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The *Safe Landing* warm up technique modification programme: An effective anterior cruciate ligament injury mitigation strategy to improve cutting and jump-movement quality in soccer players

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ABSTRACT

The objective of the study was to evaluate the effectiveness of the Safe Landing (SL), a 6-week technique-modification (TM) programme, on cutting and jump-landing movement quality in football players. In a non-randomized design, 32 male semi-professional football players from two Spanish clubs participated in the study: one served as the control group (CG, $n = 11$), while the other performed the SL ($n = 15$). Performance and movement quality of drop vertical jump and 70º change of direction (COD70) were evaluated through 2D video footage pre- and post-intervention. In such tasks, the Landing Error Scoring System for first (LESS1) and second (LESS2) landings, and the Cutting Movement Assessment Score (CMAS) were used for assessing movement quality. Pre-to-post changes and baseline-adjusted ANCOVA were used. Medium-to-large differences between groups at post-test were shown in CMAS, LESS1 and LESS2 ($p < 0.082$, $\eta^2 = 0.137–0.272$), with small-to-large improvements in SL ($p < 0.046$, *ES*=0.546–1.307), and CG remaining unchanged ($p > 0.05$) pre-to-post. In COD70 performance, large differences were found between groups ($p < 0.047$, $\eta^2 = 0.160–0.253$), with SL maintaining performance ($p > 0.05$, *ES*=0.039–0.420), while CG moderately decreasing performance ($p = 0.024$, *ES*=0.753) pre-to-post. The SL is a feasible and effective TM program to improve movement quality and thus potential injury risk in cutting and landing, while not negatively affecting performance.

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KEYWORDS
Injury risk reduction; ACL injury mechanisms; change of direction; landing

Introduction

Football (soccer) is a sport associated with a potentially high risk of injury, with an incidence rate of 6 injuries per 1000 h of exposure observed in male professional players (Ekstrand et al., 2021). Injuries that produce a high injury burden (e.g., ligament sprains such as anterior cruciate ligament (ACL) injuries) and, consequently, result in more missed matches and decreased match availability, are more likely to impact negatively in team performance (e.g., league positioning/success) (Hägglund et al., 2013). From the player's perspective ACL injuries are one of the most concerning injuries given its devastating consequences, such as the increased risk of developing early osteoarthritis (Øiestad et al., 2010), substantially higher ACL re-injury risk (Della Villa et al., 2021), with some athletes unable to return and compete at the same competitive level (Waldén et al., 2016).

In football, 88% of ACL injuries occur without contact (i.e., non-contact) or after indirect contact (i.e., not directly to the injured knee) with other players (Della Villa et al., 2020) and occur frequently during cutting and landing manoeuvres during match-play (Della Villa et al., 2020; Waldén et al., 2015). At the time of injury, a mechanism of ipsilateral trunk tilt and contralateral rotation, abducted hip, dynamic knee valgus, and flat and externally rotated foot is commonly observed (Della Villa et al., 2020). These aforementioned biomechanical and neuromuscular control deficiencies, and thus poor movement quality, are associated with greater knee joint loads and mechanical loads during landing and cutting (Donelon et al., 2020) which, when greater than the ligament's tolerance threshold, can result in ACL injury. Therefore, evaluating athletes' movement quality, with the aim of identifying aberrant and potentially risky movement patterns in the field, has arisen interest through the years. Accordingly, field-based qualitative screening tools such as the Landing Error Scoring System (LESS) and the Cutting Movement Assessment Score (CMAS) have been designed to simulate jump-landing and cutting actions, respectively, whose validity and reliability has been demonstrated (Dos'santos, McBurnie, Donelon, et al., 2019; Padua et al., 2009).

Once athletes with sub-optimal movement quality and potentially risky movement patterns have been identified, individualised injury-resistance training strategies can be developed to mitigate the risk of ACL injury. In this sense, previous research show promising results of neuromuscular training programs targeting strength and landing stabilization exercises in young athletes

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(Petushek et al., 2019). Specifically, in football, different balance, core stability and resistance training interventions have shown to be effective at reducing some ACL risk factors associated with a higher risk of ACL injury, although with several limitations (Olivares-Jabalera et al., 2021). For instance, some previous interventions were time consuming and required sophisticated equipment (i.e., isokinetic machines) which could be difficult to implement in the field. Furthermore, most of the previous ACL injuries prevention studies in football failed to report reliability measures, smallest worthwhile changes, level of the supervisor and compliance rate, which prevent them to accurately rise conclusions regarding their effectiveness (Olivares-Jabalera et al., 2021). However, given that common mechanisms of ACL injuries are known (Della Villa et al., 2020; Waldén et al., 2015), and movement quality and neuromuscular control deficits can directly influence knee mechanical loads and potential injury risk, it seems reasonable to develop strategies to improve the quality of movement in these risky actions. For example, promising results of technique modification (TM) programs to improve cutting and landing mechanics in other athletes (Dos'santos, Thomas, Comfort, et al., 2021; Dos'santos, Thomas, et al., 2019). To date, there is only one study evaluating the effectiveness of a TM intervention on movement quality, carried out in football players (Dos'santos, McBurnie, Comfort, et al., 2019), although this was limited to youth soccer players.

Football is a complex sport whose determinants of performance are composed by a myriad of factors which need to be properly trained (Stolen et al., 2005). Thus, to increase adherence and athlete and coach "buy-in", any injury mitigation programme should be cost- and time-effective, thus, developing training methods shorter than 10 min (i.e., easy to implement in the warm-up part) might be of interest to practitioners. Additionally, to be well received by coaches and athletes, injury mitigation programmes must be effective at mitigating risk factors of ACL injury but not at the expense of performance (Fox, 2018); this has recently been described as the performance-injury risk conflict (Dos'santos, Thomas, McBurnie, et al., 2021). Therefore, the aim of the study was to evaluate the effectiveness of the *Safe Landing 6-week warm-up technique modification intervention*, on landing and cutting movement quality in adult semi-professional football players. It was hypothesised that the SL TM intervention would result in improved landing and cutting movement quality without negatively affecting performance in comparison to a CG.

