Reliability of Surface EMG During High-Risk Single-Leg Jump Landing and 90° Sidestep Cutting in Female Footballers

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Abstract

Non-contact anterior cruciate ligament (ACL) injuries cause substantial time loss in female football. Although altered lower-limb muscle excitation is a modifiable risk factor, the reliability of surface electromyography (sEMG) during dynamic tasks in female players remains uncertain. This repeated-measures reliability study examined sEMG during a single-leg jump landing (LAND) and 90° sidestep cut (CUT) in 16 second-tier English female footballers. We evaluated reliability across: (1) within- versus between-session measures; (2) mean versus peak amplitudes; (3) pre-initial contact (PRE-IC) versus postinitial contact (POST-IC) phases; and (4) 10 ms versus 50 ms smoothing windows. Reliability was quantified using intraclass correlation coefficient (*ICC*[2,k]) and absolute measurement error. Within-session *ICC*s were moderate to excellent (LAND 0.61 to 0.95; CUT 0.68 to 0.96), whereas between-session *ICC*s varied from poor to excellent (LAND −0.48 to 0.94; CUT −0.08 to 0.93). Mean amplitudes showed marginally higher *ICC*s and lower absolute error than peaks. Phase-specific patterns were task-dependent: PRE-IC was more reliable in LAND, whereas POST-IC was more reliable in CUT. Practitioners should prioritize within-session comparisons using mean amplitudes, and the most reliable task-specific phase is recommended. Between-day application warrants caution, as the consistently lower reliability demonstrated may reflect task variability and/or physiological fluctuations rather than the sEMG method alone.

Keywords: EMG; muscle activation; reliability; female football; knee injury; ACL injury

1. Introduction

Lower limb injuries are the most prevalent in women's football [1,2], with female players experiencing severe joint and ligament injuries up to five times more frequently than their male counterparts [3]. Among these, anterior cruciate ligament (ACL) injuries are particularly concerning, occurring at a rate two to three times higher in female footballers than in males [4,5]. ACL injury also has longer-term implications, such as a greater risk of secondary injury [6], reduced return to play rates [7] and early knee osteoarthritis [8]. These factors underscore the need to refine screening tools and prevention interventions by utilizing reliable, task-specific markers in female football.

Non-contact and indirect injury mechanisms account for more than 80% of ACL injuries in female football [9,10], with neuromuscular dysfunction being associated with ACL injury mechanisms [11–13]. In particular, understanding muscle activation (MA) is important, as studies have proposed a link between delayed motor unit recruitment, improper myoelectric activity timing/coordination, and inadequate force generation with excessive knee loading [14,15]. Surface electromyography (sEMG) technology has been instrumental in advancing our understanding of neuromotor characteristics; however, its application in football is limited by a scarcity of research investigating its capabilities as a screening and monitoring tool. Improvements in sEMG technology have facilitated greater accessibility and easier application, suggesting it may be a viable tool for athlete screening and profiling; however, its efficacy in this applied context needs to be examined due to uncertainty over its acute and longitudinal utility.

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Three systematic reviews [16–18] have examined sex differences in neuromuscular activation patterns in relation to ACL injuries, reporting mixed trends towards quadriceps activation relative to hamstrings in females—a pattern that may elevate ACL strain. The lack of consensus may stem from methodological discrepancies that influence an sEMG signal, such as sensor positioning, normalization methods, and diversity in the tasks examined. In addition, MA has been evaluated through both amplitude analysis (magnitude against a reference contraction) and contraction timing/patterns. Timing studies have used a variety of filters and cut-off frequencies, while RMS smoothing windows (which remove noise from the sEMG signal) in amplitude-based studies ranged significantly from 3 to 125 ms. Furthermore, sEMG has been analyzed from 200 ms before initial contact with the ground (PRE-IC) to 250 ms after initial contact (POST-IC), examining anticipatory and reactive characteristics that differ substantially [19]. These inconsistencies underscore the variability in study outcomes, making it difficult for football practitioners to adopt a uniform approach when working with sEMG data.

The reliability of sEMG data in dynamic tasks is fundamental to its valid application in football for screening, rehabilitation and prevention purposes, ensuring that observed changes in MA reflect true neuromuscular adaptations rather than measurement variability [20]. Although previous research has demonstrated robust reliability during isometric lower limb tasks [21–23], few studies have extended these assessments to athletic lower limb tasks. Step-down landing and 45° cutting tasks have generally demonstrated good to excellent between-day sEMG reliability, although muscles like the rectus femoris may only achieve moderate repeatability, with coefficients of variation ranging from 20.1% to 49.3% [24]. Conversely, a hurdle jump landing task has demonstrated good to excellent within- and between-session reliability for the quadriceps and hamstrings [25], while drop jump tasks reveal good reliability for quadriceps-to-hamstrings ratios [26]. Complicating comparisons further, these studies have focused on non-athletic populations that may exhibit distinct MA patterns compared to trained individuals [27,28], and one failed to specify whether mean or peak sEMG data were analyzed [25]. In addition, studies typically analyze POST-IC data, neglecting the importance of PRE-IC activation characteristics. Another important limitation of previous studies is their exclusive focus on the quadriceps and hamstrings, ignoring the gluteal muscles. Since gluteal activation plays a key role in dynamic knee control [29], its omission limits our full understanding of neuromuscular risk factors.

We posit that this study will serve as a foundational step in understanding the reliability of sEMG, thereby enhancing its viability for application in a football setting. For the first time, this study will explore the within- and between-session reliability of lower limb MA measures in high-risk tasks with female footballers, considering several sEMG methodological variables. Based on the past literature, we hypothesized that sEMG characteristics would demonstrate good to excellent within- and between-session reliability, mean MA will show higher reliability than peak MA, and PRE-IC measures will show higher reliability than POST-IC measures.

