleration signals with the gravitational component removed. Acceleration signals were low-pass filtered using a fourth-order, zero-phase-lag Butterworth filter with a 10 Hz cut-off frequency. Resultant acceleration was calculated as the square root of the sum of the squared acceleration values from the three orthogonal axes. The first second of each 15 s trial was discarded, and the following 12 s were retained for analysis. Mean resultant acceleration over this 12 s window was used as the outcome measure, with

lower values indicating lower pelvic oscillation and, consequently, greater lumbopelvic stability [21].

2.4. Training Interventions

Training sessions were planned and delivered in coordination with the teams' coaching staff and were added to the players' regular in-season football training. Sessions were scheduled on match day −4 and match day −2 and lasted approximately 15 min. Participants continued their habitual football training with their respective teams throughout the intervention. However, regular football training content and volume, individual playing time, and match exposure were not systematically recorded; therefore, the comparability of habitual football exposure across participants and teams could not be formally assessed.

2.4.1. Standing Single-Leg Trunk Stability Programme

The standing single-leg trunk stability programme comprised four progressively more demanding variations based on the single-leg airplane exercise (Figure 1), an exercise that challenges hip control during single-leg support [25,26]. The primary objective of all variations was to maintain controlled thorax–pelvis alignment and a neutral lumbar-spine position while the trunk was controlled as a relatively rigid segment over the supporting hip. Participants were instructed to minimise relative rotation between the thorax and pelvis while controlling hip motion and maintaining whole-body balance. Thus, the exercise was used primarily as a dynamic anti-rotational trunk stability task rather than as a lower-limb strengthening or jumping exercise.

During week 1, players practised the conventional airplane exercise. During weeks 2–3, the conventional variation was retained during the warm-up, whereas the main part included an airplane incorporating a small submaximal vertical jump and an airplane performed against elastic resistance applied around the pelvis. During weeks 4–5, the main part included the resisted airplane and a resisted variation incorporating small submaximal jumps. The jumping actions and elastic resistance were introduced as self-generated and external perturbations intended to increase the demands on trunk and whole-body control during the task; jump height and landing performance were not training objectives.

Elastic resistance was provided using a green, medium-resistance elastic band (15 cm wide, supplied in a 25 m roll; Elk Sport, Zaragoza, Spain). The band was positioned around the pelvis, approximately at the level of the iliac crests, and attached to a fixed anchor. Anchor height was individually adjusted according to player stature so that resistance was applied approximately horizontally at pelvic level. Resistance was applied from either side of the participant to perturb trunk position and increase the three-dimensional control demands imposed during the hip movement. The perturbation could also challenge lower-limb alignment, including frontal-plane knee control. The same band, anchoring procedure, and relative position between the participant and anchor were maintained throughout the intervention; however, band elongation and the resulting resistance force were not formally quantified.

Three sets of 10 repetitions were prescribed for each exercise included in the session. Repetitions were performed at a controlled tempo, guided by verbal instructions from the instructor, with 30 s of recovery between sets and 60 s between exercises. The exercises included in each session were organised so that the main part lasted approximately 10 min, thereby matching the comparison groups for overall session duration, although exercise volume and mechanical loading were not formally equated between programmes. Exercise progression followed a predefined weekly schedule, with more demanding variations introduced during weeks 2–3 and 4–5 (Figure 1; Table 1). All sessions were supervised by a

qualified exercise professional, who provided verbal instructions and technical feedback to promote appropriate trunk alignment, whole-body balance, and correct exercise execution.