Methods

Experimental approach to the problem

A nonrandomized design was used to test the effectiveness of a 6-week *Safe Landing* intervention to improve movement quality in ACL injury mechanisms, using a repeated measures pre-to-post design. Two semi-professional football teams agreed to participate: one as control group (CG) and the other as intervention group (IG), assigned by convenience. The study was carried out in the middle of the competitive season, from January to March of 2021. The total duration of the study was 8 weeks. The first and last weeks were used for pre-assessments (PRE) and post-assessment (POST), respectively, while the intervention was conducted from the 2nd to the 7th week (6 weeks) (Figure 1). Movement quality evaluations consisted of the execution of a drop vertical jump (DJ) and a pre-planned 70 degrees change of direction (COD70). In both tasks, the ball was used as an external reference to increase sports specificity and cognitive loading. Both PRE and POST evaluations were performed on Tuesday (MD + 3), to ensure a sufficient recovery period from the previous match. During the interventions, the IG performed a TM-based intervention (i.e., *Safe Landing*), while the CG performed their regular warm-up.

Subjects

Thirty-two adult, male semi-professional football players agreed to participate in the study. They were recruited from two football teams competing in the 3rd Spanish Division league. By convenience (nonrandomized process), 15 players of the first team served as the IG (age: 25.5 ± 4.0 years; body mass: 74.7 ± 7.0 kg; height: 1.80 ± 0.07 m), while 11 of the second team served as CG (age: 24.3 ± 4.9 years: body mass: 74.3 ± 7.4 kg; height: 1.78 ± 0.08 m). No additional resistance training programs were performed in any team during the length of the study. To be included in the study, players had to be free of injury at the beginning of the study, not having suffered any severe knee injury in the two previous years, train at least four times a week, and possess more than 10 years of experience in football. Only outfield players were recruited for the study. All participants were informed about the risk and benefits of taking part in the study. Furthermore, they signed an informed consent prior to the data collection was carried out. The study design was approved by the Local Ethics Committee and conformed to the policy statement with respect to the Declaration of Helsinki. Initially, there were 15 and 17 players in the CG and IG, respectively. However, 6 participants (CG = 4, IG = 2) dropped out and were unable to performe POST, all of them due to injury unrelated to the training intervention. The study was performed in the middle of the competitive season to ensure that no large physical changes occurred as a result of the conditioning state (Dos'santos, McBurnie, Comfort, et al., 2019).

Procedures

Both PRE and POST evaluations were carried out on Tuesday, after 48-72 h of their last match (MD + 3), following the same procedures, and after performing a standardized warm-up consisting of 5 min of running at a self-selected pace, followed by 5 min of dynamic warm-up drills and several submaximal familiarisation trials with the tests. Participants performed, in a randomized order, three trials of a COD70 with both left and right limbs, and three trials of a DJ. The COD70 and DJ were performed following previous guidelines (Dos'santos, McBurnie, Donelon, et al., 2019; Padua et al., 2009), although with some modifications in the set-up (Figure 1 in Olivares-Jabalera et al., 2022). In the case of COD70, participants were required to execute three successful trials with both dominant (D) and nondominant (ND) limbs. At least 2-min rest periods were required between trials, although could be longer if necessary. The D limb was considered that preferred to kick the ball during a penalty kick. Three iPhone 11 (iOS 14.4.1, Apple. Inc., USA) were located upon 60-cm tripods at a distance of 3 and 5 m from the cutting or jumping in which the main movement was performed, recording at a sampling rate of 240 Hz. Once the whole protocol was performed and recorded, all video footage was viewed in Kinovea (0.8.15 for Windows, Bordeaux, France), in which the qualitative and quantitative screenings were analysed.

Movement quality data were analysed using the CMAS for the COD70, and LESS for the DJ. CMAS and LESS were performed in line with their validation studies (Dos'santos, McBurnie, Donelon, et al., 2019; Padua et al., 2009), graded by the lead researcher, which was highly experienced in both tools (i.e., with more than 120 h) and with a slight modification in the CMAS following the most recent recommendations of this tool (Dos'santos, Thomas, McBurnie, et al., 2021). These tools have shown substantial to almost perfect intra-rater reliability to evaluate movement quality of semi-professional football players (Olivares-Jabalera et al., 2022). The first and second landings (i.e., LESS1 and LESS2, respectively) of the DJ were analysed using the same 17-item LESS tool, as previously reported (Olivares-Jabalera et al., 2022). Both landings were included in the evaluation because they show differentiated neuromuscular control discrepancies and, hence, they provide useful information in injury risk identification (Bates et al., 2013; Olivares-Jabalera et al., 2022). Both CMAS and LESS provide a total score, in which higher scores were representative of poorer movement quality, and have been previously validated against 3D motion capture systems with respect to biomechanical ACL injury risk factors (Dos'santos, Thomas, McBurnie, et al., 2021; Padua et al., 2009).

Performance data were additionally obtained for both COD70 and DJ. In the case of COD70, the variable considered for evaluating performance was the contact time of the foot executing the COD70 with the ground (i.e., ground contact time (GCT) from touch down to toe-off frames). Ground contact time has been identified as a determinant and key performance indicator of COD ability (Dos'santos, Thomas, McBurnie, et al., 2021). GCT's asymmetry between D and ND limbs, expressed as a percentage difference, was further calculated, using the formula proposed by Bishop et al. (Bishop et al., 2018) for unilateral tests:

% asymmetry = 100 / (maximal value x minimum value) x (-1) + 100

In the case of DJ, jump height (JH) and the reactive strength index (RSI) were the variables selected to determine performance. The JH of the DJ was calculated by identifying the take-off and landing frames of the video, and then transforming flight time data into JH using the following formula (Bosco et al., 1983): $h = t^2 \times 1.22625$, with h being the JH in metres, and t being the flight time in seconds. The RSI was calculated by dividing the JH by the GCT (Healy et al., 2018) as a representative measure of the athlete's ability to utilize the stretch-shortening cycle (SSC).

