

Article

The Influence of a Competitive Football Match on the Knee Flexion and Extension Rate of Force Development and Isometric Muscle Strength in Female Football Players

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Abstract: Background: The scientific literature about the effect of a football match on leg force production is scarce, particularly for competitive matches in female football players. This investigation aimed to assess the acute effect of a competitive football match on the quadriceps and hamstrings' rate of force development (RFD) and isometric peak force (IPF) during knee flexion and extension actions. Methods: The study design of the present research was descriptive and longitudinal. Twenty-two female football players (20 ± 2 years) underwent unilateral maximal isometric knee extension (quadriceps) and flexion (hamstrings) force measurements at three time points: baseline (before the match), immediately after the match and 48 h post-match. The measurements were performed for both dominant and non-dominant legs in a nearly extended position (30° of knee flexion and 90° of hip flexion) using a load cell. The maximum RFD was calculated at different time phases (RFD₁₅₀ [at first 150 ms of action] and RFD₂₅₀ [at first 250 ms of action]). The hamstring–quadriceps (H:Q) ratio was calculated for all strength variables in each leg. Results: The IPF decreased after the match for the quadriceps (dominant: -11.6% and non-dominant: -14.8% , $p < 0.05$) and hamstring muscle contractions (dominant: -8.0% and non-dominant: -11.4% , $p < 0.05$). IPF values returned to baseline 48 h after the match. Similarly, RFD₁₅₀ and RFD₂₅₀ were reduced after the match (ranging from -30.3% to -13.5% ; all $p < 0.05$) for quadriceps in both legs and for the hamstring only in the non-dominant leg. The RFD₁₅₀ H:Q ratio changed from baseline values ≤ 1.03 to ≥ 1.16 at 48 h post-match. Conclusions: A competitive football match in female football players induced neuromuscular fatigue of comparable magnitude in both quadriceps and hamstring muscles as evidenced by lower IPF and RFD values in isometric actions. Most strength variables returned to baseline 48 h after the match. However, some H:Q ratios were still disturbed after this recovery time.

Keywords: fatigue; sports medicine; risk factors; soccer; women



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1. Introduction

The rupture of the anterior cruciate ligament (ACL) is likely the injury with the most burden in female football because it entails a long-term rehabilitation period [1]. A recent study reported that the time lost ranges from 246 to 334 days, with an incidence ranging

from 0.1 to 0.2 injuries per 1000 h [2]. An ACL injury occurs when the ligament is subjected to an excessive load that exceeds its mechanical tolerance, resulting in structural failure and compromised knee stability [3]. Scientific data suggest that female athletes are two to three times more vulnerable to ACL injuries than male athletes [4,5], possibly due to sex-related differences in biomechanics and neuromuscular control of the trunk and lower limbs during football-specific actions [6]. In female football players, the primary mechanism of ACL injury occurs without direct contact, typically during pressing or tackling movements [7,8], which involve deceleration and cutting actions [9].

It is well established that ACL injuries have a multifactorial causation, resulting from the interaction of various intrinsic (i.e., anatomical, biomechanical, hormonal and neuromuscular control variables) and extrinsic (i.e., shoe–surface interaction, bracing and physical and visual perturbations) risk factors in football players [6,10–12]. These risk factors can be categorised as modifiable (i.e., environmental conditions, pitch characteristics, type of football shoes, player's body mass index, neuromuscular control and fatigue) and non-modifiable (i.e., anatomical structure, genetics, sex and history of previous ACL injury) [6,12,13]. Within neuromuscular control variables, it has been suggested that excessive quadriceps strength combined with decreased hamstring co-contraction increases the shear force exerted on the anterior–posterior plane of the tibia when the knee is fully extended (around 30°), raising the possibility of suffering an ACL injury [14]. In this regard, the rapid stabilisation of the knee by mutual and balanced neuromuscular work of the quadriceps and hamstring muscles during sudden and fast movements could minimise the potential risk of ACL injury [15]. For this reason, assessing the relationship between the strength of the quadriceps and hamstring muscles in the range when the knee is fully extended is recommended to be employed as a criterion to decide the return to play after an ACL injury [16,17]. Additionally, it has been proposed that the hamstring-to-quadriceps (H:Q) ratio of maximal strength variables has limited accuracy in predicting ACL injuries. This limitation may be due to factors such as the cut-off values and body position during testing, which do not accurately replicate the conditions under which ACL injuries occur [18]. Moreover, alternative H:Q ratios have been proposed, incorporating measures such as the rate of force development (RFD) instead of maximal strength. Additional calculations based on fatigue index, muscle size and muscle activation within each muscle group have also been suggested to improve the accuracy of ACL injury risk assessment [19].