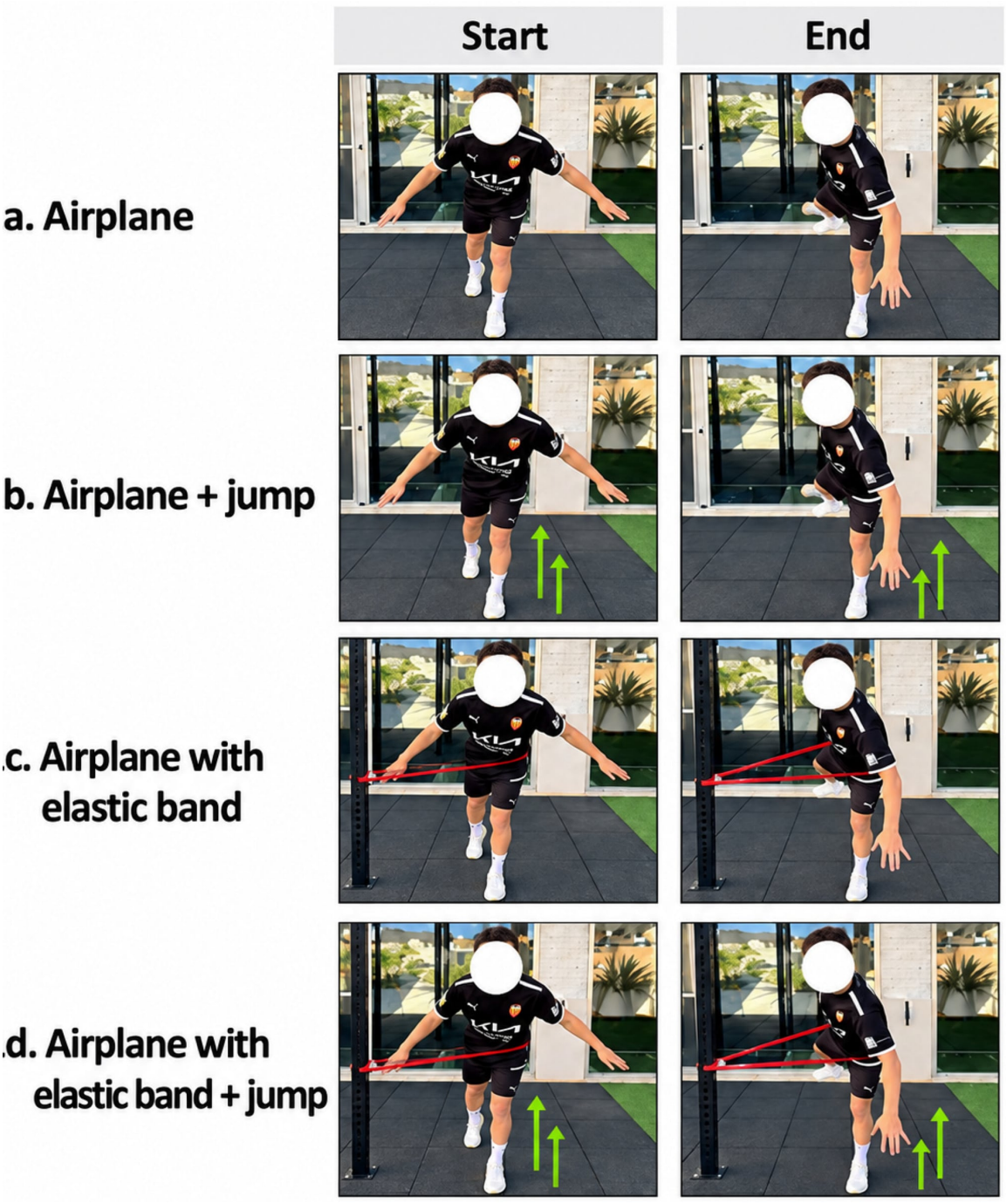


Figure 1. Progression of the standing single-leg trunk stability exercises used during the 5-week intervention programme. Panels (**a**–**d**) illustrate the exercise progression from the conventional airplane (**a**), to the airplane combined with a small submaximal vertical jump (**b**), the resisted airplane using an elastic band around the pelvis (**c**), and the resisted airplane combined with a small submaximal vertical jump (**d**). The left and right columns show the start and end positions of each exercise, respectively. Green arrows indicate the jumping action, and the red line represents the direction of elastic resistance.

Table 1. Summary of the intervention programmes.

Group	Week 1	Weeks 2–3	Weeks 4–5	Dose
Standing single-leg	Conventional airplane; additional practice of maintaining a neutral lumbar-spine position and controlled thorax–pelvis alignment.	Conventional airplane during the warm-up; airplane with a small submaximal vertical jump and resisted airplane as separate variations during the main part.	Resisted airplane and resisted airplane combined with a small submaximal vertical jump, with emphasis on maintaining trunk control during the perturbation.	3 × 10 repetitions per exercise; controlled tempo guided by verbal instructions; 30-s inter-set and 60-s inter-exercise recovery; approximately 10 min main part; 2 sessions·week^{-1}.
Floor-based	Variations 1–2 of the back bridge, side bridge, front bridge, and bird-dog, emphasizing maintenance of a neutral lumbar-spine and pelvic position.	Variations 2–3, progressing exercise difficulty through longer lever arms, reduced base of support, and contralateral limb elevation while maintaining trunk alignment.	Variations 3–4, incorporating single-limb and alternating support and controlled dynamic limb movements while minimizing unwanted trunk motion.	2 × 15 s per exercise; supporting limb changed every 5 s when prescribed; 30-s inter-set and 60-s inter-exercise recovery; approximately 10 min main part; 2 sessions·week^{-1}.
Active control	Seven general-conditioning stations including squats, hip-hinge variations, hip thrusts, upper-body pushing and pulling exercises, plyometric tasks, and sprint exercises.	The same seven-station general-conditioning circuit structure was maintained.	The same seven-station general-conditioning circuit structure was maintained.	7 × 1-min stations; brief transitions between stations; approximately 10 min main part; 2 sessions·week^{-1}.

2.4.2. Floor-Based Trunk Stability Programme

The conventional programme included progressive variations of four commonly used floor-based trunk stability exercises: the back bridge, side bridge, front bridge, and bird-dog (Figure 2). Throughout all exercises, participants were instructed to maintain a neutral lumbar-spine and pelvic position while minimising unwanted trunk motion. Exercise difficulty was progressed by manipulating mechanical factors previously shown to modify the intensity of trunk stability exercises, including increasing lever length, reducing the base of support, alternating the supporting limb, elevating the contralateral limbs, and incorporating controlled limb movements [12,13]. Variations 1 and 2 were performed during week 1, variations 2 and 3 during weeks 2–3, and variations 3 and 4 during weeks 4–5. Each exercise was performed for two 15-s sets. In variations involving alternating support, the supporting limb was changed every 5 s. Recovery intervals were 30-s between sets and 60-s between exercises. Exercise execution was standardised through verbal instructions and continuous supervision by the instructor.