Safe Landing

The *Safe Landing* is a 6-week TM-based intervention designed to improve jump-landing and cutting movement quality; two main mechanisms of ACL injury. In Table S1 in Supplementary Material, a full description of the intervention of the exercises and their progressions is provided. Briefly, the intervention consisted of a mix of jump-landing, plyometrics and COD exercises, with a specific focus on the feedback provided, given the promising results shown by these two components in mitigating risk factors of ACL injury (Arundale et al., 2022) and designed to be performed as part of the warm-up. As the *Safe Landing* was intended to be easily implemented in any football team, regardless its level or equipment available, volume remained constant through the program, while complexity of the exercises was increased, according to previous suggested progressions (Dos'santos, Thomas, et al., 2019), and being adapted to the context of a football team. The number of jumps and CODs per session was 30 and between 20 and 30, respectively (Table S1 in Supplementary Material). Regarding its intensity, maximal intensity was required for each exercise, as long as the movement quality was not compromised. The main strengths of the programme were: [1] no equipment is required and is easily integrated into field-based warm-ups prior to technical or tactical sessions, [2] it takes only ~ 9 min per session, performed three times a week, and [3] the simplicity of the progressions, which does not require time-consuming explanations or demonstrations. The sessions were led by a strength and conditioning coach with academic qualifications in Sport Sciences (Master's Degree) and more than 6 years of experience coaching in football teams. A critical component of the intervention was the quality of the feedback provided individually to the players, which was

WEEK 1		**WEEK 2 to 7**	**WEEK 8**	
Pre-test		**IG**	**Post-test**	
COD70	**DJ**	*Safe Landing* : landing, plyometrics and COD TM training with	COD70	DJ
CMAS	LESS	feedback with external focus, in the warm-up, 3 sessions/week	CMAS	LESS
GCT	DVJ JH	**CG**	GCT	DVJ JH
GCT ASY	DVJ RSI	Regular field-based warm-up consisting of self-selected	GCT ASY	DVJ RSI
IG = 17	CG = 15	running, warm-up dynamic exercises and rondo (~20')	IG = 15	CG = 11

There were 6 dropouts (2 in the IG, 4 in the CG) due to injury/illnesses, that were unable to conduct the interventions as well as conducting the post-test assessments

Figure 1. Study design and flow diagram of the participation of the players at all the stages. COD70 = 70º change of direction; DJ = drop jump; CMAS = Cutting Movement Assessment Score; LESS = Landing Error Scoring System; GCT = ground contact time; JH = jump height; ASY = asymmetry; RSI = Reactive Strength Index; IG = intervention group; CG = control group; TM = technique modification.

Table 1. Verbal cues given to the players to promote safe mechanics while maximising performance.

Verbal coaching cue	Cue's objective
For the jump-landing and plyometrics training exercises	
"Try to maintain alignment, thinking that your body is unable to bend laterally"	To promote proper full-body alignment
"At landing, try to minimise the sound of the ground" "Imagine you are a feather falling to the ground"	To promote soft landings
"After landing, jump again whipping to the ground" "Imagine that the ground is hot lava"	To promote pre-activation of muscles for a reactive foot support
"Push the ground to travel as far as possible from them" "Jump as high as you can to try to head a ball"	To promote maximum intensity
For the change of direction training exercises	
"Slam on the brakes – early" "Imagine in the last foot contact that the ground is hot lava"	To promote penultimate foot contact braking and reduce final foot contact force demands
"Try to maintain alignment, thinking that your body is unable to bend"	To promote proper full-body alignment
"Lean/face/look towards the ball or objective that determines the direction of travel"	To promote proper orientation towards the new intended direction of travel
"Push yourself as hard and fast as possible off the ground" "Attack the ground"	To promote maximum intensity

Table 2. Reliability of the selected variables at pre-test for CG and IG.

	Group	Variable	ICC	LL	UL	SEM	LL	UL	CV (%)	LL	UL
COD performance	IG	COD GCT ND	0.865	0.645	0.952	0.010	0.007	0.016	5.4	4.0	8.5
	IG	COD GCT D	0.848	0.606	0.946	0.012	0.008	0.018	6.1	4.5	9.6
	CG	COD GCT ND	0.682	0.175	0.903	0.017	0.012	0.029	8.2	5.7	14.4
	CG	COD GCT D	0.790	0.393	0.939	0.014	0.010	0.025	7.2	5.0	12.6
COD m. quality	IG	CMAS ND	0.899	0.726	0.965	0.526	0.385	0.829	10.0	7.3	15.7
	IG	CMAS D	0.165	−0.362	0.612	1.017	0.744	1.603	17.4	12.8	27.5
	CG	CMAS ND	0.760	0.328	0.929	0.899	0.628	1.579	16.4	11.4	28.7
	CG	CMAS D	0.323	−0.311	0.758	0.858	0.600	1.506	16.4	11.5	28.8
DJ Performance	IG	DJ JH	0.948	0.852	0.982	1.144	0.837	1.804	2.5	1.8	3.9
	IG	DJ RSI	0.292	−0.240	0.689	0.348	0.255	0.549	22.0	16.1	34.7
	CG	DJ JH	0.942	0.801	0.984	1.767	1.235	3.101	4.1	2.8	7.1
	CG	DJ RSI	0.746	0.298	0.925	0.236	0.165	0.414	21.8	15.3	38.3
DJ m. quality	IG	LESS1 ND	0.965	0.898	0.988	0.420	0.307	0.662	5.8	4.2	9.2
	IG	LESS1 D	0.833	0.574	0.941	0.796	0.583	1.255	10.6	7.7	16.7
	IG	LESS2 ND	0.048	−0.543	0.607	1.558	1.089	2.734	20.6	14.4	36.2
	IG	LESS2 D	0.470	−0.145	0.823	1.176	0.821	2.063	15.1	10.6	26.5
	CG	LESS1 ND	0.915	0.718	0.977	0.661	0.462	1.159	14.2	10.0	25.0
	CG	LESS1 D	0.944	0.807	0.985	0.654	0.457	1.147	12.3	8.6	21.6
	CG	LESS2 ND	0.848	0.118	0.983	1.118	0.670	3.213	14.3	8.6	41.2
	CG	LESS2 D	0.960	0.640	1.000	0.913	0.517	3.404	11.4	6.5	42.5

Key: ICC = intraclass correlation coefficient; LL = lower limit; UL = upper limit; SEM = standard error of measurement; CV = coefficient of variation; IG = intervention group; CG = control group; COD = change of direction; GCT = ground contact time; ND = non-dominant leg; D = dominant leg; ASY = asymmetry between legs; CMAS = Cutting Movement Assessment Score; DJ = drop jump; JH = jump height; RSI = Reactive Strength Index; LESS1 = Landing Error Scoring System, first landing; LESS2 = Landing Error Scoring System, second landing.

led by using mainly external coaching cues as it has shown superior effects than internal cues (Benjaminse, Welling, et al., 2015), and using strategies as implicit learning. In Table 1, some of the coaching cues used for correcting movement patterns in both jump-landing and plyometric and COD exercises are presented in line with previous suggestions (Dos'santos, McBurnie, Thomas, et al., 2019). During the 6 week-period sessions in which the IG performed the *Safe Landing* as a part of the warm-up, the CG executed their regular warm-up (Figure 1). Before executing the *Safe Landing*, the IG performed ~10 min of jogging at a self-selected pace, and warm-up dynamic drills, being the duration of the full warm-up in both groups around 20 min in duration.