2. Materials and Methods

2.1. Experimental Approach

Following the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement [30], this study adopted a test–retest reliability design to investigate the within-session (trial-to-trial repeatability on the same day) and between-session (agreement of session estimates across days) reliability of sEMG during a landing and cutting task. Six muscles were selected for investigation: vastus medialis (VM), rectus femoris (RF), vastus lateralis (VL), gluteus medius (GM), biceps femoris (BF) and semitendinosus (ST). Participants attended on two occasions separated by a minimum of three days (mean 5.9 ± 2.5 days). All visits were on non-training/match days, and participants were prohibited from exercising on the day of testing. The experimental procedures were performed on the dominant kicking limb of each participant and overseen by the same researcher.

2.2. Participants

Sixteen female footballers (mean age 24.6 ± 4.4 years, height 169.2 ± 7.2 cm, mass 64.3 ± 8.5 kg) were recruited from a second-tier team in the English women's football structure. Participants were recruited from a local team using convenience sampling. Players were free from acute injury or illness and participated in full squad training (six hours per week). Ethical approval was granted by the Coventry University Ethics Committee (ref P122636), and all participants provided written informed consent.

2.3. *sEMG Preparation*

Electromyography was evaluated using a wireless sEMG system (Delsys Trigno Avanti, Natick, MA, USA). Sensor application was completed by a single researcher with extensive experience as an academic and practitioner. Sensor locations were prepared by removing hair and cleaning the skin with abrasive gel and alcohol wipes. Sensors had an interelectrode distance of 10 mm and were attached following SENIAM guidelines [31]. Manual palpation was undertaken to confirm correct anatomical positioning and to ensure the sensor site remained over the target muscle during muscle shortening. Sensors were secured using non-woven fixation dressing tape.

2.4. *Maximal Voluntary Isometric Contraction*

Reference values of muscle activity through maximal voluntary isometric contractions (MVIC) were undertaken using an isokinetic dynamometer (HUMAC NORM, Model 770, CSMi, Stoughton, MA, USA). Following completion of a standardized warm-up, participants were firmly secured to the chair across both the pelvis and thigh of the nontested limb. For evaluation of the quadriceps, participants lay supine with the knee fixed at 60° flexion [32]. For the hamstrings, participants lay prone with the knee fixed at 30° flexion [33]. For the GM, participants lay side-lying with the hip fixed at 10° abduction. Participants undertook three familiarization trials at 50%, 75% and 95% of their perceived maximum [34]. For the three MVIC trials, participants were given a countdown and then asked to produce torque as hard and fast as possible for five seconds [35], followed by a one-minute rest [36]. Standardized verbal cues encouraged participants to push and pull [37], with three minutes of rest between testing positions. The mean amplitude of the highest one-second period across all trials was selected for the MVIC.

2.5. *Athletic Tasks*

A single-leg jump landing (LAND) and sidestep cut (CUT) were chosen, as they have been widely used to assess knee neuromuscular control in female footballers [38–40] and ensure that reliability outcomes are directly applicable to screening and injury prevention practices in female football. To establish ground contact, kinetic analysis was undertaken using an integrated AMTI model BP400600-OP-2K-ST force plate (AMTI, Watertown, MA, USA), with sampling at 1000 Hz. Five warm-up trials were utilized to familiarize the movement patterns in each task.

2.5.1. Single-Leg Jump Landing (LAND)

A solid 30 cm box was set up at 50% of the participant's height away from the center of the force plate [39]. Participants were instructed to stand with the non-dominant leg flexed backwards to 90°, then hop forward, landing on the dominant leg on a mark indicated at the center of the force plate, holding the landing position for two seconds. Participants completed a total of five trials with a 10 s rest between each. Trials were repeated if the participant touched down with the contralateral limb, the stance foot left the floor, or they did not land with part of the foot over the center of the force plate.

2.5.2. Sidestep Cut (CUT)

Two pairs of Brower TCi System infra-red photogates (Brower Timing Systems, Draper, UT, USA) were positioned 2 m and 4 m from the center of the force plate along an indoor track to determine approach velocity. Participants ran from a 10 m mark, aiming for a velocity between 4.5 and 5.5 m/s [41,42], before planting their dominant leg onto the force plate, then maximally pushing off at a 90° angle in a sidestep maneuver. Approach velocity and cutting angle were selected based on higher relative knee joint loads experienced at these values [43]. Participants completed five trials with a 30 s rest between each [34] and repeated trials if task constraints were violated.

2.6. *sEMG Data Recording and Processing*

Baseline signal noise was evaluated before data recording to ensure values were ±0.2 mV. EMG signals were sampled at 2000 Hz at 16-bit resolution using a 20–450 Hz analogue bandwidth filter (Delsys Trigno Avanti, Natick, MA, USA). Surface EMG and kinetic data were recorded through Vicon Nexus software version 2.12.1 (Oxford Metrics, Oxford, UK). A trigger module (Delsys, Natick, MA, USA) synchronized sEMG and force plate data. Data were selected for analysis from two time phases: (1) the 100 ms window before initial contact with the force plate (PRE-IC) and (2) the 100 ms window after initial contact (POST-IC). Initial contact was defined when a 20 N GRF threshold was exceeded [44]. Raw SEMG data were exported into EMGworks Analysis version 4.7.3.0 (Delsys, Natick, MA, USA) for processing. The root mean square (RMS) of the signal (which mathematically inverts negative values to positive ones) was calculated using sliding windows of 10 ms and 50 ms with 50% overlap. Shorter smoothing windows were selected as they capture quick, dynamic changes in MA and are more appropriate for fast movements [45]. Mean and peak sEMG amplitudes were identified for analysis in each time phase and normalized to the peak one-second amplitude across the MVIC trials to calculate a percentage of muscle activation (MA%). Mean sEMG was calculated as the average RMS amplitude across the full 100 ms phase. Peak sEMG was defined as the single largest value of the moving-window RMS time series occurring within each 100 ms phase.