Another intrinsic risk factor that may contribute to an increased likelihood of developing an ACL injury in football players is the acute neuromuscular fatigue developed with football practice [20,21]. Previous studies have coincided in pointing out that a football match leads to decreased quadriceps and hamstring muscle strength in both male and female football players [22,23]. Hence, two risk factors for ACL injury may concur as there are important changes in the H:Q ratio of force variables caused by the transitory fatigue induced by the match play. Previous studies have explored the effects of neuromuscular fatigue on isometric strength induced by soccer-specific intermittent protocols in male football players [24–26] and during a competitive match [27]. However, these assessments have typically focused on ranges of motion of 70–90° that differ from those where injuries are most likely to occur (such as ACL injuries occurring in positions near full knee extension) [28,29]. However, in the case of female football players, the potential decrease in quadriceps and hamstring muscle strength induced by match play has been tested only after soccer-specific intermittent protocols and a friendly match [22,30]. In these cases, strength assessment was carried out through isokinetic dynamic actions, where the maximum peak may have occurred in a range of motion far from the range of interest. Therefore, this investigation aimed to assess the acute effect of a competitive football match on the quadriceps and hamstring RFD and isometric peak force (IPF) during knee extension

and flexion actions, including their respective H:Q ratios. In addition, a secondary objective was to study the association between physical parameters during a competitive match with the change in strength variables after a match. The authors hypothesised that a competitive match would reduce both quadriceps and hamstring strength. However, the magnitude of the quadriceps strength decreases would be higher than those of the hamstrings, affecting the H:Q ratio for several strength variables based on prior research [31].

2. Materials and Methods

2.1. Study Design

The present research is developed to gauge how factors associated with an increased likelihood of ACL injury in female football players are modified by the fatigue induced by a competitive football match. This study was a descriptive longitudinal design conducted on a football field so that all the testing procedures were performed in an ecologically valid environment. Measurements were performed at three different moments: (a) at baseline, obtained 24 h before a competitive football match, (b) post-match, measured immediately at the end of the match, and (c) 48 h post-match, measured after two days of recovery. The three matches at which the assessment was performed were always official and played on an artificial turf surface, with a duration of 90 min. In addition, the average temperature and relative humidity of the matches were between 14.3 and 22.2 °C and 67.1 and 83.8%, respectively. Four days prior to the onset of the experiment, all football players performed a familiarisation session, and anthropometric measurements were collected. Leg dominance was determined by asking participants which leg they used to kick the ball [32]. Before each test session, the football players performed a standardised 8 min warm-up consisting of running exercises based on a previous study [33]. Additionally, players completed 2 sets of 6 s neuromuscular activation exercises to complete the warm-up, as previously suggested [34].

2.2. Participants

A total of 22 amateur female football players (age: 20 ± 2 years; height: 164 ± 8.0 cm; weight: 60.2 ± 8.5 kg; sport experience: 12 ± 4 years) from two teams voluntarily participated in this study. The exclusion criteria included (a) less than 90% participation in the training sessions for the three months before the intervention; (b) history of lower limb pain within the past three months; (c) participation in the football match for less than 70 min; (d) history of any type of knee injury in the previous year. Training and injury histories were collected to confirm exclusion criteria. The sample included 8 defenders, 9 midfielders and 5 forwards. Goalkeepers were excluded from the study due to the demands being different to field players throughout matches [35]. Players trained an average of 4.0 ± 0.1 h per week over the season and played about one competitive match per week, being classified as Tier 2 [36]. All players were informed of the testing procedures and signed an informed consent form obtained before the beginning of this study. Following the 2013 Declaration of Helsinki, this research was conducted and approved by the University's Ethics Review Committee (code: DCD.JLE.01.20).

2.3. Measurements

2.3.1. Knee Flexion and Extension Isometric Test

IPF was automatically measured with an accessible and cost-effective tool to assess unilateral knee extension (i.e., quadriceps action) and knee flexion (i.e., hamstrings action) isometric muscle strength in a nearly extended position (30° of knee flexion and 90° of hip flexion) in football players, and the maximum RFD (RFD_{max}) and at different time phases (RFD_{150} [at first 150 ms of action] and RFD_{250} [at first 250 ms of action]) was calculated [37].

H:Q ratios for IPF and RFD variables in each leg were also calculated. A summary of strength parameters is shown in Table 1.

Table 1. Summary of time points, measurements, parameters and tools employed.

Time Points	Measurements and Parameters (Units)	Tools
	Strength measurements:	
	• IPF (N) and its H:Q ratio • RFD_{max} (N/s) and its H:Q ratio • RFD_{150} (N/s) and its H:Q ratio • RFD_{250} (N/s) and its H:Q ratio	Load cell
	Match-derived parameters	
Baseline	• Distance covered (m) • Explosive distance covered over 1.12 m/s² (m)	
Post-match		
48 h post-match	• Distance covered at different speed thresholds [18.0–20.9 km/h; 21.0–23.9 km/h and ≥ 24.0 km/h] (m) • Total number of accelerations/decelerations (n) • Distance covered with accelerations/decelerations over ± 3 m/s² (m) • Mean heart rate (bpm)	GPS–accelerometer device and heart-rate band

IPF: isometric peak force; RFD_{max} : maximum rate of force development; RFD_{150} : rate of force development for the first 150 ms of action; and RFD_{250} : rate of force development for the first 250 ms of action; H: hamstrings; Q: quadriceps.