Statistical analyses

All statistical analyses were performed in SPSS v 25 (SPSS Inc., Chicago, IL, USA) and Microsoft Excel (version 2019, Microsoft Corp., Redmond, WA, USA). An intention-to-threat approach was conducted for the analysis of the data of interest.

Within session reliability was calculated for each group and session for the outcome variables, using Intraclass correlation coefficients (ICC), coefficient of variation (CV), and standard error of measurement (SEM). The CV, SEM and smallest detectable difference (SDD) were calculated in line with similar research (Dos'santos, McBurnie, Comfort, et al., 2019). ICCs were interpreted as followed (Koo & Li, 2016): poor (<0.50), moderate (0.50–0.75), good (0.75–0.90), and excellent (>0.90). Minimum acceptable reliability was determined with an ICC >0.7 and CV < 15% (Baumgartner & Chung, 2014).

Descriptive data are reported as mean values and SDs. Normality was inspected through a Shapiro–Wilk test. An analysis of covariance (ANCOVA) for each of the primary outcomes (dependent variables), with group as comparator (IG and CG) and baseline data (pre-test values from such variables) as a covariate, was conducted for POST data as suggested for clinical research (O'connell et al., 2017). Equality of variances was checked with the Levene's

Table 3. Reliability of the selected variables at post-test for CG and IG.

	Group	Variable	ICC	LL	UL	SEM	LL	UL	CV (%)	LL	UL
COD performance	IG	COD GCT ND	0.863	0.640	0.952	0.012	0.009	0.019	6.4	4.8	10.1
	IG	COD GCT D	0.850	0.611	0.947	0.011	0.008	0.018	6.2	4.5	9.7
	CG	COD GCT ND	0.665	0.145	0.897	0.014	0.010	0.024	6.4	4.5	11.3
	CG	COD GCT D	0.527	−0.070	0.846	0.015	0.010	0.026	7.2	5.0	12.7
COD m. quality	IG	CMAS ND	0.750	0.402	0.908	0.730	0.535	1.152	16.2	11.9	25.6
	IG	CMAS D	0.754	0.411	0.910	0.644	0.471	1.015	14.4	10.6	22.7
	CG	CMAS ND	0.901	0.676	0.972	0.531	0.371	0.932	9.6	6.7	16.8
	CG	CMAS D	0.556	−0.030	0.857	1.132	0.791	1.987	21.5	15.0	37.7
DJ performance	IG	DJ JH	0.977	0.929	0.992	0.904	0.655	1.456	2.0	1.4	3.1
	IG	DJ RSI	0.938	0.818	0.980	0.084	0.061	0.136	5.5	4.0	8.8
	CG	DJ JH	0.978	0.922	0.994	0.910	0.636	1.598	2.1	1.5	3.7
	CG	DJ RSI	0.904	0.686	0.973	0.087	0.061	0.153	8.3	5.8	14.5
DJ m. quality	IG	LESS1 ND	0.863	0.640	0.952	0.886	0.649	1.398	16.0	11.7	25.3
	IG	LESS1 D	0.765	0.433	0.915	1.117	0.818	1.762	19.8	14.5	31.3
	IG	LESS2 ND	0.746	0.328	0.920	1.022	0.724	1.736	13.4	9.6	22.9
	IG	LESS2 D	0.774	0.386	0.929	1.284	0.909	2.179	17.0	12.1	28.9
	CG	LESS1 ND	0.683	0.177	0.904	1.561	1.091	2.739	31.5	22.0	55.3
	CG	LESS1 D	0.866	0.579	0.962	1.144	0.799	2.008	22.1	15.4	38.7
	CG	LESS2 ND	0.402	−0.506	0.887	1.638	1.023	4.018	20.7	12.9	50.7
	CG	LESS2 D	0.579	−0.311	0.928	1.983	1.238	4.864	24.8	15.5	60.8

Table 4. Pre-to-post changes in both CG and IG.