2.7. *Statistical Analysis*

All analyses were conducted using SPSS version 28 (IBM, Armonk, NY, USA). Descriptive statistics were reported as means and standard deviations (*SD*). Data normality was assessed using the Shapiro–Wilk test at the 95% confidence level, along with visual inspection of QQ plots, and most variables met the assumption of normality. To assess reliability both within and between days, we used a two-way random effects, absolute agreement *ICC* for average measures (*ICC*[2,k]) with 95% confidence intervals because our aim was to quantify how closely repeated measurements agree in absolute value and to generalize these estimates beyond the specific trials and sessions we measured. In both analyses, k denotes the number of trials averaged to compute the reported value (within-day averages for within-session reliability and session averages for between-session reliability). Coefficient of variation (*CV*) was used to assess variability with calculation (1), standard error of measurement (*SEM*) quantified absolute error of MA% using calculation (2), and minimal detectable change at 95% confidence (*MDC95*) quantified the smallest change of MA% required to exceed measurement error using calculation (3):

$$CV = \left(\frac{SD}{M}\right) \times 100 \quad (1)$$

$$SEM = SD \times \sqrt{1 - ICC} \quad (2)$$

$$MDC95 = 1.96 \times \sqrt{2} \times SEM \quad (3)$$

Reliability was classified based on *ICC* values [46], where scores <0.5 = poor reliability, values between 0.5 and 0.75 = moderate, values between 0.75 and 0.9 = good, and scores >0.9 = excellent. A visual representation of *ICC* scores as heat maps was created using Microsoft Excel. *CV* values were categorized as acceptable (<12%), intermediate (12–20%), and unacceptable (>20%) [32,47]. Intermittent recording errors resulted in metric-specific sample sizes (*n* = 10–15, median = 12) with all analyses using available cases without imputation.

3. Results

All 16 players completed both days of testing. To ensure adherence to predefined task parameters, trials were repeated when violations occurred; repeat rates were 7% (day 1) and 5% (day 2) for LAND and 16% (day 1) and 9% (day 2) for CUT. Heatmaps of *ICC* and 95% CIs are presented in Figure 1 (LAND task) and Figure 2 (CUT task). Normalized MA and absolute reliability metrics are presented in Table 1 (within-session reliability) and Table 2 (between-session reliability).

Figure 1. Heatmap of *ICC* scores for the single-leg jump landing (LAND) task. Text = *ICC* [95% CI]. BF = biceps femoris; GM = gluteus medius; RF = rectus femoris; ST = semitendinosus; VL = vastus lateralis; VM = vastus medialis. Within = within-session; Between = between-session; Pre = pre-contact; Post = post-contact.

Figure 2. Heatmap of *ICC* scores for the sidestep cut (CUT) task. Text = *ICC* [95% CI]. BF = biceps femoris; GM = gluteus medius; RF = rectus femoris; ST = semitendinosus; VL = vastus lateralis; VM = vastus medialis. Within = within-session; Between = between-session; Pre = pre-contact; Post = post-contact.

Table 1. Within-session normalized MA and absolute reliability measures for LAND and CUT tasks.

Window Length (ms)	Task Phase	LAND MA% (*SD*)	LAND *CV* (%)	LAND *SEM* (MA%)	CUT MA% (*SD*)	CUT *CV* (%)	CUT *SEM* (MA%)
				VASTUS MEDIALIS			
10 ms	PRE-IC Mean	17.2 (3.2)	19.4 29.8	1.6	23.9 (5.7)	23.6	3.0 7.6
	PRE-IC Peak	42.5 (12.8)	14.9	6.5	50.6 (15.6)	31.0	5.2
	POST-IC Mean	43.0 (6.8)		3.6	52.9 (9.9)	18.8	
	POST-IC Peak	98.1 (22.4	22.2	11.6	102.0 (24.6)	24.7	12.3
50 ms	PRE-IC Mean	23.2 (9.5)	41.0	4.4	24.1 (5.0)	21.6	2.4 4.5
	PRE-IC Peak	37.8 (15.4)	40.6	7.2	37.6 (8.6)	23.0	6.1
	POST-IC Mean	55.6 (18.9)	32.5	8.9	56.6 (11.3)	19.6	
	POST-IC Peak	71.5 (23.9)	32.0	11.4	68.8 (15.6)	22.9	7.6
				RECTUS FEMORIS			
10 ms	PRE-IC Mean	14.4 (4.1)	31.4	2.2	12.8 (3.8)	29.8	2.1 6.2
	PRE-IC Peak	38.2 (11.9)	32.6	6.3	29.9 (11.4)	37.0	5.3
	POST-IC Mean	35.9 (6.3)	17.7	3.2	47.9 (9.8)	21.6	
	POST-IC Peak	24.8 (15.7)	24.8	3.8	99.0 (27.1)	26.8	15.0
50 ms	PRE-IC Mean	44.6 (7.9)	44.6	3.9	14.4 (4.6)	31.1	2.4 5.2
	PRE-IC Peak	48.2 (14.3)	48.2	6.7	24.5 (9.4)	36.7	5.4
	POST-IC Mean	45.0 (14.4)	32.9	6.7	50.4 (10.2)	21.6	
	POST-IC Peak	53.2 (17.0)	33.4	7.6	69.1 (19.1)	25.7	11.6
				VASTUS LATERALIS			
10 ms	PRE-IC Mean	16.7 (3.5)	20.1	2.1	20.2 (5.0)	25.8	2.5 8.3
	PRE-IC Peak	43.1 (12.6)	30.3	6.2	52.0 (16.1)	31.5	4.0
	POST-IC Mean	38.8 (5.7)	15.0	2.7	49.5 (8.1)	17.1	
	POST-IC Peak	79.4 (19.2)	24.4	9.0	89.6 (22.2)	24.5	11.0
50 ms	PRE-IC Mean	20.7 (7.5)	35.3	3.6	21.8 (5.6)	26.0	2.9 5.2
	PRE-IC Peak	30.8 (10.2)	33.2	4.8	35.7 (10.5)	29.7	4.1
	POST-IC Mean	45.9 (14.7)	32.1	5.9	50.1 (8.6)	18.1	
	POST-IC Peak	58.1 (19.8)	34.6	8.0	63.1 (13.6)	21.1	7.6
				GLUTEUS MEDIUS			
10 ms	PRE-IC Mean	25.8 (4.7)	18.3	2.4	34.8 (8.1)	24.7 28.0	3.9
	PRE-IC Peak	50.2 (12.6)	24.7	9.7	80.6 (21.6)	24.4	10.2
	POST-IC Mean	47.4 (9.1)	19.7	4.9	40.1 (8.9)		4.8
	POST-IC Peak	130.0 (45.3)	29.4	31.6	70.5 (22.8)	35.5	12.8
50 ms	PRE-IC Mean	32.0 (10.2) 41.9	31.1	5.3	38.0 (9.0)	25.5 27.8	4.1 6.9
	PRE-IC Peak	(14.2)	32.9	7.8	54.3 (14.3)	22.4	4.9
	POST-IC Mean	70.8 (24.5)	29.5	16.4	42.9 (8.7)		
	POST-IC Peak	79.6 (27.2)	32.3	15.7	59.7 (14.9)	29.5	7.6
				BICEPS FEMORIS			
10 ms	PRE-IC Mean	6.5 (1.7)	26.7 39.3	0.9	17.1 (3.2) 38.0	19.7 25.3	1.4 4.2
	PRE-IC Peak	17.1 (6.7)	25.5	3.5	(9.1)	27.4	2.0
	POST-IC Mean	6.8 (1.8)		1.0	14.7 (3.9)		
	POST-IC Peak	17.9 (6.6)	37.2	3.5	35.5 (12.4)	37.2	6.1