Chronojump software v2.1.2-2 and an A/D converter (Chronojump Bosco System, Barcelona, Spain) controlled a load cell (Model 620 Tedea-Huntleigh, Vishay Precision Group Inc., Modi'in-Maccabim-Re'ut, Israel) to obtain and record data at 80 Hz through a previously reported reliable protocol [37]. The isometric actions lasted for 3 s while players received standardised verbal encouragement [38] and had stabilising straps around their thighs to avoid leg movements. The starting leg (dominant or non-dominant) was randomised and counterbalanced. Two attempts with 30 s rest were performed for both the quadriceps and hamstring isometric muscle actions and dominant and non-dominant sides. The mean value of these two attempts in each leg was used for statistical analysis. The load cell was calibrated before each session using a 5 kg weight, according to the manufacturer's instructions.

2.3.2. Physical Parameters During the Competitive Match

Players' movements during the competitive match were recorded using GPS–accelerometer units (Wimu ProTM, RealTrack Systems, Almeria, Spain) at a frequency of 10 Hz. These GPS–accelerometer units have shown a good level of accuracy in the assessment of running patterns in official sports competitions [39,40]. Following the guidelines provided by the manufacturer, all instruments were placed within a vest and activated 15 min before data collection. This allowed for satellite signal acquisition and the synchronisation of the GPS clock with the atomic clock of the satellite. Additionally, a synchronised heart rate band was placed on the player's chest to monitor heart rate during the match. The selected parameters analysed were distance covered, high-speed running distance covered at different speed thresholds (18.0–20.9 km/h, 21.0–23.9 km/h and ≥ 24.0 km/h), explosive distance covered with accelerations over 1.12 m/s², total number of accelerations/decelerations, distance covered with acceleration/deceleration over 3 m/s² and

mean heart rate [41,42]. A summary of match-derived parameters is shown in Table 1. After each match, data obtained by the GPS–accelerometer units were downloaded using the customised software package SPRO™ v1.0.0 and analysed afterwards to obtain the above-mentioned parameters.

2.4. Statistical Analysis

All statistical analyses were performed with custom scripts in Python 3.7 using the open-source Pingouin v0.3.8 library [43] and pandas v1.5.3 [44]. Descriptive statistics, including mean and standard deviation, were calculated for IPF, RFD and their ratios for both legs during isometric knee extension and flexion actions. The data's normality and sphericity were verified using the Shapiro–Wilk and Mauchly's tests, respectively. An N-way ANOVA was computed to ensure parity of physical parameters between matches, and the average was reported if there were no differences between them. A one-way repeated-measures analysis of variance (ANOVA) was performed to assess changes in the isometric knee extension and flexion tests across three different moments (baseline, post-match and 48 h post-match) and between legs (dominant and non-dominant). The Greenhouse–Geisser correction was applied when sphericity was not achieved [45]. The effect size for ANOVA was reported based on partial Eta-squared values (η^2). Post hoc comparisons were executed, which were subjected to a Holm–Bonferroni correction. Effect size (ES) was reported based on Cohen's d from post hoc comparisons. ES thresholds were defined as trivial (<0.2), small (0.2 – 0.6), moderate (0.6 – 1.2), large (1.2 – 2.0) and very large (>2.0) [46]. Finally, a bivariate Pearson correlation (r) was used to analyse the association between physical parameters during the match and data obtained in the knee extension and flexion post-match tests. The significance level (p) was set a priori at <0.05 .

3. Results

3.1. Match-Derived Physical Parameters

There were no significant differences in any of the physical parameters collected (i.e., volume and intensity variables) between each competitive match. Female footballers covered a mean distance of $10,171.9 \pm 2247.3$ m ($F = 0.50$; $p = 0.614$; $\eta^2 = 0.05$), a mean distance at 18.0 – 20.9 km/h of 185.2 ± 128.4 m ($F = 1.15$; $p = 0.338$; $\eta^2 = 0.11$), a distance at 21.0 – 23.0 km/h of 70.9 ± 82.2 m ($F = 1.95$; $p = 0.170$; $\eta^2 = 0.17$) and a distance at ≥ 24 km/h of 33.4 ± 79.6 m ($F = 1.79$; $p = 0.195$; $\eta^2 = 0.16$) during the match. The total number of accelerations and decelerations was 4977 ± 754 ($F = 0.14$; $p = 0.871$; $\eta^2 = 0.01$) and 4978 ± 753 ($F = 0.14$; $p = 0.871$; $\eta^2 = 0.01$), respectively. The mean explosive distance covered at accelerations > 1.12 m/s² was 870.6 ± 301.3 m ($F = 0.46$; $p = 0.635$; $\eta^2 = 0.05$), and the mean distance covered during accelerations/decelerations over/under 3 m/s² was 183.0 ± 86.2 ($F = 0.04$; $p = 0.962$; $\eta^2 \leq 0.01$) and 131.1 ± 75.6 m ($F = 0.05$; $p = 0.952$; $\eta^2 \leq 0.01$), respectively. Finally, 157 ± 10 bpm ($F = 1.07$; $p = 0.364$; $\eta^2 = 0.10$) was the mean heart rate during the match.