			Pre		Post			Hedges'g ES					Individual responders
	Group	Variable	Mean	SD	Mean	SD	*p*	*g*	± CI	Mean diff.	SDD	Ratio to SDD	(Positive, non, negative)
COD performance	IG	COD GCT ND	0.190	0.023	0.190	0.029	0.988	-0.039	0.716	0.000	0.005	0.0	(9,0,6)
	IG	COD GCT D	0.192	0.026	0.182	0.026	0.113	-0.420	0.724	-0.010	0.005	1.9	(12,0,3)
	IG	COD GCT ASY	7.093	5.415	7.687	6.981	0.825	0.056	0.716	0.594	1.083	0.5	(8,0,7)
	CG	COD GCT ND	0.203	0.022	0.216	0.020	0.024*	0.753	0.868	0.013	0.004	2.9	(3,0,9)
	CG	COD GCT D	0.199	0.025	0.206	0.018	0.222	0.370	0.844	0.007	0.005	1.4	(4,0,8)
	CG	COD GCT ASY	7.527	4.692	8.982	8.546	0.679	0.121	0.837	1.455	0.938	1.6	(5,0,7)
COD m. quality	IG	CMAS ND	5.213	1.455	4.500	1.282	0.046*	-0.546	0.730	-0.713	0.291	2.5	(10,1,4)
	IG	CMAS D	5.733	0.872	4.467	1.141	<0.001***	-1.220	0.784	-1.266	0.174	7.3	(13,1,1)
	CG	CMAS ND	5.209	1.441	5.545	1.457	0.264	0.335	0.842	0.336	0.288	1.2	(3,1,8)
	CG	CMAS D	5.000	0.674	5.273	1.403	0.525	0.188	0.838	0.273	0.135	2.0	(4,2,6)
DJ performance	IG	DJ JH	46.187	4.671	45.754	5.585	0.530	-0.160	0.717	-0.433	0.934	0.5	(8,0,7)
	IG	DJ RSI	1.602	0.344	1.521	0.304	0.205	-0.331	0.721	-0.081	0.069	1.2	(6,0,9)
	CG	DJ JH	43.075	6.564	43.270	5.372	0.876	0.045	0.836	0.195	1.313	0.1	(8,0,4)
	CG	DJ RSI	1.094	0.363	1.054	0.244	0.634	-0.139	0.837	-0.040	0.073	0.6	(4,0,8)
DJ m.quality	IG	LESS1 ND	7.127	1.985	5.533	2.142	0.002**	-0.965	0.759	-1.594	0.397	4.0	(13,1,1)
	IG	LESS1 D	7.467	1.720	5.633	2.031	<0.001***	-1.307	0.793	-1.834	0.344	5.3	(14,0,1)
	IG	LESS2 ND	8.107	1.772	7.400	1.606	0.046*	-0.546	0.730	-0.707	0.354	2.0	(10,2,3)
	IG	LESS2 D	7.993	1.593	7.300	2.170	0.030*	-0.602	0.733	-0.693	0.319	2.2	(11,0,4)
	CG	LESS1 ND	4.691	2.147	4.955	2.339	0.325	0.294	0.841	0.264	0.429	0.6	(4,1,7)
	CG	LESS1 D	5.273	2.402	5.182	2.695	0.781	-0.081	0.836	-0.091	0.480	0.2	(7,0,5)
	CG	LESS2 ND	7.489	2.201	8.167	1.820	0.415	0.263	0.928	0.678	0.440	1.5	(4,2,6)
	CG	LESS2 D	7.743	2.060	8.429	2.652	0.456	0.256	1.053	0.686	0.412	1.7	(3,4,5)

Key: SDD = smallest detectable difference; IG = intervention group; CG = control group; COD = change of direction; GCT = ground contact time; ND = non-dominant leg; D = dominant leg; ASY = asymmetry between legs; CMAS = Cutting Movement Assessment Score; DJ = drop jump; JH = jump height; RSI = Reactive Strength Index; LESS1 = Landing Error Scoring System, first landing; LESS2 = Landing Error Scoring System, second landing.

test. Partial eta squared effect sizes were calculated from ANCOVA and its values were considered as follows: small: 0.010–0.059, medium: 0.060–0.149, and large: ≥0.150 (Cohen, 1988).

PRE to POST changes in primary outcomes for each group were assessed using paired-sample *t*-tests for parametric data and Wilcoxon-sign ranked tests for non-parametric data. Hedges' *g* effect sizes and mean change with 95% confidence intervals (CI) were used for assessing magnitude of differences. Hedges' g effect sizes were calculated as described previously (Hedges & For M-A, 1985) and interpreted as trivial (≤0.19), small (0.20–0.59), moderate (0.60–1.19), large (1.20–1.99), very large (2.0–3.99), and extremely large (≥4.00) (Hopkins, 2002). The average of the three trials were used for further analyses. Statistical significance was defined $p \leq 0.05$ for all tests.

Results

Reliability and pre-to-post changes

Within session reliability data for the outcome variables in CG and IG for both PRE and POST are presented in Tables 2 and 3, respectively. The lowest CV values were presented for the variables COD GCT (CV < 9%) and DJ JH (CV < 5%) in both time-point assessments. Regarding ICC, the highest values were found for the variables COD GCT, CMAS ND, DJ JH and LESS1 ND, with all values being >0.75 except for COD GCT in the CG at post-test (ICC = 0.527–0.665).

The pre-to-post change of variables is displayed in Table 4. In the CG, the only statistically significant pre-to-post change was the moderate decrease in COD GCT ND ($p = 0.024$, $ES = 0.753$). In the IG, there was a moderate and large improvement in CMAS with both ND ($p = 0.046$, $ES = 0.546$) and D ($p < 0.001$, $ES = 1.220$), respectively. Additionally, LESS1 and LESS2 were moderately to largely improved from PRE to POST ($p \leq 0.30$, $ES = 0.602–1.307$) except for LESS2 ND in which the improvement was small ($p = 0.046$, $ES = 0.546$). All the pre-to-post changes of variables were above the SDD. In fact, the ratio between the mean differences and the SDD was in the range of 2.0–7.3 for these variables (Table 4).

Between-group differences

COD and DJ performance

Large and significant differences were found between IG and CG in COD GCT in both ND ($p = 0.047$, $\eta^2 = 0.160$) and D ($p = 0.010$, $\eta^2 = 0.253$). In the IG, COD GCT ND and D were unchanged from PRE to POST, while the CG decreased performance in COD GCT ND (Table 4, Figure 2). There were no differences between groups for COD ASY, DJ JH or DJ RSI ($p = 0.596–0.967$). These variables remained unchanged in both groups from PRE to POST ($p = 0.056–0.876$, Table 4 and Figures S1 and S2 in Supplementary Material).

CMAS and LESS

Large and significant differences were found between IG and CG in CMAS in both ND ($p = 0.019$, $\eta^2 = 0.223$) and D ($p = 0.017$, $\eta^2 = 0.218$). CMAS was moderately improved in both legs in IG, while remaining unchanged in the CG (Table 4, Figure 3). Regarding the LESS, large and significant differences between IG and CG were found for LESS1 ND ($p = 0.020$, $\eta^2 = 0.215$) and LESS1 D ($p = 0.007$, $\eta^2 = 0.272$). These variables were moderately to largely improved in the IG, while remaining unchanged in the CG (Table 4, Figure 4). Additionally, LESS2 was moderately improved in both legs in the IG, while remained unchanged in CG from pre to post (Table 4, Figure S3). However, no differences between groups were found ($p = 0.076–0.082$).

Discussion

The novel finding of the present study is that the *Safe Landing*, a 6-week warm-up based TM-based intervention consisting of ~ 9 min of landing, plyometric and cutting exercises with external feedback regarding movement quality and technique, is an effective strategy to improve movement quality in two standard ACL injury mechanisms: jump-landing and cutting. Additionally, as previously hypothesised, movement quality was improved without a negative effect on performance.

