Under-exposure to official matches is associated with muscle injury incidence in professional footballers

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ABSTRACT: External workload from matches is considered one of the most important muscle injury risk factors for football teams. However, there is scarce published evidence to support this belief. This study examined whether a particular profile of external match workload existed prior to a muscle injury. A total of 144 professional football players belonging to 2 teams were monitored over three seasons. For each muscle injury, a profile of external workload variables was determined for 5 to 8 games and expressed as: time playing exposure, total distance (TD) covered and high-speed running (HSR) covered. In addition, acute:chronic workload ratio (ACWR) was calculated. Sixty players (41.6%) reported a total of 86 muscle injuries during the three seasons. Muscle injuries occurred principally in matches (79.1%), the hamstring being the most affected muscle (44.1%). Injured players displayed substantially lower accumulated exposure time (ES = 0.45), TD (ES = 0.45) and HSR (ES = 0.39) in comparison with uninjured players in the last 5 games prior to injury. Compared to the uninjured players, ACWR for exposure (ES = -0.29/0.02) and running load (ES = -0.24/0.00) did not differ between match 5 and 2 prior to the injury, although uninjured players displayed a substantially greater ACWR in all 3 variables (ES = 0.31/0.35) than injured players in match 1 prior to the injury. Lower playing exposure (minutes played) and associated reduced running distances (TD and HSR) were observed in injured football players. Being under-loaded in official games could be a mediator for muscle injury in this cohort of elite football players.

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INTRODUCTION

Almost one-third of all injuries in professional football are muscle injuries [1]. A professional club can expect a mean of 15 muscle injuries each season, which would cause more than a quarter of the total injury absence [1]. Thus, preventing muscle injuries in football players is important [2]. In order to implement preventive measures, identification of the risk factors and understanding potential mechanisms of muscle injuries are paramount. Several risk factors have been identified for lower limb muscle injuries in football, although results from different studies are contradictory. However, regardless of the interplay of risk factors or inciting biomechanical event, every athletic injury is sustained while athletes are exposed to training and competition loads [3]. Specifically, match play has been consistently associated with a several-fold greater rate of muscle injuries than training in professional players [4–6]. A combination of the increased demands of matches in comparison with training sessions [7], together with insufficient recovery time in between games [8] might be responsible, at least partially, for those match play injury rates due to the appearance of fatigue signs in professional football players [9]. In this regard, in terms of volume, match play-derived workloads typically represent the most demanding session of the week in professional football [10]. Indeed, match-running load (e.g., total distance covered) can represent ~40% to 85% of the total weekly training load, depending on players having a one-, two- or three-game week schedule [10]. Moreover, distances covered at high speed running and sprinting during official matches can account for ~82% to 97% and ~97% to 99%, depending on players having a one-, two- or three-game week schedule [10]. These results clearly indicate that matches are likely to represent the most intense and demanding source of weekly training load, and specifically high-speed actions, in professional football [10].

TABLE 1. Descriptive characteristics (mean ± standard deviation) and physical performance parameters of the all-professional soccer players.

	Season 1	Season 2	Season 3	All seasons
No. of players	45	47	52	144
Age (years)	26.9 ± 4.1	26.8 ± 3.6	26.3 ± 3.8	26.7 ± 3.8
Anthropometrics				
Height (cm)	181.1 ± 5.8	180.7 ± 5.3	180.4 ± 5.6	180.7 ± 5.5
Mass (kg)	75.0 ± 5.3	74.5 ± 5.6	73.7 ± 5.7	74.5 ± 5.6
Parameters physical performance				
Overall distance running (m/player)	8570.3 ± 3912.1	8133.2 ± 2821.9	10959.4 ± 2053.2	9295.4 ± 1266.5
High-speed running (HSR) (m/player)	591.7 ± 427.2	431.7 ± 217.1	433.6 ± 225.8	485.6 ± 91.8
Exposure matches (h/player)	27.4 ± 15.9	25.2 ± 15.5	25.4 ± 16.2	25.9 ± 15.8

Note: Values are presented as means ± SD.