50 ms	PRE-IC Mean	7.5 (2.0)	29.0		1.0	18.5 (3.2)	18.8	1.5 2.3
	PRE-IC Peak	10.9 (3.6)	33.6		1.8	24.7 (5.0)	21.5	2.2
	POST-IC Mean	8.3 (2.7)	30.8		1.3	16.7 (4.4)	27.2	
	POST-IC Peak	11.3 (4.0)	33.8	**SEMITENDINOSUS**	2.0	23.3 (6.5)	30.3	3.3
10 ms	PRE-IC Mean	10.6 (2.4)	22.8		1.2	26.7 (4.5)	17.5	2.3 7.1
	PRE-IC Peak	27.5 (7.3)	28.7		3.7	59.0 (14.9)	25.9	1.6
	POST-IC Mean	7.4 (1.9)	26.0		0.9	12.2 (3.2)	27.6	
	POST-IC Peak	19.6 (7.4)	38.1		3.7	30.5 (10.3)	38.0	5.0
50 ms	PRE-IC Mean	13.4 (3.8)	29.1		1.7	31.1 (7.9)	25.0	3.9 4.3
	PRE-IC Peak	17.8 (5.4)	30.6		2.5	40.0 (9.2)	23.6	2.2
	POST-IC Mean	9.7 (2.8)	29.4		1.5	17.9 (4.9)	30.5	
	POST-IC Peak	14.2 (4.9)	35.1		2.5	26.4 (9.3)	40.1	4.3

CV = coefficient of variation; MA% = percentage of muscle activation; PRE-IC = pre-initial contact; POST-IC = post-initial contact; SEM = standard error of measurement.

Table 2. Between-session normalized MA and absolute reliability measures for LAND and CUT tasks.