There are limited data available specifically to football player movement quality in the literature to compare our results to, as not many studies have investigated the effects of TM-based interventions in improving mechanisms of ACL injury in football players (Olivares-Jabalera et al., 2021). Although several studies have found promising results in improving COD movement quality following technique modification (Dempsey et al., 2007, 2009; Dos'santos, Thomas, Comfort, et al., 2021), only one study has investigated this intervention strategy in a youth football player (Dos'santos, McBurnie, Comfort, et al., 2019), in which a 6-week of TM and COD velocity programme was found to be effective at achieving moderate to large ($g = 0.85–1.46$) improvements in movement quality during a COD70 using the CMAS. The slightly higher magnitudes of *ES* achieved than in the present study ($g = 0.55–1.20$) can be explained by the higher volume of training (40 vs 27 min/week) and that only COD training was addressed, in comparison with our intervention. Furthermore, the effectiveness of our programme (i.e., small to large improvements in LESS) is in line with previous TM programs that have shown to be effective at improving movement quality in jump-landing tasks in different sports (Chijimatsu et al., 2020; Neilson et al., 2019). However, to the authors' knowledge, this is the first that investigated such effects in semi-professional adult football players using a low dose.

The inclusion of exercises designed to mitigate risky movement patterns should be an important component of ACL injury prevention programs, even though they are not commonly included in all programmes (Dischiavi et al., 2021). Additionally, the effectiveness of such interventions can be highly influenced by the feedback provided to the athletes (Benjaminse, Welling, et al., 2015). In terms of the way in which the feedback can be directed, different strategies such as providing an external feedback and using implicit learning methods (i.e., when the amount of declarative (explicit) knowledge about movement execution is minimised) has shown to be very effective in decreasing the risk of ACL injury (Arundale et al., 2022; Benjaminse, Welling, et al., 2015). Specifically, such methods have proven to be effective at promoting improved movement quality, with increased knee flexion angles, decreased knee frontal-plane movements, peak ground reaction forces, reduce movement noises, co-contraction, and decrease electromyographic activity, among others (Benjaminse, Gokeler, et al., 2015; Gokeler et al., 2015). On the other hand, the quality of the feedback provided by the supervisor is suggested to have a positive influence on the effectiveness of the intervention in a TM program (Benjaminse, Gokeler, et al., 2015). With this in mind, in the present intervention, a large emphasis was placed on the provision of feedback. Therefore, part of the effectiveness of the *Safe Landing* in improving movement quality of cutting and landing tasks could be explained by the implicit learning and the external feedback provided to the players (Table 1), in addition to the level of quality of the instructions and corrections by the supervisor of the program (i.e., a strength and conditioning specialist with high academic qualifications and high experience in football) (Petushek et al., 2019).

Another possible explanation of the findings could be the introduction of unanticipated movements in the latest stages of the program also present in previous interventions (Dos'santos, McBurnie, Comfort, et al., 2019; Dos'santos, Thomas, Comfort, et al., 2021), given that neurocognitive demands seem to be an important factor in ACL injuries, which are shown to occur in unanticipated COD where less time is available to correct or change an already initiated movement (Gokeler et al., 2021).

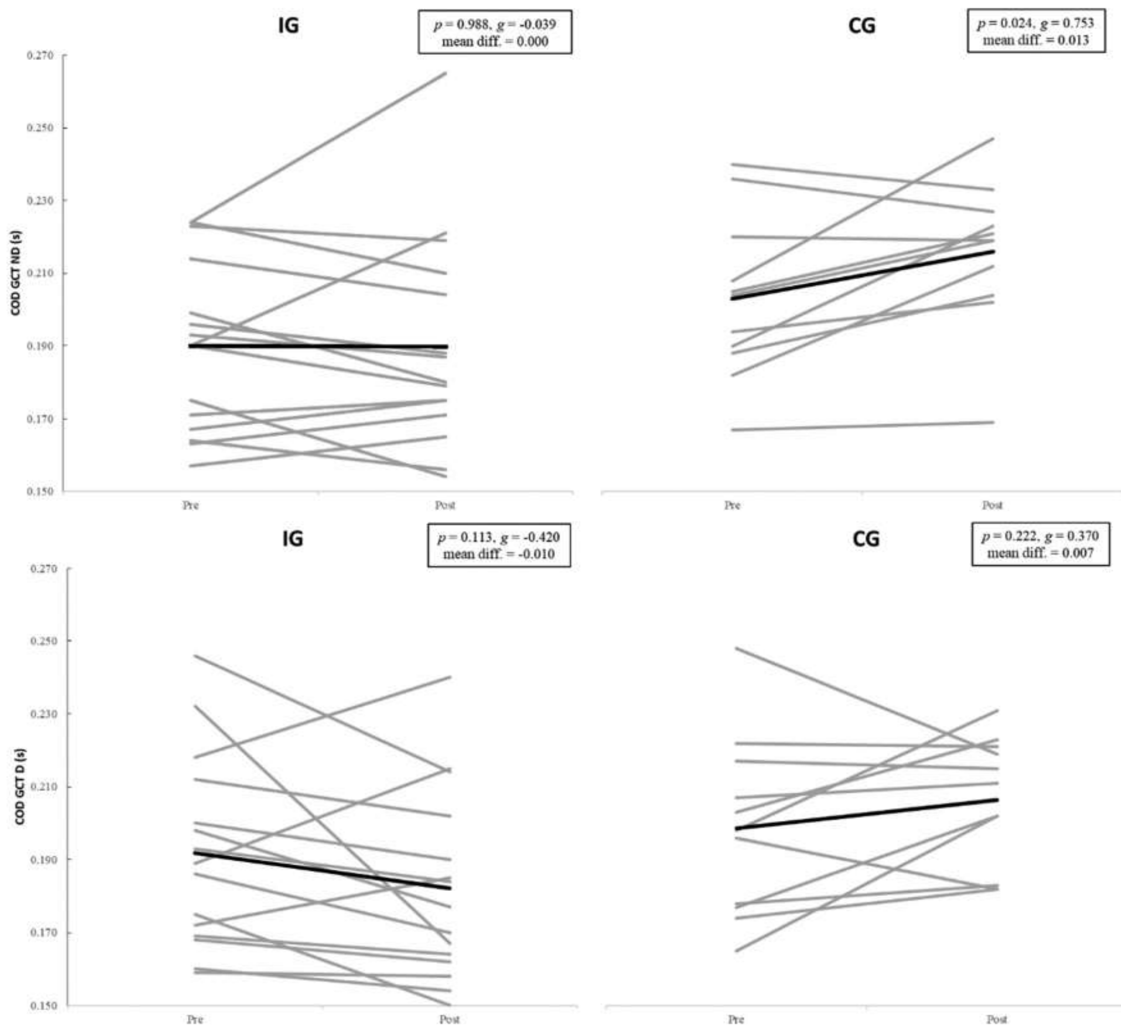

Figure 2. Individual changes and mean differences from pre- to post-assessments of CG and IG in the GCT of the COD for both ND and D. COD = change of direction; GCT = ground contact times; ND = non-dominant leg; D = dominant leg; mean diff = mean differences; IG = intervention group; CG = control group. Note black line denotes mean.