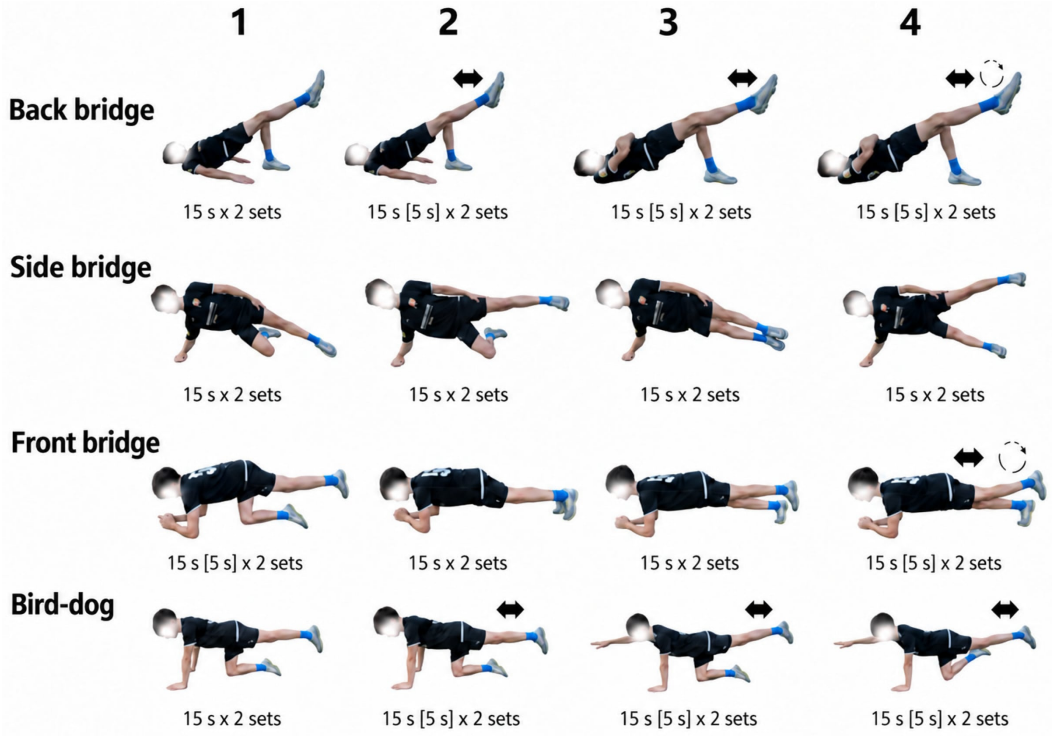


Figure 2. Progression of the floor-based trunk stability exercises performed during the 5-week intervention programme. The four exercise families included back bridge, side bridge, front bridge, and bird-dog. Columns 1–4 represent the progressive exercise variations used throughout the programme. For the back bridge, front bridge, and bird-dog exercises, the notation [5 s] indicates that the supporting limb was changed every 5 s during the 15-s set when required. Circular arrows indicate controlled circular movements of the elevated limb, and horizontal double-headed arrows indicate alternating support or controlled limb displacement. Each exercise was performed for 2 sets of 15 s.

2.4.3. Active Control Programme

The active control group did not perform either of the two prescribed trunk-focused programmes. Instead, players completed a duration-matched general-conditioning circuit comprising seven 1-min exercise stations per session. The circuit included upper and lower-body strength exercises: (1) squats, (2) hip-hinge variations, (3) hip thrusts, (4) upper-body pushing exercises, (5) upper-body pulling exercises, (6) plyometric tasks, and (7) short sprint drills. Each station was performed for 1 min, with brief transitions between stations, resulting in a main-part duration of approximately 10 min. The same general circuit structure was maintained throughout the 5-week intervention, and no formal progression in external load was prescribed. Sessions were completed twice per week (Table 1).

2.5. Statistical Analysis

Data are presented as mean ± standard deviation (SD) unless otherwise stated. LESS and bilateral mean CMAS were treated as co-primary outcomes, whereas bilateral mean COD time, front-bridge acceleration, and bird-dog acceleration were secondary outcomes. Lower values represented more favourable outcomes for all measures. Analyses were performed on an adherence-restricted available-case basis without imputation.

Between-group effects were examined using separate ANCOVA models for each outcome, with the post-intervention value as the dependent variable, group as a fixed factor, and the corresponding baseline value as a covariate. Inference was based on heteroscedasticity-consistent HC3 covariance estimates. Adjusted post-intervention means and 95% confidence intervals (CI) were estimated at the overall mean baseline value. Familywise error across the two co-primary omnibus tests was controlled using the Holm procedure; when an omnibus

effect was significant, Holm adjustment was also applied across the three pairwise group comparisons. The magnitude of each adjusted between-group contrast was expressed as Hedges' g, calculated by dividing the ANCOVA-adjusted mean difference by the residual standard deviation of the corresponding model (square root of the residual mean square) and applying the exact small-sample bias correction factor, $J(\nu)$, based on the residual degrees of freedom ($\nu = N - 4$). Ninety-five percent confidence intervals for Hedges' g were obtained using 20,000 non-parametric stratified bootstrap resamples, with participants sampled with replacement within each intervention group while preserving group sample sizes. The ANCOVA model was refitted and Hedges' g recalculated in each resample. Confidence intervals were defined by the 2.5th and 97.5th percentiles of the bootstrap distribution. A fixed random seed (20261022) was used for reproducibility. Partial eta-squared (ηp^2) from the conventional ANCOVA was reported descriptively.

Model assumptions and potentially influential observations were examined using residual diagnostics, the Shapiro–Wilk and Breusch–Pagan tests, and Cook's distance. Complementary within-group pre-to-post comparisons were performed using paired-samples t-tests, with Holm-adjusted *p*-values and Cohen's dz; these analyses were considered descriptive. As complementary sensitivity analyses, side-specific CMAS scores and COD times were analysed using generalised estimating equations (GEE). This approach was selected because left- and right-side observations from the same participant may be correlated and therefore should not be treated as independent. GEE enables the joint analysis of correlated observations while estimating population-averaged group effects [27,28]. Models included the corresponding side-specific baseline value, intervention group, and side, with participant specified as the clustering variable. Chronological age was additionally included in age-adjusted models, and group-by-side interactions were examined separately. A Gaussian distribution with an identity link and an exchangeable working correlation structure were specified, allowing a common within-participant correlation between left- and right-side observations. Bias-reduced robust covariance estimates were used to mitigate potential small-sample bias in the standard errors [29]. These analyses complemented the primary ANCOVA models based on bilateral mean outcomes and allowed available side-specific observations to be retained. All tests were two-sided with $\alpha = 0.05$. Analyses were conducted in Python 3.13.5 using stats models 0.14.6 and SciPy 1.17.0.

3. Results

3.1. Participants and Data Availability

Thirty-one football players were included: 11 in the standing single-leg trunk stability training group, 12 in the conventional floor-based exercise group, and 8 in the active control group. All participants completed the pre- and post-intervention assessment sessions and attended at least eight of the ten scheduled training sessions (≥80% adherence). Complete data were available for LESS, COD time, and both lumbopelvic stability tests. The co-primary bilateral CMAS analysis included 30 players because the baseline right-side CMAS score was missing for one participant in the floor-based group. The corresponding right-side COD time and left-side CMAS score were available, although the reason for the missing CMAS score could not be established from the original records. Descriptive pre- and post-intervention data are presented in Table 2, and adjusted between-group comparisons for the co-primary outcomes are presented in Table 3. Full ANCOVA and sensitivity analyses are provided in the Supplementary Materials.

