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Abstract

Background: Anterior cruciate ligament (ACL) injuries are common in professional women's football and involve a complex interplay of intrinsic and extrinsic factors. Increasing match demands and travel requirements may contribute to cumulative workload and fatigue; however, their relationship with ACL injury remains unclear. **Objective:** To quantify and compare pre-injury match exposure and travel workload patterns in ACL-injured professional women's footballers using a within-player, season-matched control design. **Methods:** This prospective cohort study included professional women's football players (Tier 3–5) between 2022 and 2024. For each ACL-injured player, match and travel workloads in the injury season were compared with the same calendar window in the preceding season. Match exposure (minutes, appearances, and starts) was assessed across 30-, 60-, and 90-day pre-injury windows using publicly available databases. Paired tests and Cohen's *d* quantified differences. A mixed-effects logistic regression model examined associations between workload variables and ACL injury status, and Spearman's correlations assessed relationships between match exposure and travel. **Results**: Data from 375 players were analysed. Across all pre-injury windows, players accumulated greater match exposure in the injury season than in their control season (d = 0.21–0.37). Travel distance in the 30 days preceding injury was significantly greater in injury seasons (2724 ± 4821 km vs 2194 ± 4624 km, $p < 0.001$), though variability was high (d = 0.106). In the mixed-effects logistic regression model, players who did not travel were less associated with the ACL-injured season (OR = 0.53, $p = 0.024$). Match was moderately correlated with travel distance ($\rho = 0.339–0.556$, $p < 0.001$); this was most evident among players transitioning from Tier 3 to Tier 4 or competing at Tier 5. **Conclusions:** ACL-injured professional women's footballers demonstrated modestly greater match exposure and travel distance compared to their own control season. Although effect sizes were small and variability across players and competitions was considerable, these patterns were more common among players operating at or transitioning to higher competitive tiers, suggesting a potential contextual workload risk marker that warrants targeted preventive strategies.

Keywords: ACL, Women's football, Workload, Match exposure, Travel demands, Fatigue

Introduction

In professional football (soccer), lower injury burden is consistently associated with superior team performance, including higher league rankings, more matches won, greater goal difference, and increased points per match (1, 2). Consequently, injury prevention is a key priority across professional football environments. Among all injuries, anterior cruciate ligament (ACL) ruptures represent a substantial burden due to prolonged recovery timelines following either conservative management or ACL reconstruction (ACLR), accounting for ~28% of total time lost to injury and averaging 292 days of absence (3, 4). Beyond immediate time loss, ACL injuries are associated with a 2 to 4-fold increased risk of subsequent knee injury (5-7), persistent impairments in strength and skill performance (8), elevated risk of post-traumatic knee osteoarthritis (9), and, in many cases, premature career termination (10, 11).

In women's football, ACL injuries are of particular concern due to a two- to three-fold higher incidence and poorer return-to-play outcomes compared with male players (12, 13). The aetiology of ACL injury is multifactorial, reflecting complex interactions between intrinsic factors (e.g. prior injury history, training adaptations, age, and sex-related mechano-biological characteristics) and extrinsic factors (e.g. access to facilities, training exposure, equipment quality, playing surface, competition scheduling, travel demands and accumulated fatigue (14-16)). Whilst some of these factors are non-modifiable, greater attention to potentially modifiable exposures, such as cumulative match and travel workload, may help identify risk markers, defined as variables associated with injury occurrence without implying direct causality(17), to inform preventive strategies and future research in professional women's football.

Match and travel workload, broadly defined as the cumulative physical and logistical demands imposed on players over a given timeframe, has been discussed as a potential risk marker for ACL injury in elite women's football (18). A study commissioned by the global players' union (FIFPRO) observed that players who sustained ACL injuries in European elite leagues demonstrated higher

match exposure than uninjured peers, including greater match frequency, more frequent instances of short (<5 days) recovery intervals between fixtures, longer travel distances, more time zone crossings, and reduced recovery intervals in the four weeks preceding injury. These patterns may reflect the combined physiological and logistical stress associated with congested competition schedules and repeated travel (19). Travel-related sleep disruption and circadian misalignment (20) may transiently impair neuromuscular function, high-speed running capacity and force production (21, 22), with potential downstream effects on performance and match outcomes (23). Notably, sex-specific differences in circadian regulation, including slightly shorter intrinsic circadian periods (24) and earlier chronotypes in females (25), may further increase susceptibility to travel-related fatigue in women footballers.

Match workload and travel demands have been discussed as potential risk markers that may promote neuromuscular fatigue and affect physical performance, potentially being relevant to the aetiology of ACL injuries (17, 20, 26-28). However, direct empirical evidence examining these exposures in professional women's football is limited, and existing findings are inconsistent (28). This is partly attributable to the relative scarcity of injury prevention research focused on women's football (14), where studies often focus on the top-tier European leagues, with relatively small sample sizes (28). Moreover, prior work comparing ACL-injured players with uninjured controls from the same league (28) may insufficiently account for substantial inter-individual heterogeneity in intrinsic (e.g. anatomy, hormonal milieu, injury history) and extrinsic factors (e.g. playing role, training history, competition level). A within-player (in-line) control design, in which players serve as their own comparator across seasons, offers a methodologically robust approach to reduce between-player and contextual variability and better isolate work-related patterns. Accordingly, this study aimed to quantify and compare pre- injury match and travel workload patterns in professional women footballers who sustained an ACL injury, using each player's previous season as a within-player control.