Generally, the exercises included in the programme were intended to be relatively simple and non-complex so that the athletes could perform them easily. However, towards the latter stages of the intervention, unanticipated CODs were introduced to increase contextual interference and cognitive loading, as suggested by Dos'Santos et al. (Dos'santos, McBurnie, Comfort, et al., 2019). Further strengths of the SL intervention were that no sophisticated equipment is required and only a small training dose/volume of ~ 27 min/week divided into three warm-ups is needed (9 min/session), making the Safe Landing a feasible TM program that can be easily implemented in any football context. This was highlighted by the high level of compliance presented in the IG (93%), an aspect that may have further determined the effectiveness of the programme, as it might have a clear positive relationship with compliance (Arundale et al., 2022).

Of a great importance for ACL injury prevention programmes to be implemented and adhered to in practice is that performance is not negatively affected upon completion (Fox, 2018). As there may be an injury-performance trade-off regarding some biomechanics variables, practitioners should be cautious when addressing them in TM programs. For example, increasing knee flexion angles to promote a softer landing, while reducing the loads affecting the ACL, might also impair performance by negatively prolonging ground contact times (Dos'santos, Thomas, McBurnie, et al., 2021; Fox, 2018). One of the strengths of the present intervention is key performance cutting and jumping performance measures were not negatively reduced, indicating that the SL TM was effective at reducing risk of ACL injury while, at least, maintaining performance. Ideally, while it would be further advantageous to demonstrate concurrent performance improvements in addition to injury mitigation adaptations (Fox, 2018), it appears that the SL TM dose/volume approach was not enough to do so (i.e., no more than 30 jumps/CODs per session), and probably more volume of work and also targeting other important components (e.g., eccentric strength) may be needed to see further improvements in performance (Dos'santos, Thomas, et al., 2019). However, if included, the intervention would have required more equipment and time-consuming, which may therefore

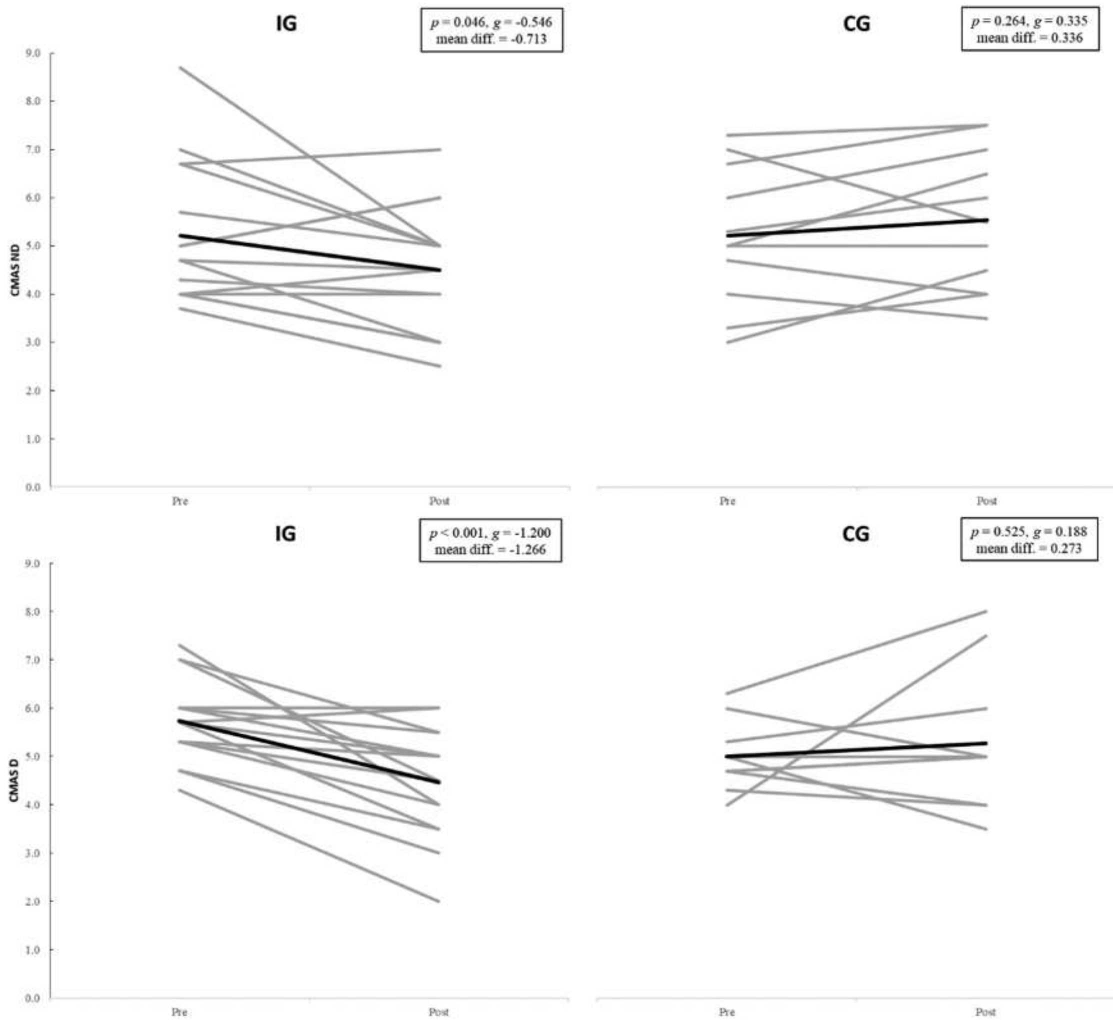

Figure 3. Individual changes and mean differences from pre- to post-assessments of CG and IG in the CMAS for both ND and D. CMAS = Cutting Movement Assessment Score; ND = non-dominant leg; D = dominant leg; mean diff = mean differences; IG = intervention group; CG = control group. Note black line denotes mean.

restrict its feasibility and hence implementation in the real context. Such interventions might be designed by practitioners considering the capabilities, budget, context of the club and characteristics of the players, being aware of the variety of different contexts that can be found in the football world.