Table 2. Descriptive pre-intervention, post-intervention, and change scores by group.

Outcome	Group	n	Pre-Intervention	Post-Intervention	Change
LESS (points)	Standing single-leg	11	5.95 ± 2.31	3.18 ± 2.09	−2.77 ± 2.21
LESS (points)	Floor-based	12	5.62 ± 1.57	6.33 ± 2.27	0.71 ± 2.25
LESS (points)	Active control	8	5.94 ± 0.86	7.62 ± 1.30	1.69 ± 1.44
Bilateral CMAS (points)	Standing single-leg	11	7.41 ± 1.01	3.95 ± 1.44	−3.45 ± 1.59
Bilateral CMAS (points)	Floor-based	11	7.55 ± 0.71	5.86 ± 1.23	−1.68 ± 1.28
Bilateral CMAS (points)	Active control	8	8.22 ± 0.78	6.94 ± 1.08	−1.28 ± 1.09
Bilateral COD time (s)	Standing single-leg	11	2.01 ± 0.13	1.86 ± 0.14	−0.15 ± 0.06
Bilateral COD time (s)	Floor-based	12	1.92 ± 0.10	1.78 ± 0.11	−0.15 ± 0.06
Bilateral COD time (s)	Active control	8	1.90 ± 0.06	1.83 ± 0.08	−0.07 ± 0.08
Front bridge acceleration ($m \cdot s^{-2}$)	Standing single-leg	11	0.48 ± 0.13	0.52 ± 0.11	0.04 ± 0.16
Front bridge acceleration ($m \cdot s^{-2}$)	Floor-based	12	0.41 ± 0.19	0.44 ± 0.10	0.03 ± 0.17
Front bridge acceleration ($m \cdot s^{-2}$)	Active control	8	0.38 ± 0.11	0.50 ± 0.14	0.11 ± 0.19
Bird-dog acceleration ($m \cdot s^{-2}$)	Standing single-leg	11	0.33 ± 0.08	0.35 ± 0.15	0.02 ± 0.12
Bird-dog acceleration ($m \cdot s^{-2}$)	Floor-based	12	0.41 ± 0.14	0.31 ± 0.09	−0.10 ± 0.14
Bird-dog acceleration ($m \cdot s^{-2}$)	Active control	8	0.52 ± 0.12	0.32 ± 0.09	−0.21 ± 0.11

Note. Data are presented as mean ± standard deviation. Change was calculated as post-intervention minus pre-intervention; therefore, negative values indicate a favourable change for all outcomes. Bilateral CMAS is the mean of the left and right sides and includes participants with complete bilateral data. Abbreviations: LESS, Landing Error Scoring System; CMAS, Cutting Movement Assessment Score; COD, change of direction.

Table 3. Adjusted between-group comparisons for the co-primary outcomes.

Outcome	Comparison	Adjusted Difference (95% CI)	Holm-Adjusted *p*	Hedges' g (95% CI)
LESS	Standing single-leg—Floor-based	−3.30 [−5.11, −1.50]	0.002	−1.72 [−3.08, −0.92]
LESS	Standing single-leg—Active control	−4.45 [−6.04, −2.87]	<0.001	−2.32 [−3.55, −1.66]
LESS	Floor-based—Active control	−1.15 [−2.82, 0.53]	0.172	−0.60 [−1.51, 0.16]
Bilateral CMAS	Standing single-leg—Floor-based	−1.86 [−3.11, −0.61]	0.010	−1.43 [−2.72, −0.61]
Bilateral CMAS	Standing single-leg—Active control	−2.70 [−3.92, −1.48]	<0.001	−2.07 [−3.64, −1.21]
Bilateral CMAS	Floor-based—Active control	−0.84 [−1.92, 0.24]	0.123	−0.64 [−1.65, 0.06]

Note. Differences are expressed as the first group minus the second group. Negative values favour the first group because lower scores indicate better movement quality. *p*-values were adjusted using the Holm procedure. Abbreviations: LESS, Landing Error Scoring System; CMAS, Cutting Movement Assessment Score; CI, confidence interval.

3.2. Landing Movement Quality

A significant overall group effect was observed for baseline-adjusted LESS scores, $F(2.27) = 17.02$, $p < 0.001$, $\eta p^2 = 0.53$. The standing single-leg group showed a lower adjusted LESS score than the floor-based group (adjusted mean difference −3.30 points, 95% CI −5.11 to −1.50; *p*Holm= 0.002; Hedges' g = −1.72, 95% CI −3.08 to −0.92) and the active control group (−4.45 points, 95% CI −6.04 to −2.87; *p*Holm < 0.001; g = −2.32, 95% CI −3.55 to −1.66). No clear difference was observed between the floor-based and active control groups (Figure 3A; Table 3).