Window Length (ms)	Task Phase	Day 1 LAND MA% (*SD*)	Day 2 LAND MA% (*SD*)	LAND *CV* (%)	LAND *SEM* (%)	LAND *MDC95* (MA%)	Day 1 CUT MA% (*SD*)	Day 2 CUT MA% (*SD*)	CUT *CV* (%)	CUT *SEM* (MA%)	CUT *MDC95* (MA%)
					VASTUS MEDIALIS						
10 ms	PRE-IC Mean	23.2 (19.0)	18.2 (8.6)	68.5	13.0	36.1	30.4 (15.4)	21.2 (8.8)	43.1	7.5	20.7
	PRE-IC Peak	52.0 (41.5)	45.5 (20.6)	62.1	28.4	78.7	71.0 (39.1)	47.1 (19.2)	45.7	18.3	50.7
	POST-IC Mean	56.1 (29.4)	49.3 (19.9)	50.0	31.2	86.6	71.2 (31.7)	51.9 (11.6)	42.7	20.4	56.7
	POST-IC Peak	131.3 (72.3)	107.5 (39.9)	51.8	65.3	181.0	140.7 (59.1)	107.0 (25.9)	46.6	54.1	150.1
50 ms	PRE-IC Mean	34.3 (24.0)	24.8 (12.6)	66.3	17.1	47.4	32.6 (16.4)	23.3 (9.3)	43.5	8.7	24.2
	PRE-IC Peak	55.3 (39.0)	39.5 (16.3)	57.9	22.0	60.9	49.3 (24.9)	35.9 (13.8)	39.0	10.7	29.7
	POST-IC Mean	83.9 (38.4)	62.5 (22.3)	47.0	31.6	87.7	75.9 (32.3)	55.4 (11.5)	43.4	22.7	63.0
	POST-IC Peak	108.3 (49.2)	80.5 (28.4)	46.2	38.9	107.9	95.7 (40.1)	71.7 (15.6)	48.2	35.9	99.5
					RECTUS FEMORIS						
10 ms	PRE-IC Mean	14.8 (10.3)	14.5 (9.7)	21.1	0.9	2.4	12.8 (7.1)	12.3 (6.6)	19.6	0.7	2.0
	PRE-IC Peak	38.8 (20.9)	40.5 (22.3)	19.7	2.2	6.2	38.2 (25.3)	30.3 (16.4)	35.1	5.7	15.8
	POST-IC Mean	34.0 (16.8)	35.3 (15.1)	22.7	2.7	7.6	42.3 (23.2)	43.1 (21.2)	33.4	8.7	22.3
	POST-IC Peak	71.9 (40.8)	71.9 (26.7)	23.7	6.6	18.2	93.3 (55.2)	89.1 (42.1)	35.8	19.5	54.1
50 ms	PRE-IC Mean	23.7 (16.2)	19.5 (12.8)	21.6	1.3	3.5	15.2 (9.0)	14.0 (7.0)	21.4	0.9	2.6 6.3
	PRE-IC Peak	38.2 (20.7)	33.8 (19.7)	15.6	1.2	3.4	27.2 (17.7)	24.4 (13.4)	25.6	2.3	22.4
	POST-IC Mean	50.2 (22.7)	46.2 (22.3)	24.9	4.8	13.3	44.8 (23.9)	45.8 (22.3)	32.2	8.1	
	POST-IC Peak	64.1 (31.8)	56.3 (26.4)	30.1	8.7	24.1	60.7 (34.3)	61.9 (34.7)	36.7	13.3	36.8
					VASTUS LATERALIS						
10 ms	PRE-IC Mean	15.6 (8.7)	17.3 (8.5)	34.9	3.3	9.2	21.1 (8.7)	21.3 (9.5)	30.7	4.3	11.9
	PRE-IC Peak	39.7 (22.2)	42.2 (18.9)	34.4	9.1	25.3	51.6 (21.0)	49.6 (22.2)	32.2	11.4	31.6
	POST-IC Mean	36.5 (8.5)	41.2 (15.5)	31.5	12.1	33.5	50.2 (14.5)	50.3 (13.4)	22.6	8.8	24.5
	POST-IC Peak	75.1 (20.7)	84.2 (33.1)	35.8	36.5	101.0	99.6 (27.6)	95.3 (24.9)	21.2	14.8	41.0
50 ms	PRE-IC Mean	24.8 (14.1)	20.7 (8.3)	36.6	4.9	13.7	23.0 (9.5)	24.0 (12.1)	37.2	7.0	19.3
	PRE-IC Peak	39.5 (20.0)	33.6 (11.8)	34.6	8.2	22.7	34.8 (13.4)	36.8 (15.7)	31.3	8.1	22.3
	POST-IC Mean	56.2 (15.0)	48.4 (11.8)	27.4	13.3	36.8	52.4 (14.6)	52.8 (13.3)	22.4	9.8	27.2
	POST-IC Peak	70.1 (19.9)	61.0 (16.7)	28.7	18.1	50.1	65.8 (17.9)	67.4 (19.4)	22.2	11.0	30.4
					GLUTEUS MEDIUS						
10 ms	PRE-IC Mean	23.4 (13.1)	25.2 (14.8)	55.9	11.2	30.9	42.6 (20.8)	45.3 (22.9)	43.9	15.7	43.5
	PRE-IC Peak	52.4 (26.3)	54.0 (31.9)	43.0	17.5	18.5	89.3 (36.8)	108.6 (60.2)	46.0	39.8	110.3
	POST-IC Mean	38.0 (20.7)	71.2 (72.0)	91.5	54.4	150.9	43.0 (20.9)	52.3 (27.3)	47.0	19.9	55.2
	POST-IC Peak	81.2 (37.8)	111.2 (60.3)	87.3	74.7	207.1	94.9 (49.3)	122.1 (84.8)	62.4	70.7	195.9
50 ms	PRE-IC Mean	37.9 (21.5)	32.5 (20.2)	47.6	12.8	35.6	49.0 (28.6)	50.9 (28.1)	49.2	19.9	55.0
	PRE-IC Peak	49.9 (25.8)	43.6 (26.2)	45.4	16.7	46.2	62.9 (27.8)	75.5 (45.1)	48.5	29.3	81.3
	POST-IC Mean	60.8 (36.8)	87.1 (88.5)	85.0	70.8	196.3	47.1 (23.0)	57.5 (31.4)	48.1	22.8	63.2
	POST-IC Peak	74.2 (36.4)	122.9 (141.6)	99.1	113.9	315.8	64.8 (31.8)	83.6 (49.0)	49.3	31.0	86.0
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10 ms	PRE-IC Mean	6.5 (2.2)	6.5 (3.1)	26.7	1.0	2.8	18.5 (4.8)	17.4 (4.6)	19.7	2.2	6.2
	PRE-IC Peak	15.8 (6.8)	16.5 (9.1)	29.1	2.5	6.9	43.5 (11.2)	39.9 (8.5)	20.7	6.8	18.9
	POST-IC Mean	8.1 (3.5)	6.9 (2.6)	29.5	1.1	3.1	18.8 (21.7)	15.8 (7.1)	68.9	8.9	24.6
	POST-IC Peak	15.8 (5.7)	15.7 (6.7)	19.2	1.2	3.2	44.6 (48.3)	37.1 (18.2)	70.1	23.2	64.3
50 ms	PRE-IC Mean	10.3 (3.4)	7.8 (3.6)	30.6	1.9 2.4	5.1	20.4 (4.7)	19.2 (5.1)	17.4 21.7	2.0 4.8	5.7
	PRE-IC Peak	14.2 (5.2)	11.5 (5.8)	31.0	1.9	6.8	28.3 (7.8)	25.8 (5.8)	71.8	11.0	13.3
	POST-IC Mean	11.7 (4.3)	8.2 (3.1)	32.8		5.4	21.7 (24.6)	17.5 (8.2)			30.5
	POST-IC Peak	14.6 (5.4)	11.1 (4.0)	30.9	2.4	6.6	29.8 (31.3)	24.7 (12.2)	65.6	13.6	37.8
					SEMITENDINO	**SUS**					
10 ms	PRE-IC Mean	11.9 (3.1)	12.4 (2.5)	21.1	1.5	4.2	23.3 (6.4)	27.2 (5.4)	22.2	4.7	13.1
	PRE-IC Peak	29.0 (9.3)	29.2 (5.9)	23.9	4.5	12.3	48.5 (14.7)	61.5 (15.1)	26.5	11.8	32.6
	POST-IC Mean	7.7 (2.9)	7.7 (2.6)	23.4	1.1	2.9	12.3 (6.8)	14.3 (7.4)	35.4	2.4	6.7
	POST-IC Peak	20.9 (6.3)	20.6 (9.1)	27.1	3.4	9.5	31.7 (17.6)	35.8 (16.9)	34.6	6.2	17.3
50 ms	PRE-IC Mean	18.4 (5.5)	15.5 (3.4)	24.3	2.2	6.2	34.3 (10.2)	32.6 (6.5)	22.5	6.1	16.9
	PRE-IC Peak	25.1 (8.1)	20.7 (4.5)	26.0	3.4	9.3	44.1 (13.9)	42.5 (7.4)	21.9	7.4	20.6
	POST-IC Mean	12.3 (4.7)	9.9 (3.5)	29.5	2.1	5.7	20.0 (8.5)	18.2 (8.8)	32.9	3.7	10.2
	POST-IC Peak	17.4 (5.3)	15.0 (5.8)	28.7	3.2	8.8	30.0 (11.5)	26.0 (10.9)	32.3	5.8	16.0