Several studies have evaluated the relationship between the overall (training sessions + matches) training load and injury occurrence in football, with mixed results. For example, in professional football [11] a relationship between non-contact soft tissue injuries and a greater distance covered per minute in the weeks before injury, in comparison with the players' season average values, was reported. Furthermore, overall contact and non-contact injury risk significantly increased following > 9254 accelerations accumulated over 3 weeks in elite young football players [12]. However, Lu et al. [13] found no such evidence for workload prior to injury occurrence in professional players. However, all those studies examined non-contact and/or overall injuries. To the best of our knowledge, only one recent study examined the association between external training load variables and injury risk with elite Gaelic football players [14]; however, no previous work has specifically examined the potential link between training load and muscle injuries in football. Moreover, perhaps surprisingly, the impact that match-derived load might have on the risk of muscle injury in professional football players has never been evaluated.

Paramount in the management of football players is the understanding of competition demands and associated workloads and how these demands might impact injury risk. Considering that match muscle injury rates are several-fold greater compared with training, and that training load, particularly high-speed running (> 19.7 $km \cdot h^{-1}$), has been linked with the aetiology and risk of muscle injuries [11, 12], and the fact that official matches represent the most intense and demanding load in professional footballers [10], the aim of the present study was to analyse the contribution of exposure and match-running demands during official games on the incidence of muscle injuries in professional football players. Moreover, a secondary aim was to examine the incidence and musculoskeletal injury characteristics (occurrence of muscle injuries, type of injuries, mechanisms, incidence).

MATERIALS AND METHODS

Participants

In this prospective observational study, player data from 144 field football professional players from 2 different football teams that played in the top division of the Spanish football (*La Liga*) across three consecutive seasons (2013–2016) were used (Table 1). A total of 60 field football players suffered 86 muscle injuries during 3 seasons. These player injuries were randomly matched (1:1 match), using several matching criteria, against 86 control players. Each control was matched from the same team to minimize potential between team differences in training activities, injury prevention strategies, quality of fields, and rehabilitation strategies [15]. Moreover, controls were matched from the same field playing position as playing position largely determines match (and training) load and effort intensity [16]. The controls were required to have participated as a starting player in the match where the paired players suffered the muscle injury or the last game they participated before getting injured. When more than one control player was able to fulfil all the matching criteria, a simple randomization method was employed. The 8 games preceding the muscle injury were investigated for both the control and the paired players. Goalkeepers, and their muscle injuries (n = 6) were excluded from the performance analysis due to the different nature of their activity. Written informed consent was obtained from each player prior to the start of each season. The study was approved by the University Office for Research Ethics Committee (code: DPC.VMP.01.18), and conformed to the recommendations of the Declaration of Helsinki. Furthermore, to ensure team and player confidentiality, all performance and injury data were anonymized before analysis via an electronic database.

Training information

Participants usually performed 5 days of field training that included physical conditioning exercises, small-sided games, skill-based routines and tactical exercises. In addition, players performed a strength-based training programme with free weights with 2 macrocycles: the first one, carried out from August to December, included two strength training sessions per week, consisted of ~4 exercises per session with a load individually set at ~80% of the participant's one maximum repetition (1RM) and participants performed 2 series of 4–5 repetitions per exercise. The second macrocycle, from January to June, included just one strength training session per week, consisted of ~4 exercises per session at ~60% 1RM and participants performed 2 series of 6–8 repetitions per exercise. In both macrocycles, the strength-based session was carried out after a standardized warm-up and the velocity execution was set to maximal velocity.

Data collection

Injury definition and classification

Muscle injuries, match exposure and match running data were collected during 3 consecutive competitive seasons. All muscle injuries that occurred during training or matches in each season were diagnosed and classified by the medical staff of the club using the classification system developed by Fuller et al. [17]. The doctors were previously instructed on how to correctly fill out the questionnaire and to report muscle injuries. With a periodicity of once a week, the staff of teams sent an electronic document with information about the number of injuries and information related to the injury development. In the present study, the injury classification system developed by International football Injury Consensus Groups [17] was used to categorize injury. An injury was defined as: "*Any physical complaint sustained by a player that result from a soccer match or soccer training"* and led to an absence of the next training session or match [17]. Recurrence was defined as *"An injury of the same type and at the same site as an index injury and which occurs after a player's return to full participation from the index injury"* [17].