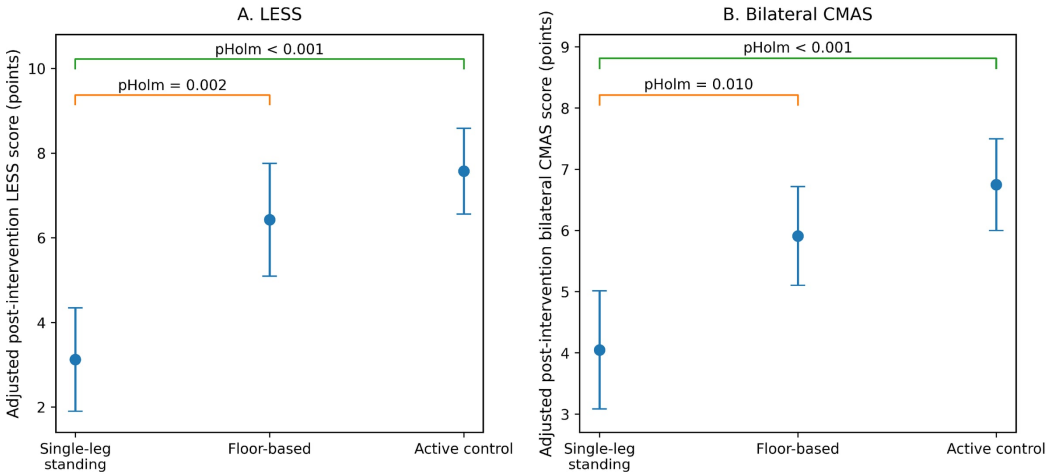


Figure 3. Adjusted between-group comparisons for Landing Error Scoring System (LESS) and bilateral Cutting Movement Assessment Score (CMAS). Panel (**A**) shows adjusted post-intervention LESS scores and panel (**B**) shows adjusted post-intervention bilateral mean CMAS scores. Values were adjusted for the corresponding baseline score using ANCOVA. Points represent adjusted means and whiskers indicate 95% confidence intervals. Only significant Holm-adjusted pairwise (*p*Holm) comparisons are shown. Lower values indicate better movement quality.

3.3. Cutting Movement Quality

A significant overall group effect was also observed for bilateral CMAS, $F(2.26) = 10.45$, $p < 0.001$, $\eta p^2 = 0.45$. The standing single-leg group showed lower adjusted CMAS scores than the floor-based group (adjusted mean difference −1.86 points, 95% CI −3.11 to −0.61; *p*Holm= 0.010; Hedges' g = −1.43, 95% CI −2.72 to −0.61) and the active control group (−2.70 points, 95% CI −3.92 to −1.48; *p*Holm < 0.001; g = −2.07, 95% CI −3.64 to −1.21). No clear difference was observed between the floor-based and active control groups (Figure 3B; Table 3). Both co-primary omnibus group effects remained significant after Holm adjustment (both *p*Holm < 0.001).

3.4. Secondary Outcomes

No statistically significant omnibus between-group effects were observed for bilateral COD time ($p = 0.126$), front-bridge acceleration ($p = 0.323$), or bird-dog acceleration ($p = 0.277$). However, the adjusted pairwise estimates showed considerable uncertainty. For example, the standing single-leg versus active control contrast was −0.059 s (95% CI −0.134 to 0.016) for COD time, whereas the standing single-leg versus floor-based contrast was 0.069 $m \cdot s^{-2}$ (95% CI −0.032 to 0.171) for front-bridge acceleration. For bird-dog acceleration, the standing single-leg versus active control contrast was 0.117 $m \cdot s^{-2}$ (95% CI −0.029 to 0.263). These confidence intervals are compatible with effects of varying magnitude and, in some cases, either direction. Therefore, the absence of statistically significant group effects should not be interpreted as evidence of equivalent intervention effects. All adjusted pairwise contrasts and 95% confidence intervals are provided in Supplementary Table S2.

3.5. Sensitivity Analyses

The LESS finding remained robust after adjustment for age. The age-adjusted bilateral CMAS omnibus effect remained significant ($p = 0.047$), although pairwise comparisons were attenuated after Holm adjustment (both pHolm = 0.058 for comparisons involving the standing single-leg group). Importantly, the complementary age-adjusted side-specific generalised estimating equations (GEE) analysis retained all 31 participants (61 available side-specific observations), including the left-side CMAS data from the participant excluded from the bilateral analysis. This analysis continued to support a significant group effect ($p = 0.012$), with lower CMAS scores in the standing single-leg group than in both the floor-based (pHolm = 0.017) and active control (pHolm = 0.014) groups. No group-by-side interaction was detected ($p = 0.260$). Full sensitivity analyses are presented in Supplementary Table S4.

3.6. Diagnostics

Model diagnostics showed no evidence of heteroscedasticity. Residuals were approximately normally distributed for all outcomes except bird-dog; sensitivity analyses excluding potentially influential observations did not materially alter the conclusions (Supplementary Table S5).

3.7. Complementary Within-Group Analyses

Complementary within-group analyses are shown in Supplementary Table S3 and Supplementary Figure S1. These analyses were descriptive and were not used to determine intervention superiority.

4. Discussion

The aim of this study was to compare the effects of a 5-week standing single-leg trunk stability programme, a conventional floor-based trunk stability programme, and an active general-conditioning control programme in early-adolescent male football players. The main finding of this small active-controlled randomised trial was that a 5-week standing single-leg trunk stability programme was associated with lower baseline-adjusted LESS and bilateral CMAS scores than conventional floor-based trunk stability training and active general conditioning in early-adolescent male football players. In contrast, no clear between-group differences were observed for COD time or accelerometer-derived pelvic acceleration during the single-leg front-bridge and bird-dog stability tests. Overall, this pattern is consistent with a task-specific training response, whereby the greatest adaptations were observed in assessment tasks that shared postural and coordinative demands with the standing intervention.

One possible explanation is that the standing single-leg programme challenged trunk control under conditions that more closely resembled the mechanical demands of landing and cutting. The exercises required participants to control thorax–pelvis alignment while maintaining single-leg balance and performing hip movement under both self-generated and externally applied perturbations. The elastic resistance applied around the pelvis may have increased the demand for active trunk control, whereas the small submaximal vertical jumps introduced transient perturbations without being intended as maximal jumping or landing drills. Therefore, the programme was designed primarily to increase the difficulty of maintaining trunk stability during dynamic single-leg tasks rather than to train jumping performance itself. However, because upright unilateral support, elastic resistance, and jumping actions were combined within the same intervention, their individual contributions to the observed improvements cannot be distinguished. The findings should therefore be interpreted as the effects of the multicomponent programme as implemented, rather

than as evidence that upright posture or trunk-stability training alone was responsible for the differences.