Limitations

The present study is not free of limitations. Firstly, while there were only an 11.8% of drop-outs in the IG, 26.7% of players in the CG were unable to be evaluated at POST. Although this considerably decreased the sample size in the CG, it is a limitation commonly found in studies that aim at evaluating football players in their real context. These drop-outs were caused by injuries, which is not uncommon in the part of the competitive season in which the study was carried out. Importantly, there were only 2 drop-outs in the IG, none of them being related to the proposed intervention (i.e., contact injuries). Secondly, only male, adult semi-professional football players were included, which may limit the generalisation of the findings. To further explore if the SF TM is effective in other populations (i.e., professional, female, young players), more research is needed. Finally, while a nonrandomized design is sometimes the only feasible approach to study semi-professional football players in their specific context, proper randomized-controlled trials are encouraged to be conducted in which the influence of the group's assignation process is known to be minimum.

Conclusions

The *Safe Landing* is a 6-week TM-based intervention which is effective at improving movement quality without negatively affecting performance of two of the main mechanisms of ACL injury in football: cutting and jump-landing actions. This programme is based on landing, COD and plyometrics training with an important emphasis posed on the technical execution of the movements, to which the quality of the feedback provided to the players appear to be crucial (i.e., by a specialised S&C coach and based on external feedback and implicit learning). Additionally, its effectiveness can be further explained by the feasibility of the programme, which is demonstrated by the high

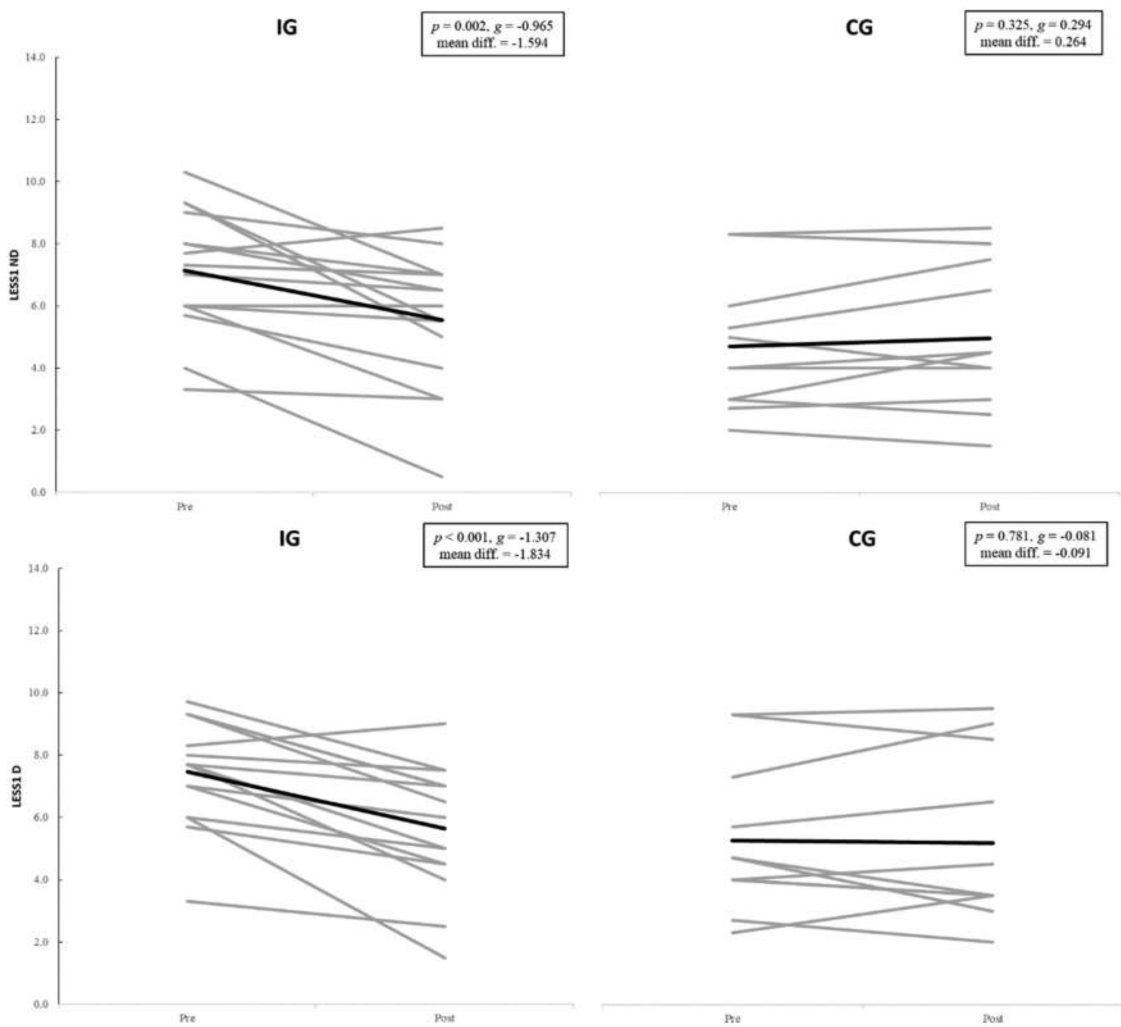

Figure 4. Individual changes and mean differences from pre- to post-assessments of CG and IG in the LESS1 for both ND and D. LESS1 = Landing Error Scoring System first landing; ND = non-dominant leg; D = dominant leg; mean diff = mean differences; IG = intervention group; CG = control group. Note black line denotes mean.

compliance of the IG (93%). Important features such as the low volume and dose (~9 mins/session, 3 times/week) and the lack of sophisticated equipment required may have contributed to this, hence making the *Safe Landing* a simple, feasible and attractive training strategy for coaches and practitioners that can mitigate ACL risk factors in-season, in a real-world sporting environment.

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