Match exposure and running performance

Playing exposure (minutes played), total distance (TD) covered and high-speed running (HSR) distance covered (> 24 $km \cdot h^{-1}$) during official matches were extracted by a valid multicamera tracking system and the associated software Mediacoach (Mediacoach, Spain) and collected by one researcher. From the Mediacoach tool the reports were generated for the predefined performance indicators. The reliability and validity of this software to assess movement demands during match play have been obtained through high agreement of the multicamera tracking analysis with the data obtained with GPS [18] and with data obtained from a reference camera systems (i.e., VICON motion capture system [19]). The correlations between distances and participants recorded via the Mediacoach multicamera tracking system and the GPS were all strong (r > 0.80), including very strong correlations (r > 0.95) [18]. The intraclass correlation coefficient for this multicamera tracking system ranged from 0.75 to 0.99 [18]. This tracking system evaluated the movements of the 22 players during the match play by means of 8 stable synchronized and calibrated cameras positioned at the top of the stadium with a sampling frequency of 25 Hz. Signals and angles obtained by the encoders were sequentially converted into digital data and recorded on computers for post-match analyses.

Data analysis

Once each individual data file (which corresponded to a player's individual match) was entered in a spreadsheet, one absolute and one relative variable were calculated for playing exposure, TD and HSR for the 5 (absolute variable) or 8 (relative variable) matches preceding the injury.

Absolute variables:

- ✓ Single match load – the minutes played and the distance covered across a single match and accumulated matches (up to 5 matched preceding the injury).

Relative variables:

- ✓ Acute:chronic workload ratio (ACWR) – the ratio of minutes played and distance covered in a single match (acute workload) compared with the average of the same variable over the preceding 4-matches (chronic workload). Note that the 4-match period over which the chronic workload is calculated is inclusive of the acute workload match [20]. Also note that to compute the ACWR for game 5 prior to injury, games 6, 7 and 8 were needed.

When a player sustained a muscle injury during a match that incurred in a player substitution (i.e., the player was unable to continue playing as a result of the injury), the match prior to the injury occurring was considered the player's last match and was used for statistical analysis. When the injury was sustained in training, the last match the player was available was used. For that match, a control player was then randomly matched (see above).

Statistical analyses

Descriptive statistics for physical performance and playing exposure parameters are presented as means and standard deviations. In addition, the incidence and characteristics of the muscle injuries (the number of muscle injuries, exposure, circumstances, mechanism of traumatic, severity and re-injuries) were described using frequencies and percentages. Pairwise comparisons between the matched and paired case-controls for the weeks prior to sustaining an injury for each of the 3 variables were carried out. Possible differences in exposure and workload variables were analysed for practical significance using magnitude-based inferences by pre-specifying 0.2 between-subject SDs as the smallest worthwhile effect [21]. The standardized difference or effect size (ES, 90% confidence limit [90%CL]) in the selected variables was calculated. Threshold values for assessing magnitudes of the ES (changes as a fraction or multiple of baseline standard deviation) were > 0.20, 0.20, 0.60, 1.2 and 2.0 for trivial, small, moderate, large and very large respectively [21]. Quantitative chances of higher or lower changes were evaluated qualitatively as follows: < 1%, almost certainly not; 1−5%, very unlikely; 5−25%, unlikely; 25−75%, possible; 75−95%, likely; 95−99%, very likely; > 99%, almost certain [21]. Additionally, differences in exposure and workload variables between matched and controls were tested for statistical significance using Student's t-test for paired comparisons. An alpha level of 0.05 was used to judge statistical significance.