3.2. IPF and RFD

The ANOVA revealed a main effect of time for both legs IPF for quadriceps and hamstrings (quadriceps: $0.13 \leq \eta^2 \leq 0.29$, $p < 0.05$; hamstrings: $0.18 \leq \eta^2 \leq 0.21$, $p < 0.05$), RFD_{max} for hamstrings ($0.19 \leq \eta^2 \leq 0.20$, $p < 0.05$) with no time effect for quadriceps ($0.01 \leq \eta^2 \leq 0.04$, $p > 0.05$), RFD₁₅₀ for quadriceps and hamstrings (quadriceps: $0.13 \leq \eta^2 \leq 0.16$, $p < 0.05$; hamstrings: $0.13 \leq \eta^2 \leq 0.29$, $p < 0.05$) and RFD₂₅₀ for quadriceps and hamstrings (quadriceps: $0.18 \leq \eta^2 \leq 0.22$, $p < 0.05$; hamstrings: $\eta^2 = 0.14$, $p < 0.05$). A summary of mean $\pm$ standard deviation (SD) values, repeated-measures ANOVA and post hoc comparisons for strength parameters measured across the time

of measurement is presented in Table 2. IPF values for the isometric quadriceps action showed a significant decrease post-match with respect to baseline values in the dominant leg ($ES = -0.46$, $p = 0.008$) and non-dominant leg ($ES = -0.61$, $p = 0.001$). Overall, IPF during the isometric quadriceps action regained baseline values after 48 h post-match, evidenced by a significant 48 h post-match increase with respect to post-match values for the non-dominant leg ($ES = 0.64$, $p = 0.001$). During the isometric hamstrings test, IPF values showed a significant post-match decrease from baseline values in the dominant leg ($ES = -0.32$, $p = 0.041$) and non-dominant leg ($ES = -0.55$, $p = 0.027$). Similarly, 48 h post-match values for isometric hamstrings IPF increased from post-match values in the dominant ($ES = 0.53$, $p = 0.007$) and non-dominant leg ($ES = 0.61$, $p = 0.011$) and were similar to baseline values.

RFD_{max} values during the isometric hamstrings test remained unchanged from baseline to post-match but 48 h post-match values increased to baseline in the dominant leg ($ES = 0.80$, $p = 0.008$) and concerning post-match values in the non-dominant leg ($ES = 0.65$, $p = 0.004$). RFD₁₅₀ values showed significant changes during both quadriceps and hamstring actions. During the isometric quadriceps test, post-match values decreased from baseline in both dominant ($ES = -0.68$, $p = 0.003$) and non-dominant legs ($ES = -0.69$, $p = 0.023$). Overall, RFD₁₅₀ during the isometric quadriceps action regained baseline values 48 h post-match. During the isometric hamstrings test, RFD₁₅₀ values decreased post-match in the non-dominant leg ($ES = -0.73$, $p = 0.006$) to baseline. Isometric hamstring RFD₁₅₀ results showed no changes in 48 h post-match values from baseline but there were significant increases in 48 h post-match changes to post-match values in the dominant ($ES = 0.41$, $p = 0.046$) and non-dominant leg ($ES = 0.88$, $p = 0.001$). Lastly, RFD₂₅₀ values during the isometric quadriceps action showed a significant post-match decrease from baseline values in dominant ($ES = -0.67$, $p = 0.001$) and non-dominant leg ($ES = -0.72$, $p = 0.004$). RFD₂₅₀ during the isometric quadriceps test regained baseline values after 48 h post-match, with a significant 48 h post-match increase with respect to post-match only for the dominant leg ($ES = 0.50$, $p = 0.034$). During the isometric hamstrings test, post-match RFD₂₅₀ values decreased from baseline values in the non-dominant leg ($ES = -0.55$, $p = 0.040$). Apart from that, RFD₂₅₀ during the isometric hamstrings test regained baseline values 48 h post-match, with a significant 48 h post-match increase with respect to post-match values in the non-dominant leg ($ES = 0.52$, $p = 0.046$).

3.3. H:Q Ratios

The ANOVA revealed a main effect of time for both legs' H:Q RFD₁₅₀ ($0.13 \leq \eta P^2 \leq 0.14$, $p < 0.05$) and for dominant leg H:Q RFD₂₅₀ ($\eta P^2 = 0.19$, $p < 0.05$), with no time effects for H:Q IPF ($\eta P^2 \leq 0.09$, $p > 0.05$) and H:Q RFD_{max} ($\eta P^2 \leq 0.09$, $p > 0.05$). A summary of mean $\pm$ standard deviation (SD), repeated measures ANOVA and post hoc comparisons for H:Q ratio parameters measured across the time of measurements is presented in Table 3. Only some H:Q RFD ratio parameters were significantly modified after the match. Specifically, the H:Q RFD₁₅₀ and H:Q RFD₂₅₀ increased post-match in the dominant leg ($ES = 0.65$, $p = 0.012$ and $ES = 0.62$, $p = 0.024$, respectively). In addition, the H:Q RFD₁₅₀ values increased 48 h post-match from baseline values in the dominant leg ($ES = 0.62$, $p = 0.014$).

Table 2. Force variables for isometric quadriceps and hamstring muscle actions at baseline, post-match and 48 h after a competitive football match in female players.