The observed pattern is consistent with the principle of task specificity, whereby training adaptations may be more evident when training and assessment tasks share similar postural, coordinative, and mechanical demands [14]. In contrast to the standing programme, conventional floor-based training challenged trunk stability primarily in supine, lateral, prone, and quadruped positions. These differences in task demands may partly explain the greater improvements in LESS and CMAS scores following the standing programme, whereas no clear between-group differences were observed in COD time or the floor-based stability tests. Previous research has suggested that trunk-focused or more sport-specific core-stability programmes can improve selected performance outcomes in youth football players, although findings vary across outcomes and training approaches [6,15]. The present results extend this evidence by suggesting that observable landing and cutting movement quality may be responsive to training programmes incorporating sport-relevant postural and mechanical demands. Importantly, the present trial assessed changes in video-based LESS and CMAS screening scores rather than directly measuring three-dimensional knee joint kinematics, joint loading, or prospective injury incidence. Therefore, improvements in these scores should be interpreted as changes in observable movement quality and not as direct evidence of reduced ACL injury risk [18].

The applicability of these assessments to early-adolescent football players also warrants consideration. A recent systematic review in soccer players reported high intra- and inter-rater reliability for the LESS and acceptable validity, but inconsistent evidence regarding its prognostic utility [18]. LESS scores may also be influenced by growth and maturation during adolescence [30]. The CMAS has been validated against three-dimensional biomechanical measures and has shown responsiveness to technique-modification interventions in older youth players [19,31]. However, age-specific normative values and criterion thresholds have not been established for early-adolescent players. Accordingly, the present findings should primarily be interpreted as changes in movement quality rather than as indicators of individual injury risk. The attenuation of the bilateral CMAS pairwise comparisons after adjustment for chronological age further warrants caution. In early-adolescent football players, biological maturation may influence strength, coordination, and landing and cutting mechanics independently of chronological age. Because maturation status was not assessed, age adjustment cannot exclude residual developmental confounding, even though the complementary age-adjusted side-specific analysis continued to support a group effect.

No clear between-group difference was observed for COD time. Although the estimate was imprecise and the small sample limits strong conclusions, the absence of a clear superiority effect may partly reflect the content of the active control programme, which included strength, plyometric, and sprint exercises, together with continued football training in all groups. Recent evidence indicates that these training modalities, particularly when combined with sprint and COD-oriented exercises, can improve COD performance in adolescent team-sport and youth football players [32,33]. Thus, the active control programme may itself have provided a relevant stimulus for COD performance, reducing the likelihood of detecting an additional effect of the standing trunk-stability programme. Similarly, no clear between-group differences were observed for the single-leg front-bridge or bird-dog stability tests. This may reflect the task-specific nature of adaptation, limited sensitivity of these floor-based tests to changes induced by an upright unilateral programme, or the short intervention duration. The raw improvement observed in bird-dog performance in the floor-based group did not remain significant after Holm correction and was not greater than the change observed in the active control group.

From a practical perspective, the standing single-leg trunk stability programme was brief, required little equipment, and could be integrated into the players' normal training week. Two 15-min sessions per week were associated with substantial improvements in LESS and CMAS scores. These findings suggest that standing unilateral trunk stability exercises incorporating controlled elastic perturbations and small submaximal jumps may be useful when the aim is to improve movement quality during football-related landing and cutting tasks. However, such exercises should complement rather than replace broader neuromuscular injury-prevention programmes that also include lower-limb strength, deceleration technique, landing mechanics, and appropriately progressed plyometric training [34].

Several limitations should be considered. First, no formal allocation-concealment procedure was implemented, and LESS and CMAS scoring was performed by a single evaluator who was aware of group allocation and assessment occasion, introducing potential risks of selection and detection bias. Although scoring followed standardised operational criteria and high-speed frame-by-frame video analysis, evaluator-specific intra-rater reliability was not assessed. Future studies should incorporate allocation concealment, blinded assessors, and formal reliability testing. Second, the sample was small and included only male players from two teams, limiting generalisability. Although randomisation was conducted separately within each team, potential differences in coaching practices, habitual training content, and competitive exposure cannot be completely excluded as sources of residual confounding. Furthermore, because participants assigned to different intervention conditions continued training within the same team environments, possible contamination between programmes cannot be excluded. Third, biological maturation was not assessed, and adjustment for chronological age cannot fully account for developmental differences in strength, coordination, and movement mechanics. This limitation is particularly relevant given the attenuation of the bilateral CMAS pairwise comparisons after age adjustment, despite the supportive findings of the complementary side-specific analysis. Fourth, for LESS and the accelerometer-based stability tests, baseline values were calculated from two valid trials, whereas post-intervention values were based on a single trial. Although this procedure was applied consistently across intervention groups, the unequal number of trials may have affected measurement precision and increased uncertainty in the estimation of intervention-related changes. Fifth, habitual football training content and volume, individual playing time, and match exposure were not formally quantified. Furthermore, although the intervention programmes were approximately matched for session duration, exercise volume, external resistance, and mechanical loading were not formally equated. Consequently, the observed effects should be attributed to the multicomponent programmes as implemented rather than to standing posture, trunk-stability training, or any individual exercise component in isolation. Sixth, the final analytical sample comprised participants who completed the pre- and post-intervention assessments and attended at least 80% of the scheduled training sessions. Thus, the analyses represent an adherence-restricted available-case approach rather than a strict intention-to-treat analysis. In addition, one participant was excluded from the bilateral CMAS analysis because of a missing baseline right-side score, although the complementary side-specific analysis retained the available observations from all 31 participants. Finally, the 5-week intervention may have been insufficient to detect some training adaptations, particularly for the secondary outcomes. Moreover, the study assessed movement-quality screening scores and performance outcomes rather than directly measured three-dimensional joint loading or prospective injury incidence. Therefore, the findings should not be interpreted as evidence of reduced ACL injury risk.