RESULTS

Characteristics of injuries

From the 144 professional football players who participated in in this study, 46 (31.9%) did not report injuries, 38 (26.5%) presented injuries of joint/ligament type and 60 players (41.6%) reported a total of 86 muscle injuries during the three seasons and eight muscle injuries (9.3%) were recorded as recurrent (Table 2). Table 2 shows the incidence and severity of total muscle injuries per season.

A total of 68 (79%) muscle injuries occurred during matches and 18 (21%) during training (Table 3). Hamstring muscle injuries represented 44.1% of all muscle injuries. The majority of those injuries occurred in the second half (63.1%) and specifically in the last 15 minutes of the second half (Figure 1) while sprinting (26.7%) (Table 3). The distribution of injuries during a match is shown in Figure 1.

Among all muscle groups, hamstring and quadriceps injuries were distributed rather evenly across the whole competitive season. Adductors and calf muscle injuries occurred mainly (48% of the total number recorded in the whole season) during the first 2 months of the season (August and September). The distribution of injuries during the season is shown in Figure 2.

Match-play exposure and associated running load

Injured players typically displayed substantially lower accumulated exposure time (i.e., minutes) and running load (i.e., TD and HSR) in comparison with uninjured players (Table 4).

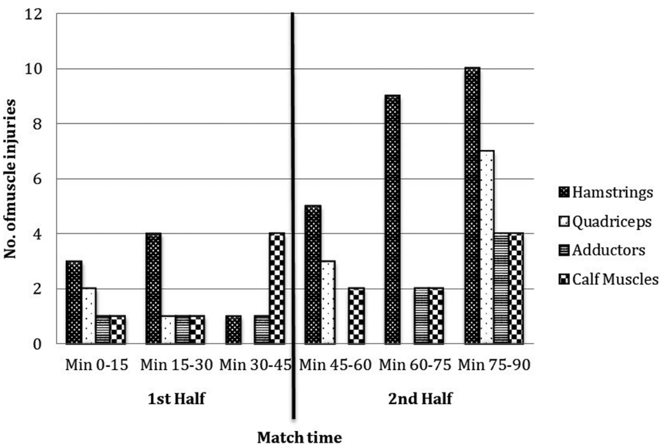

FIG. 1. Distribution of muscle injuries during a match in three seasons.

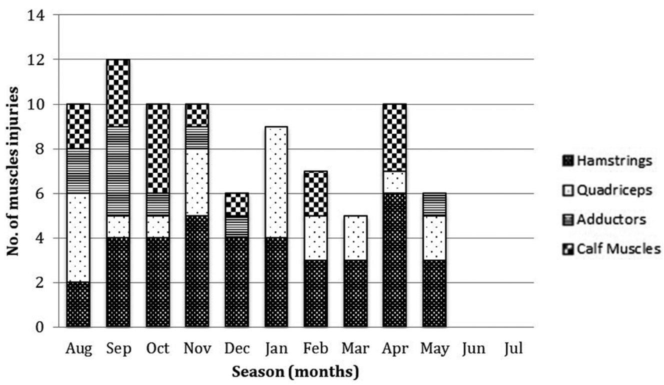

FIG. 2. Distribution of muscle injuries during three seasons.

TABLE 2. Descriptive characteristics of total incidence injuries and muscles injuries/season.

	Season 1	Season 2	Season 3	All seasons
No. of total injuries (%)	68 (37.1)	68 (37.1)	47 (25.6)	183 (100)
No. of total muscle injuries (%)	26 (30.2)	31 (36.1)	29 (33.7)	86 (46.9)
No. of players with muscle injuries (%)	15 (25)	23 (38.3)	22 (36.6)	60 (41.6)
Muscle injuries incidence in matches	21.1	26.2	21.9	23
No. and injuries severity (%)				
Minimal (1–3 days)	3 (3.4)	4 (4.6)	1 (1.1)	8 (9.3)
Mild (4–7 days)	2 (2.3)	9 (10.4)	4 (4.6)	15 (17.4)
Moderate (8–28 days)	13 (15.1)	14 (16.2)	20 (23.2)	47 (54.6)
Severe (> 28 days)	8 (9.3)	4 (4.6)	4 (4.6)	16 (18.6)
Days of absence/muscle injury	20.4 ± 11.3	17.9 ± 20.1	20.2 ± 12.8	19.5 ± 15.3
No. of muscle reinjures (%)	3 (3.4)	2 (2.3)	3 (3.4)	8 (9.3)

Note: Values are presented as means and percentage.