Variable	Muscle	Leg	Baseline	Post-Match	48 h Post-Match	ANOVA	Baseline— Post-Match	Baseline— 48 h Post-Match	Post-Match—48 h Post-Match
			Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD	$F; p; \eta P^2$	p, ES	p, ES	p, ES
IPF (N)	Q	D	237.40 $\pm$ 57.96	212.66 $\pm$ 48.66	229.76 $\pm$ 55.76	3.83; 0.047; 0.13	0.008, −0.46	0.530, −0.13	0.132, 0.33
		ND	230.95 $\pm$ 49.47	201.18 $\pm$ 48.75	234.50 $\pm$ 55.00	8.68; 0.001; 0.29	0.001, −0.61	0.724, 0.07	0.001, 0.64
	H	D	245.84 $\pm$ 61.81	227.69 $\pm$ 50.30	258.83 $\pm$ 66.31	5.57; 0.007; 0.21	0.041, −0.32	0.175, 0.20	0.007, 0.53
		ND	236.99 $\pm$ 40.27	212.68 $\pm$ 47.49	243.42 $\pm$ 53.74	4.75; 0.014; 0.18	0.027, −0.55	0.538, 0.14	0.011, 0.61
RFD _{max} (N/s)	Q	D	1415.19 $\pm$ 719.98	1600.05 $\pm$ 989.50	1352.85 $\pm$ 722.01	0.29; 0.749; 0.01	-	-	-
		ND	1326.15 $\pm$ 831.81	1306.63 $\pm$ 622.75	1434.71 $\pm$ 728.23	0.94; 0.400; 0.04	-	-	-
	H	D	905.24 $\pm$ 293.28	977.89 $\pm$ 340.81	1224.84 $\pm$ 483.46	5.28; 0.009; 0.20	0.338, 0.23	0.008, 0.80	0.053, 0.59
		ND	1101.66 $\pm$ 447.53	945.23 $\pm$ 393.92	1241.41 $\pm$ 515.23	5.00; 0.011; 0.19	0.106, −0.37	0.163, −0.29	0.004, 0.65
RFD ₁₅₀ (N/s)	Q	D	508.19 $\pm$ 109.14	424.35 $\pm$ 134.86	462.64 $\pm$ 132.29	4.13; 0.023; 0.16	0.003, −0.68	0.117, −0.38	0.279, 0.29
		ND	485.99 $\pm$ 93.41	414.24 $\pm$ 112.84	469.32 $\pm$ 159.08	3.01; 0.049; 0.13	0.023, −0.69	0.657, −0.13	0.065, 0.40
	H	D	479.12 $\pm$ 111.43	464.85 $\pm$ 116.13	521.74 $\pm$ 159.10	3.19; 0.044; 0.13	0.462, −0.13	0.089, −0.31	0.046, 0.41
		ND	497.34 $\pm$ 87.50	425.08 $\pm$ 109.71	516.32 $\pm$ 97.87	8.72; 0.001; 0.29	0.006, −0.73	0.410, 0.20	0.001, 0.88
RFD ₂₅₀ (N/s)	Q	D	291.95 $\pm$ 88.13	224.12 $\pm$ 111.93	275.59 $\pm$ 94.33	5.95; 0.005; 0.22	0.001, −0.67	0.425, −0.18	0.034, 0.50
		ND	290.21 $\pm$ 81.76	225.08 $\pm$ 97.85	270.97 $\pm$ 115.29	4.22; 0.020; 0.18	0.004, −0.72	0.442, −0.19	0.070, 0.43
	H	D	319.75 $\pm$ 81.52	300.95 $\pm$ 89.22	332.93 $\pm$ 123.64	1.68; 0.199; 0.07	-	-	-
		ND	307.57 $\pm$ 57.54	271.03 $\pm$ 73.41	315.01 $\pm$ 94.19	3.51; 0.040; 0.14	0.040, −0.55	0.651, −0.10	0.046, 0.52

Q: quadriceps; H: hamstrings; SD: standard deviation; ES: effect size; D: dominant leg; ND: non-dominant leg; IPF: isometric peak force; RFD_{max}: maximum rate of force development; RFD₁₅₀: rate of force development for the first 150 ms; RFD₂₅₀: rate of force development for the first 250 ms.

Table 3. Hamstring-to-quadriceps (H:Q) ratio parameters for isometric muscle actions performed at baseline, post-match and 48 h after a competitive football match in female players.

Variable	Leg	Baseline	Post-Match	48 h Post-Match	ANOVA	Baseline— Post-Match	Baseline—48 h Post-Match	Post-Match— 48 h Post-Match
		Mean ± SD	Mean ± SD	Mean ± SD	<i>F; p; η²</i>	<i>p, ES</i>	<i>p, ES</i>	<i>p, ES</i>
H:Q IPF	D	1.06 ± 0.28	1.09 ± 0.21	1.14 ± 0.29	1.86; 0.169; 0.09	-	-	-
	ND	1.03 ± 0.20	1.10 ± 0.27	1.05 ± 0.23	1.38; 0.263; 0.07	-	-	-
H:Q RFD _{max}	D	0.77 ± 0.39	0.95 ± 1.04	1.34 ± 1.30	1.93; 0.159; 0.09	-	-	-
	ND	1.08 ± 0.63	0.84 ± 0.44	1.26 ± 1.41	1.95; 0.156; 0.09	-	-	-
H:Q RFD ₁₅₀	D	0.97 ± 0.24	1.24 ± 0.54	1.16 ± 0.35	3.04; 0.040; 0.14	0.012, 0.65	0.014, 0.62	0.554, −0.18
	ND	1.03 ± 0.22	1.09 ± 0.33	1.26 ± 0.50	2.89; 0.050; 0.13	0.469, 0.20	0.081, 0.51	0.113, 0.33
H:Q RFD ₂₅₀	D	1.19 ± 0.55	1.92 ± 1.57	1.30 ± 0.64	4.69; 0.015; 0.19	0.024, 0.62	0.255, 0.18	0.062, −0.51
	ND	1.12 ± 0.47	1.59 ± 1.35	1.82 ± 2.32	1.76; 0.185; 0.08	-	-	-