CV = coefficient of variation; MA% = percentage of muscle activation; MDC95 = minimal detectable change at 95% confidence; PRE-IC = pre-initial contact; POST-IC = post-initial contact; SEM = standard error of measurement.

3.1. *Within-Session Versus Between-Session Reliability*

Within-session reliability was moderate to excellent for LAND (*ICC* 0.61–0.95; CI 0.12–0.98) and CUT (*ICC* 0.68–0.96; CI 0.32–0.99), whereas between-session values spanned poor to excellent for LAND (*ICC* −0.48–0.94; CI −6.58–0.99) and CUT (*ICC* −0.08–0.93; CI −4.20–0.98). When within-session *ICC*s were good to excellent (>0.74), CIs were tighter but still poor in some instances (LAND 0.44–0.98; CUT 0.42–0.99), whilst moderate *ICC*s (0.50–0.74) showed broader intervals (LAND 0.12–0.90; CUT 0.32–0.92). Between-day estimates frequently had lower bounds crossing zero, especially for GM (*ICC* −0.08–0.59; CI −4.20–0.86). Absolute error (*SEM*) and variability (*CV*) favored within-session with LAND *SEM* often <10%, and between-day *SEM* rising notably for VM (1.6–11.6% to 13.0–65.3%), VL (2.1–9.0% to 3.3–36.5%) and GM (2.4–31.6% to 11.2–113.9%). *CV*s were unacceptable in 87% of within-session and 94% of between-session parameters.

3.2. *Mean Versus Peak Amplitude Reliability*

Mean sEMG produced slightly higher *ICC*s than peaks across muscles, tasks and windows (differences predominantly < 0.1) and narrower 95% CIs than peak estimates when *ICC* scores were moderate or better (>0.5). *SEM* was predominantly lower in mean measures in LAND, with the largest differences in reliability against peak measures seen at 10 ms for VM, VL, and GM (1.2–43.1%). In CUT, the mean *SEM* was exclusively lower than the peak across all metrics (Tables 1 and 2). *CV* was invariably lower in mean sEMG measures across all muscles and metrics, although this was less consistent in between session measures. When present, differences were more pronounced when smoothing with a 10 ms RMS window. *MDC95* thresholds were consistently lower than the corresponding peaks for all mean parameters (Table 2).

3.3. *Pre Versus Post-Contact Phase Reliability*

PRE- and POST-IC phases showed broadly comparable *ICC*s (phase differences generally < 0.1), with higher reliability PRE-IC in LAND and POST-IC in CUT. Where phase effects appeared, CIs mirrored the *ICC* pattern, being tighter in the more reliable phase. POST-IC tended to inflate absolute error, with the greatest differences seen in the LAND task. Greater within-session SEM was seen in VM and GM (2.0–20.9%), and greater between session SEM was seen for VM, RF, VL, and GM (3.5–97.2%). In CUT, POST-IC increases were smaller (0.8–8.8%), with some muscle-specific exceptions. The PRE-IC *CV* was higher in VM, RF and VL and lower in GM, BF and ST for within-session measures, and time phase *CV* varied by muscle and task between sessions. *MDC95* thresholds were consistently lower for all PRE-IC parameters (Table 2).

3.4. *RMS Window Length Reliability*

The 10 ms window length generally showed higher *ICC* scores than 50 ms in the LAND task within-session, with the largest differences seen in the VM and VL muscles. Between sessions, *ICC*s were similar between window lengths in both the LAND and CUT tasks. Absolute reliability, as measured by *CV* and *SEM*, was generally similar across window lengths. *MDC95* was generally lower across both tasks when processed with a 50 ms window for mean parameters in VM, VL, BT and ST.

4. Discussion

Despite past research using sEMG to investigate muscle excitation as a risk factor for ACL injury, there remains a paucity of reliability data for this method. We therefore investigated the within- and between-session reliability of sEMG during a single-leg jump landing and a 90° sidestep cutting task in female footballers and explored the influence of selected methodological parameters. Our results demonstrate, for the first time, moderate to excellent within-session reliability, whereas between-session values were lower, ranging from poor to excellent. sEMG may therefore have benefits in the acute assessment of muscle activation characteristics; however, its use for longitudinal monitoring should be approached with caution.