TABLE 3. Incidence and characteristics of the 4 most common locations of muscle injuries.

	Hamstrings	Quadriceps	Adductors	Calf	All muscles
No. of total muscle injuries (%)	38 (44.1)	21 (24.4)	11 (12.8)	16 (18.6)	86 (100)
			Injury rate per 1000 h exposure		
Match	1.2	0.5	0.3	0.5	2.6
Training	0.2	0.3	0.1	0.1	0.7
			No. and exposure injuries (%)		
Match	32 (37.2)	13 (15.1)	9 (10.4)	14 (16.2)	68 (79.1)
Training	6 (6.9)	8 (9.3)	2 (2.3)	2 (2.3)	18 (20.9)
			No. and injury circumstances (%)		
Traumatic	31 (36.1)	13 (15.1)	9 (10.4)	13 (15.1)	66 (76.7)
Overuse	7 (8.1)	8 (9.3)	2 (2.3)	3 (3.4)	20 (23.2)
			No. and mechanism of traumatic injury (%)		
Sprint	11 (12.7)	5 (5.8)	1 (1.1)	6 (6.9)	23 (26.7)
Kicking	10 (11.6)	6 (6.9)	5 (5.8)	3 (3.4)	24 (27.9)
Contact	0 (0)	1 (1.1)	0 (0)	2 (2.3)	3 (3.4)
Stretch	6 (6.9)	1 (1.1)	3 (3.4)	3 (3.4)	13 (15.1)
Twist	3 (3.4)	0 (0)	0 (0)	0 (0)	3 (3.4)
Others	8 (9.3)	8 (9.3)	2 (2.3)	2 (2.3)	20 (23.2)
			No. and injury severity (%)		
Minimal (1–3 days)	3 (3.4)	3 (3.4)	0 (0)	2 (2.3)	8 (9.3)
Mind (4–7 days)	4 (4.6)	7 (8.1)	2 (2.3)	2 (2.3)	15 (17.4)
Moderate (8–28 days)	21 (24.4)	10 (11.6)	8 (9.3)	8 (9.3)	47 (54.6)
Severe (> 28 days)	10 (11.6)	1 (1.1)	1 (1.1)	4 (4.6)	16 (18.6)
No. of reinjuries (%)	4 (4.6)	2 (2.3)	1 (1.1)	1 (1.1)	8 (9.3)
Days absence/injury	23 ± 18.4	14 ± 12.6	20.1 ± 11.4	17.3 ± 10.7	19.5 ± 15.4

Note: Values are presented as number and percentages (%).

Compared to the uninjured players, exposure and running load did not differ between match 5 and 2 prior to the injury, although uninjured players displayed a substantially greater ACWR for all the 3 variables than injured players in match 1 prior to the injury (Table 5).

DISCUSSION

To our knowledge, this is the first study to investigate the association of official matches playing exposure, external load and muscle injury incidence in elite football. Muscle injuries were more likely to occur during matches, particularly in the last 15 minutes of the second half, than in training sessions. Under this scenario, players sustaining muscle injuries typically displayed substantially less accumulated match playing exposure, and associated running workloads, than uninjured players in the same position within the team.

Muscle injuries in matches

In accordance with previous findings [1, 5, 6, 22], the present results confirm the higher incidence rate (injuries/1000 h) of muscle injuries during matches (2.6) compared to training (0.7). Similarly, current findings also show that around half of all reported injuries were muscle injuries involving almost exclusively the legs [1, 6], and especially affecting the hamstring muscles [4, 5]. Furthermore, a disproportionate amount of those muscle injuries occurred in the last minutes of the second half (Figure 1), which is in line with previous research [4, 23]. The fact that matches are the primary risk factor for sustaining a muscle injury has been linked with the increased physical demands compared to training [10] in addition to the subsequent fatigue [24] induced by the augmented physical load. However, despite the link between match physical load and muscle injuries, the potential reasons remain largely unexplored to date.