Q: quadriceps; H: hamstrings; SD: standard deviation; ES: effect size; D: dominant leg; ND: non-dominant leg; IPF: isometric peak force; RFD_{max}: maximum rate of force development; RFD₁₅₀: rate of force development for the first 150 ms; RFD₂₅₀: rate of force development for the first 250 ms.

3.4. Correlations Between Match-Derived Physical Parameters and Strength Variables

Pearson's correlation tests between the post-match-to-baseline change in the neuromuscular parameters collected during the isometric knee extension test and match-derived physical parameters are shown in Table 4. IPF values during the isometric quadriceps action in the dominant leg showed a significant association with the explosive distance covered over 1.12 m/s^2 and distance covered with acceleration over 3 m/s^2 ($r = 0.44$, $p = 0.042$ and $r = 0.44$, $p = 0.040$). In addition, a significant correlation was shown between the change in RFD_{150} during the isometric quadriceps action in the dominant leg and the distance covered with acceleration over 3 m/s^2 ($r = 0.49$, $p = 0.022$). Pearson's correlation tests between the post-match-to-baseline change in the neuromuscular parameters collected during the isometric knee extension test and match-derived physical parameters are shown in Table 5. A significant correlation was detected between the post-match-to-baseline difference in IPF, RFD_{150} and RFD_{250} during the isometric hamstring action test in the non-dominant leg and the total number of accelerations/decelerations performed during the match (IPF: $r = 0.51$, $p = 0.014$ and $r = 0.51$, $p = 0.015$, respectively; RFD_{150} : $r = 0.46$, $p = 0.032$ and $r = 0.46$, $p = 0.033$, respectively; and RFD_{250} : $r = 0.53$, $p = 0.011$ and $r = 0.53$, $p = 0.011$, respectively). The hamstring RFD_{250} difference in the dominant leg correlated with the total number of accelerations/decelerations performed ($r = 0.47$, $p = 0.029$ and $r = 0.46$, $p = 0.030$, respectively). Lastly, a significant correlation was shown between the IPF values during the isometric hamstring action in the dominant leg and the distance covered with acceleration over 3 m/s^2 ($r = 0.49$, $p = 0.021$).

Table 4. Correlations between the match-derived physical parameters and the post-match-to-baseline change in the neuromuscular parameters collected during unilateral maximal isometric knee extension (quadriceps).

	Non-Dominant			Dominant		
	IPF (N)	RFD_{150} (N/s)	RFD_{250} (N/s)	IPF (N)	RFD_{150} (N/s)	RFD_{250} (N/s)
Distance covered (m)	−0.2	−0.42	−0.29	0.42	0.28	0.18
Explosive distance over 1.12 m/s^2 (m)	0.08	−0.31	−0.06	0.44 *	0.33	0.16
Distance covered at 18–21 km/h (m)	−0.04	−0.3	0.07	0.33	0.19	0.15
Distance covered at 21–24 km/h (m)	−0.01	−0.14	0.1	0.18	0.11	−0.02
Distance covered at $>24 \text{ km/h}$ (m)	−0.18	−0.16	0.04	0.1	0.01	−0.07
Total number of accelerations (n)	0.15	0.2	−0.11	0.25	0.19	0.32
Total number of decelerations (n)	0.15	0.2	−0.12	0.25	0.19	0.32
Distance covered with acceleration over 3 m/s^2 (m)	0.22	−0.15	0.09	0.44 *	0.49 *	0.29
Distance covered with decelerations under -3 m/s^2 (m)	0.24	−0.12	0.13	0.39	0.28	0.24
Mean heart rate (bpm)	−0.09	−0.03	−0.09	0.08	−0.05	0.37

IPF: isometric peak force; RFD_{150} : rate of force development at first 150 ms of action; RFD_{250} : rate of force development at first 250 ms of action; * significant correlation between match-derived physical parameters and fitness tests in female football players ($p < 0.05$).

Table 5. Correlations between the match-derived physical variables and the post-match-to-baseline change in the neuromuscular parameters collected during unilateral maximal isometric knee flexion (hamstrings).