4.1. Within- Versus Between-Session Measures

The reliability of sEMG was muscle-specific, and irrespective of sampling window, phase of movement, and task, *ICC*s were greater within-sessions and poorer betweensessions. *CV* values were high and are an established method for assessing reliability; however, they should be interpreted cautiously in phases with low mean activation, where ratio-based metrics can be inflated by a small denominator. *CV* should therefore be contextualized alongside *ICC* (with CIs) and absolute error indices (*SEM* and *MDC95*). For example, in LAND PRE-IC (10 ms) for BF, *CV* exceeded 20% despite *SEM* = 1.0% and *MDC95* = 2.8%, illustrating the inflation of ratio-based metrics when mean activation is low. In addition, absolute measurement error (*SEM*) increased notably between sessions for VM, VL, and GM, indicating reduced precision of day-to-day estimates for these muscles. Collectively, this suggests that LAND and CUT may provide repeatable sEMG estimates across multiple muscles on a single testing day, whereas day-to-day monitoring is more sensitive to other sources of variability.

Poor between-session reliability may be attributable to several interacting methodological, biomechanical and physiological factors. Small deviations in electrode positioning may alter the area of motor units being measured [20], while fluctuations in skin temperature and moisture [48] may affect the impedance of the sEMG signal, although the ambient environment was controlled in this study. In addition, normalizing to fixed-angle isometric dynamometer MVICs may have added normalization noise due to day-to-day maximal effort variability [49]. Alternative methods for sEMG normalization exist [50], with standardized submaximal [21] or dynamic [51] reference contractions demonstrating good between-session reliability. Other work has proposed that MVICs remain reliable compared to these methods [24,52], supporting that there may be no single best normalization method and that choice should be muscle- and task-dependent [53]. Neuromuscular recovery in footballers may require up to 48 h post-match [54]; therefore, in-season testing schedules could result in day-to-day fluctuations in MVIC capacity. Finally, biomechanical variability inherently reduces measurement consistency in dynamic tasks [55,56], and lower betweensession reliability may partly reflect this, rather than just measurement noise. Therefore, between-session variability likely reflects a combination of methodological factors and genuine day-to-day changes in movement strategy or physiological state, and the relative contribution of each cannot be isolated from sEMG data alone.

Consistent with sample sizes commonly reported in applied sEMG reliability research [24–26], our study yields informative preliminary estimates; however, modest sample sizes can widen *ICC* confidence intervals, particularly for between-session outcomes, where variability is inherently greater. Accordingly, *ICC* CIs spanning zero (or with negative lower bounds) should be interpreted as reflecting estimation imprecision/instability rather than true negative reliability, especially where the number of usable paired observations was smaller.

While situated within the broader reliability literature, a direct comparison is difficult due to the diversity of methods and the lack of previous studies investigating the GM. Two studies [24,26] failed to undertake a sex-specific analysis and focused on bipedal jumps, which do not replicate the unilateral loading patterns associated with ACL injury mechanisms. Our findings contrast with the high between-session reliability proposed by [25], likely because their protocol required participants to stabilize for two seconds POST-IC, capturing a relatively steady stance phase and reducing short-latency variability that is intrinsic to reactive landing and ACL injury risk.

4.2. Mean Versus Peak Amplitude Measures

Mean sEMG amplitude showed marginally higher *ICC*s and narrower CIs than peak sEMG within sessions across all muscles and tasks, while *SEM* and *MDC95* were uniformly lower for mean sEMG in both LAND and CUT, indicating that mean sEMG may offer greater reliability. Mean sEMG exhibited superior reliability, likely because it smooths extreme fluctuations and attenuates the impact of outliers [45,57]. By averaging activation over the entire PRE-IC or POST-IC phase, mean sEMG yields a more consistent measure of neuromuscular activation. In contrast, peak sEMG captures only discrete maxima in myoelectric activity, making it particularly susceptible to motion artefacts [58]. This may reduce the repeatability of peak metrics, but does not necessarily diminish their physiological relevance, given that brief high-amplitude bursts may reflect rapid neuromuscular responses to impact and directional loading.

This study is the first to investigate the reliability of mean and peak MA characteristics during the PRE-IC and POST-IC phases of dynamic tasks. Our findings are novel, given that past reliability studies [24–26] all fail to identify whether mean or peak data were used to normalize sEMG signals. Observational studies of sEMG in dynamic tasks [44,59,60] have predominantly reported on mean activation values across the phase of a task, an approach supported by the findings of this study. Nevertheless, where peak activation is of primary interest (e.g., quantifying transient bursts), the lower reliability observed here highlights the need for careful standardization and interpretation alongside indices of measurement error.

4.3. Pre- Versus Post-Contact Tasks Phases

Differences in *ICC* between the PRE-IC and POST-IC phases were minimal, with slightly higher stability observed PRE-IC in the LAND task and POST-IC in the CUT task. Variability and error tended to increase POST-IC across most muscles, particularly in the GM, suggesting that phase-to-phase differences are muscle- and task-specific. POST-IC reliability in the LAND task was reduced, likely reflecting elevated signal noise from ground reaction forces (GRFs). In female athletes, peak GRFs reach approximately 2.69 × body weight during a 90° cut [61] and 4.89 × body weight in single-leg jump–land tasks [62]. These forces exacerbate motion artefacts as the sensor moves relative to the skin during braking [63]. Despite using adhesive tape and band-pass filtering to attenuate low-frequency drift, some variability in post-contact measurements appears unavoidable, particularly in the GM. More broadly, the extent to which landing and cutting are standardized may further influence the observed variability and, consequently, reliability estimates.

While our results generally showed lower reliability than those of Fauth et al. [24], who found higher PRE-IC and POST-IC *ICC* scores in the quadriceps and hamstrings, our results provide a more accurate reflection of movement variability and natural fluctuations in neuromuscular activation in football. Our minimal instruction protocol contrasts with the tightly controlled approach of Fauth et al. [24], who provided detailed mechanical guidelines and required participants to achieve consistent pre-trial performance. Their stringent standardization likely suppressed the natural variability inherent in landing and cutting, thereby artificially elevating reliability metrics compared to our more ecologically valid assessments. This trade-off between internal and external validity is important when interpreting sEMG in applied settings. Increased variability may better reflect real-world movement patterns, but it can also reduce the interpretability of sEMG-derived metrics for screening or threshold-based classification, particularly when decisions rely on stable between-session estimates.