TABLE 4. Comparison of game load during the 5 games prior to a muscle injury between players suffering a muscle injury and matched controls.

	Injured	Controls	Standardized Differences (90%CL)		Qualitative Assessment	P value
Age	26.9 ± 3.3	26.7 ± 3.7	-0.05 (-0.33/0.22)	7/75/19	Unclear	0.758
Body mass (kg)	73.2 ± 5.8	74.4 ± 4.7	0.21 (-0.03/0.45)	53/47/0	Possibly lighter injured players	0.095
Height (cm)	179.4 ± 5.2	181.2 ± 5.3	0.35 (0.09/0.61)	82/18/0	Likely shorter injured players	0.019
Time Played (min) Match 5 Prior to Injury	50.1 ± 43.9	60.9 ± 42.9	0.24 (-0.03/0.51)	60/40/0	Possibly lower in injured players	0.144
Time Played (min) Match 4 Prior to Injury	56.9 ± 42.5	64.6 ± 40.3	0.18 (-0.08/0.26)	45/54/1	Possibly lower in injured players	0.312
Time Played (min) Match 3 Prior to Injury	61.2 ± 39.0	70.1 ± 35.9	0.23 (-0.02/0.48)	57/43/0	Possibly lower in injured players	0.135
Time Played (min) Match 2 Prior to Injury	61.4 ± 40.5	73.0 ± 34.4	0.28 (0.04/0.24)	72/28/0	Possibly lower in injured players	0.046
Time Played (min) Match 1 Prior to Injury	63.3 ± 37.4	89.3 ± 11.8	0.69 (0.50/0.88)	100/0/0	Most likely lower in injured players	0.001
Sum Time Played (min) Matches 5 -1 Prior to Injury	282.7 ± 144.6	348.5 ± 116.3	0.45 (0.21/0.69)	96/4/0	Very likely lower in injured players	0.005
Total Distance (m) Match 5 Prior to Injury	5842 ± 5040	6898 ± 4911	0.21 (-0.06/0.48)	52/47/1	Possibly lower in injured players	0.206
Total Distance (m) Match 4 Prior to Injury	6475 ± 4910	7344 ± 4534	0.18 (-0.08/0.43)	44/55/1	Possibly lower in injured players	0.312
Total Distance (m) Match 3 Prior to Injury	6820 ± 4505	8082 ± 4025	0.28 (0.03/0.52)	70/30/0	Possibly lower in injured players	0.066
Total Distance (m) Match 2 Prior to Injury	7137 ± 4656	8413 ± 3954	0.27 (0.03/0.51)	69/31/0	Possibly lower in injured players	0.054
Total Distance (m) Match 1 Prior to Injury	6968 ± 4293	10120 ± 1551	0.73 (0.53/0.92)	100/0/0	Most likely lower in injured players	0.001
Sum Total Distance (m) Matches 5–1 Prior to Injury	32323 ± 16413	39786 ± 13450	0.45 (0.21/0.69)	96/4/0	Very likely lower in injured players	0.003
High-speed running (> 24 km/h) (m) Match 5 Prior to Injury	302 ± 292	364 ± 322	0.21 (-0.08/0.50)	52/47/1	Possibly lower in injured players	0.253
High-speed running (> 24 km/h) (m) Match 4 Prior to Injury	328 ± 278	379 ± 295	0.18 (-0.09/0.46)	46/53/1	Possibly lower in injured players	0.321
High-speed running (> 24 km/h) (m) Match 3 Prior to Injury	363 ± 275	420 ± 287	0.20 (-0.06/0.47)	51/49/1	Possibly lower in injured players	0.186
High-speed running (> 24 km/h) (m) Match 2 Prior to Injury	366 ± 266	436 ± 276	0.26 (-0.01/0.52)	64/36/0	Possibly lower in injured players	0.090
High-speed running (> 24 km/h) (m) Match 1 Prior to Injury	359 ± 269	528 ± 203	0.63 (0.39/0.86)	100/0/0	Most likely lower in injured players	0.001
Sum High-Speed Running (> 24 km/h) (m) Matches 5–1 Prior to Injury	1650 ± 983	2051 ± 1004	0.39 (0.12/0.65)	88/12/0	Likely lower injured players	0.010