5. Conclusions

In this small active-controlled randomised trial, a 5-week standing single-leg trunk stability programme was associated with lower baseline-adjusted LESS and bilateral CMAS scores than conventional floor-based trunk stability training and active general conditioning in early-adolescent male football players. No clear between-group differences were observed for COD time or accelerometer-derived lumbopelvic stability. These findings support a task-specific training effect on observable landing and cutting movement quality, but they should not be interpreted as evidence of reduced ACL injury risk. From a practical perspective, brief standing single-leg trunk stability exercises may be a feasible supplementary component of football training, particularly when the aim is to expose young players to upright unilateral and landing-related movement demands. However, these exercises should complement rather than replace broader neuromuscular programmes incorporating lower-limb strength, deceleration, landing, sprint, and plyometric training. Larger trials with blinded outcome assessment, maturation measures, and longer-term follow-up are needed to confirm these findings.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/sports14110506/s1, Table S1: Baseline participant characteristics by group; Table S2: ANCOVA results for all outcomes and adjusted pairwise contrasts for secondary outcomes; Table S3: Complementary within-group pre-to-post changes; Table S4: Sensitivity analyses; Table S5: Model diagnostics and influential-observation analyses; Figure S1: Complementary within-group pre-to-post changes.

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Informed Consent Statement: Written informed consent was obtained from a parent or legal guardian of each participant, and assent was obtained from all participants involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author due to the confidentiality of the participating minors.

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References

1. Dennis, J.D.; Choe, K.H.; Montgomery, M.M.; Lynn, S.K.; Crews, B.M.; Pamukoff, D.N. Lower extremity and trunk sagittal plane coordination strategies and kinetic distribution during landing in males and females. *J. Sports Sci.* **2024**, *42*, 169–178. [CrossRef] [PubMed]
2. Singh, U.; Leicht, A.S.; Connor, J.D.; Brice, S.M.; Alves, A.; Doma, K. Biomechanical determinants of change of direction performance: A systematic review. *Sports Med.* **2025**, *55*, 2207–2224. [CrossRef] [PubMed]
3. Zazulak, B.T.; Hewett, T.E.; Reeves, N.P.; Goldberg, B.; Cholewicki, J. Deficits in neuromuscular control of the trunk predict knee injury risk: A prospective biomechanical-epidemiologic study. *Am. J. Sports Med.* **2007**, *35*, 1123–1130. [CrossRef] [PubMed]