4.4. RMS Window Length Choices

Within-session VM and VL reliability was higher for the LAND task with a 10 ms window, but additional smoothing provided by a 50 ms window did not generally influence reliability measures across all other within-session metrics or any between-session metrics. Therefore, the choice between a 10 ms or 50 ms window length is a relatively minor determinant of reliability in dynamic tasks. Given the minimal effect of window length on reliability, window selection may be guided primarily by the balance between temporal resolution and signal stability. By reducing the window length, we keep more data samples for interpretation and therefore, can detect more rapid changes in the sEMG signal. Neuromotor characteristics are likely to change rapidly in response to dynamic loading tasks; therefore, processing with shorter window lengths may be advocated to capture these changes [64]. However, shorter windows may also increase sensitivity to timing variability and transient noise, while longer windows may provide greater smoothing at the expense of reducing short-lived activation bursts. Therefore, prioritizing shorter windows is best justified by the need to identify rapid neuromuscular changes around key events, rather than by clear reliability advantages.

Many studies have reported the use of short RMS window lengths ≤50 ms to examine female sEMG characteristics during landing and cutting [34,44,60,65–67], but our study is the first to present reliability data for these tasks. Previous work has reported only minor reliability differences across windows in GM during a side-lying clam exercise (*ICC*s 0.79–0.87, CIs unreported) across 10–10,000 ms windows [68], whilst other work found similarly high *ICC*s (0.87–0.98, CIs 0.65–0.99) across 200–3000 ms windows in the quadriceps during a leg press [69]. However, comparison with both studies is challenging due to the substantial variance in the range of window lengths explored and the low complexity of the tasks studied. Collectively, these findings support the notion that when adopting window lengths typically used in applied studies of dynamic tasks with complex movement patterns (≤50 ms), the practical choice may be driven by the required temporal specificity of analysis.

4.5. *Practical Recommendations*

Our findings suggest changes in sEMG characteristics are best judged within the same session, minimizing noise from electrode reapplication or day-to-day physiological variability. Examples for football include within-day asymmetry checks, immediate technique refinement with feedback, and same-day readiness decisions for training/rehabilitation. By contrast, applying these metrics to longitudinal monitoring (e.g., rehabilitation milestones or return-to-play decisions) should be approached cautiously and limited to muscles/phases demonstrating acceptable between-session precision. When using sEMG to generate MA profiles, practitioners should focus on mean rather than peak values, as they provide a more stable assessment; however, peak measures may still be informative for questions focused on brief activation bursts, albeit with greater measurement error. Mean sEMG facilitates reliable within-session comparisons to identify abnormal recruitment patterns and monitor intervention effects, while minimizing the noise introduced by transient signal spikes. As PRE-IC and POST-IC phases yield comparable reliability, practitioners should select the phase that shows the highest reliability metrics for the task and muscle(s) of interest, rather than universally prioritizing PRE-IC or POST-IC measures. Since window length minimally impacts reliability, practitioners can select a 10 ms smoothing window to capture rapid EMG fluctuations during deceleration tasks when temporal specificity is required, recognizing that longer windows may provide additional smoothing at the expense of masking short-lived changes.

4.6. *Limitations*

Whilst this study offers important new insight into sEMG reliability, it is not without limitations. A modest sample size may have reduced *ICC* precision; therefore, future work should use larger cohorts and/or derive estimates from repeated measurements across multiple sessions to further develop the understanding of between-session consistency. We did not control for the menstrual cycle, which may affect sEMG characteristics [70,71], but this reflects the applied nature of how the assessment approach might be used in practice. Acute and/or cumulative fatigue may have contributed to lower reliability scores during the competitive season [72]; however, player workloads were not quantified in our study. The generalizability of our findings may be limited by tasks that do not challenge cognitive load or reactive decision-making [73] and by differences in competitive level (e.g., elite vs recreational athletes), which can influence MA characteristics [74]. Our study only assessed the dominant kicking limb, so future work may wish to investigate bilateral differences. Finally, we investigated the amplitude of myoelectric activity; however, the timing and pattern characteristics of the signal may also be linked to ACL injury risk [59,75]. Therefore, the reliability of these measures should be the subject of future investigation.

5. Conclusions

Surface EMG, when processed as mean RMS, demonstrated generally moderate to excellent within-session reliability for assessing lower-limb MA in female footballers, supporting the exploratory methodological aim of identifying metrics that are sufficiently repeatable in applied contexts. Our study proposes that sEMG may be a viable tool for identifying acute neuromuscular activation characteristics, such as within-session screening for asymmetry, confirmation of response to coaching cues, and assessment of drill progression/regression. Longitudinal use for season-long screening, tracking rehabilitation efficacy over days or weeks, or return-to-sport clearance should be approached cautiously and should not be used in isolation, as it is unclear whether reduced reliability and measurement error stem from sEMG as a measurement tool, task variability, or physiological fluctuations.

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Abbreviations

The following abbreviations are used in this manuscript:

ACL	Anterior cruciate ligament
BF	Biceps femoris muscle
CUT	Sidestep cut task
CV	Coefficient of variation
GM	Gluteus medius muscle
ICC	Intraclass correlation coefficient
LAND	Single-leg jump landing task
MA	Muscle activation
MA%	Percentage of muscle activation normalized to a reference task
MDC95	Minimal detectable change at 95% confidence
MVIC	Maximal voluntary isometric contraction
POST-IC	Post-initial contact
PRE-IC	Pre-initial contact
RF	Rectus femoris muscle
RMS	Root mean square
SD	Standard deviation
SEM	Standard error of measurement
sEMG	Surface electromyography
SENIAM	Surface Electromyography for the Non-Invasive Assessment of Muscles
ST	Semitendinosus muscle
VL	Vastus lateralis muscle
VM	Vastus medialis muscle

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