TABLE 5. Comparison of the acute:chronic workload ratio game loads during the 5 games prior to a muscle injury between players suffering a muscle injury and matched controls.

	Injured	Controls	Standardized Differences (90%CL)	Qualitative Assessment		P values
Time Played (min) Match 5 Prior to Injury	1.22 ± 1.33	1.04 ± 0.96	-0.16 (-043/0.11)	1/59/40	Possibly greater in injured players	0.240
Time Played (min) Match 4 Prior to Injury	1.26 ± 0.85	1.01 ± 0.73	-0.29 (-0.55/-0.02)	0/29/71	Possibly greater in injured players	0.083
Time Played (min) Match 3 Prior to Injury	1.33 ± 1.05	1.24 ± 0.80	-0.08 (-0.32/0.16)	3/77/20	Likely trivial differences	0.821
Time Played (min) Match 2 Prior to Injury	1.22 ± 1.10	1.25 ± 0.87	0.02 (-0.21/0.26)	11/84/5	Likely trivial differences	0.877
Time Played (min) Match 1 Prior to Injury	1.10 ± 0.78	1.35 ± 0.61	0.32 (0.09/0.56)	81/19/0	Likely lower in injured players	0.023
Total Distance (m) Match 5 Prior to Injury	1.24 ± 1.13	1.03 ± 0.96	-0.19 (-0.46/0.08)	1/52/47	Possibly greater in injured players	0.180
Total Distance (m) Match 4 Prior to Injury	1.22 ± 0.82	1.02 ± 0.72	-0.24 (-0.51/0.03)	0/40/60	Possibly greater in injured players	0.143
Total Distance (m) Match 3 Prior to Injury	1.29 ± 1.05	1.24 ± 0.78	-0.05 (-0.29/0.19)	4/81/15	Likely trivial differences	0.922
Total Distance (m) Match 2 Prior to Injury	1.23 ± 1.08	1.21 ± 0.80	-0.02 (-0.25/0.21)	5/84/11	Likely trivial differences	0.890
Total Distance (m) Match 1 Prior to Injury	1.08 ± 0.79	1.33 ± 0.60	0.31 (0.08/0.55)	79/21/0	Likely lower in injured players	0.029
High-speed running (> 24 km/h) (m) Match 5 Prior to Injury	1.23 ± 1.15	1.03 ± 0.95	-0.17 (-0.44/0.09)	1/56/43	Possibly greater in injured players	0.243
High-speed running (> 24 km/h) (m) Match 4 Prior to Injury	1.19 ± 0.81	1.04 ± 0.73	-0.18 (-0.44/0.09)	1/55/44	Possibly greater in injured players	0.254
High-speed running (> 24 km/h) (m) Match 3 Prior to Injury	1.33 ± 1.07	1.25 ± 0.81	-0.08 (-0.32/0.16)	3/76/21	Likely trivial differences	0.732
High-speed running (> 24 km/h) (m) Match 2 Prior to Injury	1.22 ± 1.08	1.22 ± 0.84	0.00 (-0.24/0.23)	8/84/8	Unclear	0.928
High-speed running (> 24 km/h) (m) Match 1 Prior to Injury	1.07 ± 0.80	1.35 ± 0.65	0.35 (0.11/0.59)	85/15/0	Likely lower in injured players	0.010