4. Dong, K.; Yu, T.; Chun, B. Effects of core training on sport-specific performance of athletes: A meta-analysis of randomized controlled trials. *Behav. Sci.* **2023**, *13*, 148. [CrossRef] [PubMed]
5. Rodríguez-Perea, Á.; Reyes-Ferrada, W.; Jerez-Mayorga, D.; Chirosa Ríos, L.; Van den Tillar, R.; Chirosa Ríos, I.; Martínez-García, D. Core training and performance: A systematic review with meta-analysis. *Biol. Sport* **2023**, *40*, 975–992. [CrossRef] [PubMed]
6. Saeterbakken, A.H.; Stien, N.; Andersen, V.; Scott, S.; Cumming, K.T.; Behm, D.G.; Granacher, U.; Prieske, O. The effects of trunk muscle training on physical fitness and sport-specific performance in young and adult athletes: A systematic review and meta-analysis. *Sports Med.* **2022**, *52*, 1599–1622. [CrossRef] [PubMed]
7. Robles-Palazón, F.J.; López-Valenciano, A.; De Ste Croix, M.; Oliver, J.L.; García-Gómez, A.; Sainz de Baranda, P.; Ayala, F. Epidemiology of injuries in male and female youth football players: A systematic review and meta-analysis. *J. Sport Health Sci.* **2022**, *11*, 681–695. [CrossRef] [PubMed]
8. Castillo, D.; Marqués-Jiménez, D.; Bertollo, M.; López-Flores, M.; Bovolon, L.; De Fano, A.; Pompa, D. A systematic review and meta-analysis of various injury prevention programs in youth soccer players. *BMC Sports Sci. Med. Rehabil.* **2025**, *17*, 190. [CrossRef] [PubMed]
9. Imai, A.; Kaneoka, K.; Okubo, Y.; Shiraki, H. Effects of two types of trunk exercises on balance and athletic performance in youth soccer players. *Int. J. Sports Phys. Ther.* **2014**, *9*, 47–57. [PubMed]
10. Takai, Y.; Nakatani, M.; Akamine, T.; Shiokawa, K.; Komori, D.; Kanehisa, H. Effect of core training on trunk flexor musculature in male soccer players. *Sports Med. Int. Open* **2017**, *1*, E147–E154. [CrossRef] [PubMed]
11. Vera-Garcia, F.J.; Irles-Vidal, B.; Prat-Luri, A.; García-Vaquero, M.P.; Barbado, D.; Juan-Recio, C. Progressions of core stabilization exercises based on postural control challenge assessment. *Eur. J. Appl. Physiol.* **2020**, *120*, 567–577. [CrossRef] [PubMed]
12. Calatayud, J.; Casaña, J.; Martín, F.; Jakobsen, M.D.; Colado, J.C.; Andersen, L.L. Progression of core stability exercises based on the extent of muscle activity. *Am. J. Phys. Med. Rehabil.* **2017**, *96*, 694–699. [CrossRef] [PubMed]
13. Heredia-Elvar, J.R.; Juan-Recio, C.; Prat-Luri, A.; Barbado, D.; de Los Ríos-Calonge, J.; Vera-Garcia, F.J. Exercise intensity progressions and criteria to prescribe core stability exercises in young physically active men: A smartphone accelerometer-based study. *J. Strength Cond. Res.* **2024**, *38*, 266–273. [CrossRef] [PubMed]
14. Barbado, D.; Barbado, L.C.; Elvira, J.L.L.; van Dieën, J.H.; Vera-Garcia, F.J. Sports-related testing protocols are required to reveal trunk stability adaptations in high-level athletes. *Gait Posture* **2016**, *49*, 90–96. [CrossRef] [PubMed]
15. Brull-Muria, E.; Beltran-Garrido, J.V. Effects of a specific core stability program on the sprint and change-of-direction maneuverability performance in youth, male soccer players. *Int. J. Environ. Res. Public Health* **2021**, *18*, 10116. [CrossRef] [PubMed]
16. Padua, D.A.; Marshall, S.W.; Boling, M.C.; Thigpen, C.A.; Garrett, W.E.; Beutler, A.I. The Landing Error Scoring System (LESS) is a valid and reliable clinical assessment tool of jump-landing biomechanics: The JUMP-ACL study. *Am. J. Sports Med.* **2009**, *37*, 1996–2002. [CrossRef] [PubMed]
17. Padua, D.A.; DiStefano, L.J.; Beutler, A.I.; de la Motte, S.J.; DiStefano, M.J.; Marshall, S.W. The Landing Error Scoring System as a screening tool for an anterior cruciate ligament injury-prevention program in elite-youth soccer athletes. *J. Athl. Train.* **2015**, *50*, 589–595. [CrossRef] [PubMed]
18. Li, Z.; Yang, Y.; Fu, Y.; Guo, X.; Fan, L. Reliability, validity, and predictive value of the Landing Error Scoring System in soccer players: A systematic review. *Sports Health* **2026**. *advance online publication*. [CrossRef] [PubMed]
19. Dos'Santos, T.; McBurnie, A.; Donelon, T.; Thomas, C.; Comfort, P.; Jones, P.A. A qualitative screening tool to identify athletes with 'high-risk' movement mechanics during cutting: The Cutting Movement Assessment Score (CMAS). *Phys. Ther. Sport* **2019**, *38*, 152–161. [CrossRef] [PubMed]
20. Miralles-Iborra, A.; De Los Ríos-Calonge, J.; Del Coso, J.; Vera-García, F.J.; Elvira, J.L.L.; Dos'Santos, T.; Nakamura, F.Y.; Moreno-Pérez, V. Spanish adaptation of the Cutting Movement Assessment Score (CMAS): Agreement and inter-rater reliability among Spanish-speaking football practitioners. *Phys. Ther. Sport* **2025**, *76*, 27–36. [CrossRef] [PubMed]
21. Vera-Garcia, F.J.; López-Plaza, D.; Juan-Recio, C.; Barbado, D. Tests to measure core stability in laboratory and field settings: Reliability and correlation analyses. *J. Appl. Biomech.* **2019**, *35*, 223–231. [CrossRef] [PubMed]
22. McKay, A.K.A.; Stellingwerff, T.; Smith, E.S.; Martin, D.T.; Mujika, I.; Goosey-Tolfrey, V.L.; Sheppard, J.; Burke, L.M. Defining training and performance caliber: A participant classification framework. *Int. J. Sports Physiol. Perform.* **2022**, *17*, 317–331. [CrossRef] [PubMed]
23. Brown, D.; Hanson, R.M.; Christian, W. *Tracker Video Analysis and Modeling Tool*, version 6.1.6; Open Source Physics: Davidson, NC, USA, 2024. Available online: https://opensourcephysics.github.io/tracker-website/ (accessed on 24 September 2026).
24. van Melick, N.; Meddeler, B.M.; Hoogeboom, T.J.; Nijhuis-van der Sanden, M.W.G.; van Cingel, R.E.H. How to determine leg dominance: The agreement between self-reported and observed performance in healthy adults. *PLoS ONE* **2017**, *12*, e0189876. [CrossRef] [PubMed]
25. McGill, S.M. *Ultimate Back Fitness and Performance*, 6th ed.; Backfitpro Inc.: Waterloo, ON, Canada, 2017.
26. Song, J.K.; Yoo, W.-G. Effects of modified hip airplane exercise on gluteal muscle activation in healthy individuals. *J. Back Musculoskelet. Rehabil.* **2025**, *38*, 1021–1030. [CrossRef] [PubMed]

27. Liang, K.-Y.; Zeger, S.L. Longitudinal data analysis using generalized linear models. *Biometrika* **1986**, *73*, 13–22. [CrossRef]
28. Zeger, S.L.; Liang, K.-Y.; Albert, P.S. Models for longitudinal data: A generalized estimating equation approach. *Biometrics* **1988**, *44*, 1049–1060, Erratum in *Biometrics* **1989**, *45*, 347. [CrossRef]
29. Mancl, L.A.; DeRouen, T.A. A covariance estimator for GEE with improved small-sample properties. *Biometrics* **2001**, *57*, 126–134. [CrossRef] [PubMed]
30. Lehnert, M.; Krejčí, J.; Janura, M.; De Ste Croix, M. Age-related changes in landing mechanics in elite male youth soccer players: A longitudinal study. *Appl. Sci.* **2022**, *12*, 5324. [CrossRef]
31. Dos'Santos, T.; McBurnie, A.; Comfort, P.; Jones, P.A. The effects of six-weeks change of direction speed and technique modification training on cutting performance and movement quality in male youth soccer players. *Sports* **2019**, *7*, 205. [CrossRef] [PubMed]
32. Chen, Y.; Tulhongjiang, M.; Ling, T.; Feng, X.; Mi, J.; Liu, R. The optimal training intervention for improving the change of direction performance of adolescent team-sport athletes: A systematic review and network meta-analysis. *PeerJ* **2025**, *13*, e18971. [CrossRef] [PubMed]
33. Wang, K.; He, J.; Zhu, A.; Bi, X. Effects of different training modalities on lower-limb explosive power, acceleration, 20-m sprint performance, and change-of-direction ability in youth soccer players: A systematic review and network meta-analysis. *BMC Sports Sci. Med. Rehabil.* **2026**, *18*, 410. [CrossRef] [PubMed]
34. Emery, C.A.; Roy, T.O.; Whittaker, J.L.; Nettel-Aguirre, A.; van Mechelen, W. Neuromuscular training injury prevention strategies in youth sport: A systematic review and meta-analysis. *Br. J. Sports Med.* **2015**, *49*, 865–870. [CrossRef] [PubMed]

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