	Non-Dominant			Dominant		
	IPF (N)	RFD ₁₅₀ (N/s)	RFD ₂₅₀ (N/s)	IPF (N)	RFD ₁₅₀ (N/s)	RFD ₂₅₀ (N/s)
Distance covered (m)	0.15	0.04	0.10	0.36	0.23	−0.02
Explosive distance over 1.12 m/s ² (m)	0.17	0.05	0.10	0.42	0.15	−0.01
Distance covered at 18–21 km/h (m)	0.01	−0.04	0.01	0.35	0.13	0.03
Distance covered at 21–24 km/h (m)	0.09	0.19	0.15	0.36	0.23	0.14
Distance covered at 24–50 km/h (m)	0.03	0.18	0.14	0.24	0.18	0.03
Total number of accelerations (n)	0.51 *	0.46 *	0.53 *	0.38	0.26	0.47 *
Total number of decelerations (n)	0.51 *	0.46 *	0.53 *	0.38	0.26	0.46 *
Distance covered with acceleration over 3 m/s ² (m)	0.26	−0.05	0.15	0.49 *	0.09	0.03
Distance covered with decelerations under −3 m/s ² (m)	0.18	0.06	0.16	0.42	0.22	0.11
Mean heart rate (bpm)	0.04	−0.09	0.01	0.13	0.42	0.35

IPF: maximum voluntary isometric action; RFD₁₅₀: rate of force development at first 150 ms of action; RFD₂₅₀: rate of force development at first 250 ms of action; * significant correlation between match-derived physical parameters and fitness tests in female football players ($p < 0.05$).

4. Discussion

This study aimed to assess the acute effect of a competitive football match on IPF and RFD parameters of knee extensors (quadriceps) and flexors muscles (hamstrings) and their respective ratios in amateur female football players. The findings of this study revealed significant neuromuscular fatigue induced by the competitive football match, evidenced by reductions in IPF, RFD₁₅₀ and RFD₂₅₀ for both quadriceps and hamstring muscles immediately after the football match. However, 48 h post-match, most neuromuscular parameters were fully recovered to baseline. Regarding H:Q strength ratio parameters, the dominant leg RFD H:Q ratio (i.e., RFD₁₅₀ and RFD₂₅₀) was increased after the match and did not fully recover 48 h post-match. Furthermore, correlation analysis ($r = 0.40$ – 0.53) revealed a moderate association between players covering greater explosive distances (>1.12 m/s²) and high-acceleration distances (>3 m/s²) during the match and smaller post-match deviations in neuromuscular parameters (IPF and RFD₁₅₀) for dominant knee extension. Similarly, players with more accelerations/decelerations showed smaller deviations in knee flexion parameters (IPF, RFD₁₅₀, RFD₂₅₀).

One of the main findings of this investigation indicates that IPF was significantly reduced post-match during isometric knee extension (by -11.6% and -14.8% in the dominant and non-dominant leg, respectively) and flexion tasks (by -8.0% and -11.4% in the dominant and non-dominant leg, respectively), but most of the values were recovered 48 h post-match. Our outcomes generally agree with the findings shown by Andersson et al. [22], who reported a reduced isokinetic peak torque in knee extension and flexion by -7.1% and by -9.4% after a friendly football match in elite female players. Additionally, our data are in line with the peak torque recovery at 51 h post-match evidenced by Anders-

son et al. [22]. The greater reduction in knee extension and flexion strength in this study may be explained by the demands of football matches as players are required to perform multiple short high-intensity movements (e.g., kicking, acceleration, deceleration, sprints and rapid changes in direction) [47], which imposes elevated concentric and eccentric demands on the quadriceps and hamstrings muscles [30,48,49]. Previous studies have shown increases in some substances' concentration (e.g., creatine kinase, urea, uric acid) after a football match [22,50,51]. Although not measured in this study, the potential mechanisms explaining the strength reduction impairments may be related to disruptions within the muscular fibres [22]. Thus, myofibre disruptions have been suggested to be responsible for the decline in the force generation capacity after a football match [22,52].

Moreover, our results also show that quadriceps and hamstring actions' RFD₁₅₀ and RFD₂₅₀ values decreased post-match (quadriceps: between -17.3% and -30.3% and hamstring: between -13.5% and -17.0%), and most of these values were recovered 48 h after the match. These findings partially agree with those reported by Grazioli et al. [53], who found only a significant reduction in knee flexion RFD₂₀₀ (-11%) after a match in professional male football players. Conversely, our results show a greater impact on knee extensor RFD₂₅₀ values that could be explained due to the existing relationship between the ability of the quadriceps to quickly produce a peak force and the deceleration [54] or kicking actions [55], which are numerous in a female football match. The difference between the findings could be explained by thigh muscle activity and sex differences in strength (greater strength in the quadriceps than in the hamstrings after menarche and greater muscle activity in the rectus femoris in female athletes than in male counterparts) [56–58]. Our data complete these findings as, for the first time, we have assessed the effect of a competitive football match on quadriceps and hamstring muscle isometric strength in amateur female football players.