Match-play exposure and associated load

A substantially lower accumulated (chronic) match exposure (i.e., min) and associated running load (i.e., TD and HSR) were observed in the injured players (Table 4). No previous studies have evaluated match exposure/load alone and their potential association with muscle injuries in football. Therefore, comparisons are not possible. However, Bowen et al. [25] after analysing combined accumulated training and game workloads in English Premier League football players reported that a low amount of TD accumulated over 4 weeks resulted in an increased risk of sustaining a non-contact injury. Interestingly, Lu et al. [13] reported greater absolute exposure in all the 3 weeks preceding the week where a non-contact injury occurred. The same authors [13] found no significant differences in total distance covered between weeks 3, 2, 1 and injury week. However, this is contradictory to our results. A potential explanation for these differences is that Lu et al. [13] did not include match workload data despite the fact that, as stated by the authors: 1) the majority of injuries recorded were sustained during matches, 2) in-season running match loads were normally greater than training. Regarding HSR, previous studies have reported that greater volumes of high- and very high-speed running were associated with an increased soft tissue injury risk in Australian footballers [26–28]. In the present study, similar to playing exposure and total distance, cumulative (i.e., chronic) high-speed running (> 24 km/h^{-1}) distances were greater in the uninjured players. Our findings are partially at odds with previous research showing either no significant injury risk for high-speed and sprint distance [12] or greater high-speed and very high-speed running distances covered 2 weeks prior to injury compared to the week of injury [11, 13]. Therefore, the fact that uninjured players displayed greater accumulated chronic (game) loads seems to support a growing body of literature suggesting a protective effect against a large proportion of non-contact injuries when players are chronically exposed to relative higher loads [20, 25]. Ultimately, exposing the players to the specific match workloads should ensure that players develop a greater degree of adaptation and tolerance to the demands of the competition. By contrast, reducing match exposure and associated workloads, while lowering a player's exposure to risk, may also have a negative effect on physical preparedness to compete, potentially predisposing players to injury [20].

ACWR

Monitoring the ACWR in professional football has been suggested as a key injury prevention strategy [25]. However, current results showed no clear differences in the ACWR between the injured and uninjured players. Specifically, most of the ACWR did not differ between the injured and uninjured players with the only exception being the ACWR derived from the last game before injury, which in fact was actually greater in the uninjured group (Table 4). These results support the findings of a previous study [13], which found no excessively inflated ACWR prior to injury. In addition, Bowen et al. [25] also reported a limited (i.e., only for very high ratios) non-contact injury risk association with ACWR for TD and a lack of significant injury risk for high-speed and sprint distance. Thus, results of the present study appear to indicate that injury mediators identified by match exposure and associated running data are more related to chronic load rather than interaction between acute and chronic ratios. Potentially, a moderate-high chronic load base allows players to tolerate greater load fluctuations than when chronic load is low [29]. This has important practical implications, as these findings raise further questions over the practical usefulness of the ACWR when determining the risks associated with prescription of training loads [13].

There are some limitations to the current study. It examined only the external load (i.e., exposure and running loads) derived only from official matches while other studies also included external loads incurred during training. Furthermore, the statistical power of this study was not calculated prospectively. As retrospective power analysis calculations are not appropriate [30], the power analysis was not included. Nevertheless, the current study included 86 injury cases, which seems enough to make moderate to strong associations regarding injury risk factors [31]. In addition, the cohort used in the study consisted of male professional players competing in one of the most competitive leagues in the world. Therefore, generalization of the findings to other populations (e.g., lower level leagues, youth, female) is not possible. In addition, we did not account for the potential effect of confounding variables such as period of the season or match time of injury occurrence.

Practical applications

Professional players sustaining muscle injuries typically displayed substantially less accumulated match playing exposure, total distance covered and high-speed running distance covered than uninjured players occupying the same position within the team. Being underloaded in official games may be a mediator for muscle injury in elite football players. Based on our results, training specificity is important for stimulating training adaptations to improve performance in injured football players. Understanding the training and competition demands of a sport is therefore of paramount importance for strength and conditioning coaches in order to ensure that the appropriate dose is planned to maximise the fitness-fatigue response within athletes and prevent muscle injuries during matches.

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Conflict of interest

The authors declare that they have no conflict of interest derived from the outcomes of this study.

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