Regarding H:Q ratio measurements, we analysed this ratio for all strength variables before and after an official football match. This approach may provide a more accurate assessment of ACL and muscle injury risk in female football players, as the majority of these injuries occur during competitive matches [55,59]. Our results show no post-match changes in the H:Q ratio for IPF; however the H:Q ratio for RFD₁₅₀ and RFD₂₅₀ assessments was increased post-match in the dominant leg by 22% and 38% (i.e., quadriceps muscles experienced higher reductions in RFD values than those of the hamstrings). Furthermore, H:Q ratios for RFD variables did not fully recover 48 h post-match, particularly in the dominant leg, unlike the isolated strength measurements of the quadriceps and hamstring muscles, which showed full recovery. This suggests that neuromuscular function, particularly the ability to generate force rapidly, remains impaired 48 h post-match due to the differing recovery rates of the quadriceps and hamstring muscles in returning to baseline levels. This H:Q ratio disruption could increase the risk of ACL and muscle injuries if players return to high-intensity activities before full neuromuscular recovery [31], although this is a hypothesis that requires further testing. The authors of this study speculate that these increases in RFD₁₅₀ and RFD₂₅₀ H:Q ratios may occur as the kicking and deceleration actions performed during the match involve the quadriceps more than the hamstring muscles in female football players [54,55]. Additionally, the test position (30° of knee flexion, with 0° representing full extension) places the hamstrings in a stretched state, providing a mechanical advantage to generate force compared to the quadriceps [60].

Furthermore, the correlation analysis showed that female players who performed higher running metrics during the match (explosive distance covered over 1.12 m/s^2 and distance covered with acceleration over 3 m/s^2) had minor differences between post-match-to-baseline measurements and values of neuromuscular parameters during knee extension in the dominant leg (IPF and RFD₁₅₀). Lastly, female players who performed

a major number of accelerations/decelerations during the match had minor differences between post-match and baseline neuromuscular parameters during the knee flexion test (IPF, RFD₁₅₀ and RFD₂₅₀). Collectively, the players who performed the most actions at the highest intensity in the match are the players who experienced the smallest post-match-to-baseline differences. The authors hypothesised that those players who perform more high-speed actions may be well adapted to the demands of the match. Despite the intriguing relationship between higher running metrics during the match and neuromuscular parameters during knee extension reported in our study, future experimental studies are required to confirm the association between these two variables.

This research contains several limitations that should be clearly discussed to understand the actual usefulness of the experiment. This study did not establish normative values for IPF, RFD or H:Q in female football players. However, it highlights the fluctuations in strength variables induced by the acute effect of a competitive football match using accessible and cost-effective equipment. This study focused on unilateral testing to provide a well-controlled and isolated assessment of leg muscle function, enhancing reproducibility and allowing for a detailed analysis of the quadriceps and hamstrings independently. However, football is an intermittent sport in which players adopt various body positions, and most high-intensity actions are performed involving both legs. Therefore, future research should also incorporate bilateral testing using more ecologically valid movements, such as jumps, changes in direction and linear sprints, to better replicate the demands of football. Additionally, only the physical parameters imposed by the official match (i.e., running metrics and mean heart rate) were assessed, while the physical volume and intensity parameters from training sessions in the days leading up to the match were not measured. Moreover, other potential factors influencing fatigue development in players (beyond physical demands) were not controlled. These include team formation, contextual variables and the competitive level of the opposing team. Reporting recovery habits (i.e., sleep time, post-match diet, hydration, etc.) were not collected in this experiment even though they may be essential to understanding individual differences in the recovery patterns. Lastly, despite the practical relevance of this study, we were unable to assess physiological variables during the match to identify the underlying causes of fatigue. Key indicators such as blood lactate concentration, blood glucose concentration, blood markers of muscle damage and muscle glycogen content could have provided deeper insights into the mechanisms of fatigue during competition and their association with strength decreases. Future research should incorporate these measures to explore the potential mechanisms underlying neuromuscular fatigue induced by competitive matches in female football players. This study was focused on reporting data as a group means, but future research should measure individual patterns of recovery after a competitive match as, in the real world, football practitioners must apply research findings on an individual basis.

5. Conclusions

The present investigation in female football players demonstrated significant post-match reductions in IPF, RFD₁₅₀ and RFD₂₅₀ during the isometric quadriceps and hamstring muscle strength assessments. However, these measures were fully restored 48 h post-match. Still, some RFD-based H:Q ratios were still disturbed 48 h after the match, with values > 1.15 for H:Q RFD₁₅₀. This suggests that some parameters of players' neuromuscular function, particularly the ability to generate force rapidly, remain impaired 48 h post-match due to the differing recovery rates of the quadriceps and hamstring muscles in returning to baseline levels. Furthermore, players who executed the highest number of high-intensity actions during the match exhibited the smallest post-match-to-baseline differences. This

suggests that those who engage in more high-speed movements may be better adapted to the physical demands of competition.

As a practical application, the findings of this study suggest that a minimum recovery period of 48 h is necessary before engaging in high-intensity training after a competitive match, as neuromuscular function, particularly RFD variables, remains impaired immediately post-match but returns to baseline after two days. However, individual recovery rates vary, indicating the importance of personalised strength assessments to tailor post-match recovery and subsequent training volume and intensity. Given that quadriceps strength showed a greater post-match decline than hamstrings, targeted recovery strategies such as neuromuscular activation exercises, well-monitored quadriceps muscles training and adequate nutritional and hydration protocols should be emphasised to accelerate muscle function restoration. Additionally, monitoring RFD-based hamstring-to-quadriceps (H:Q) ratios could help to identify players at higher risk of injury if neuromuscular fatigue persists beyond 48 h.

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Abbreviations

The following abbreviations are used in this manuscript:

ACL	Anterior cruciate ligament
IPF	Isometric peak force
RFD	Rate of force development
H:Q	Hamstring-to-quadriceps
ANOVA	Analysis of variance

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