Methodology

Study design and sample

This prospective cohort study explored match workload exposure (minutes played and match appearances) and estimated travel distance (kilometres [km]) preceding ACL injury in professional women football players competing between January 2022 and December 2024. Eligible participants were classified as Tier 3–5 (Tier 3: highly trained; Tier 4: elite/international, Tier 5: world class) (29), according to the McKay et al (2022) participation classification framework, modified for Football (30). Tier designation was assigned for each respective season. Because Tier 5 classification depends on participation in the latter stages (quarter-final) of major international tournaments held every 2–4 years (e.g. FIFA World Cup, Olympic Games), eligibility could not always be determined within the injury or control season. In these cases, Tier 5 status was assigned based on participation in the most recent eligible international tournament prior to ACL injury. Both match- and training-related ACL injuries were included. Changes in team or league affiliation between seasons were recorded. Workload and travel variables were examined as potential risk markers, defined as variables associated with injury occurrence without implying causality (17).

Identification and classification of ACL injuries

ACL injuries were identified using a validated media-based surveillance approach. One researcher [VC] systematically screened official club communications, media reports, player interviews, and publicly available injury registries (31) to identify ACL injuries. A second researcher [WH] independently verified player identity, ACL diagnosis, and injury classification (match- or training-related). This approach has sound validity and reliability for recording ACL injuries in professional football (18, 32, 33). No discrepancies were identified during verification.

Match workload data

Match workload data were extracted primarily from SoccerDonna, with Sofascore used as a secondary source. These publicly available platforms provide information on match participation, including playing position (forward, midfielder, defender, and goalkeeper), match minutes, starting status, competition format (cup, league, or friendly), match venue, and competition level (domestic league, international club competition, or national team fixture) (33, 34).

Cumulative match exposure was quantified over a 90-day pre-injury window to capture representative phases of the competitive season, including domestic and international fixtures. This period was subdivided into 30-, 60-, and 90-day intervals to examine short-term and progressively cumulative workload patterns. Although training load data were unavailable, match exposure has been shown to be a reliable proxy for cumulative load in elite football populations (35, 36). To facilitate comparison with existing literature, match workload metrics were defined in accordance with den Hollander et al. (2024), including:

- Total match minutes played (min)
- Number of match appearances
- Number of starting appearances
- Unused substitute appearances (i.e. named in the squad but did not play)
- Recovery time (days) between consecutive matches
- Indicators of fixture congestion:
    - <3 days between matches
    - <5 days between matches
    - “Critical zone” matches (back-to-back matches with <5 days recovery and ≥45 minutes played per match)

Travel workload estimation

Travel demands were quantified for the 30 days preceding each ACL injury, consistent with prior work (18, 37). Travel distance (km) was estimated using the Haversine formula implemented via https://www.distance.to. For away matches, travel distance was calculated as the round-trip distance between the player's home club stadium and the match venue, whereas home club matches were assigned a travel distance of 0 km. For home national team fixtures, travel distance was calculated from the player's home club stadium to the national team venue. For international club or national team tournaments (e.g. Women's FIFA World Cup or UEFA Women's Champions League), travel distance was calculated from the home club stadium to the tournament location, with intra-tournament travel assumed to be negligible (0 km) unless matches were played in a different city. If a player's first match within the calculation window occurred as a part of a national or club tour, the starting location was assumed to be the previous match venue rather than the home club stadium. For match-related ACL injuries, travel distance was calculated as a one-way journey instead of a round trip, as the injury occurred at the travelled location. In addition to travel distance, the number of time zone crossings was recorded. Travel calculations were cross-validated against the FIFPRO women's workload monitoring tool (n=17; https://www.fifpro.org/en/workload-monitoring-report-women), showing perfect agreement (ICC = 1.00), low measurement variability (CV = 0.65%) and minimal error (SEM = 15.0 km)

Within-player control design

Each injured player served as their own control. Match and travel workloads in the injury season were compared with those from the same calendar window exactly 365 days prior to the ACL injury date (preceding season). When the final match in the control period occurred during a national or club tour, travel distance was treated as a one-way journey, consistent with assumptions in the injury season.

Ethical Considerations

All data analysed were publicly available and related to individuals already identifiable through mainstream media. No private or confidential information was collected, and no direct interaction

with athletes occurred. Ethical approval was therefore not required, and the study was granted exemption by the local Human Research Ethics Committee (HREC reference: 2024/316).

Statistical analysis

Normality of all continuous variables was assessed using the Shapiro–Wilk test. Data deemed normally distributed are reported as mean ± standard deviation (SD) and compared between the injury and preceding season using paired t-tests. Data deemed non-normally distributed are reported as median and interquartile range (IQR) and analysed using Wilcoxon signed-rank tests (V). Effect sizes were calculated using Cohen's *d* and interpreted as small (0.2), medium (0.5), or large (0.8) (38).

Excess workload was defined as the difference in match minutes, match appearances or travel distance during the 30 days preceding injury (injury season) relative to the corresponding 30-day control period (preceding season). Associations between excess match workload (minutes or appearances) and travel distance were assessed using Spearman's rank correlation coefficient (ρ) due to non-normally distributed data. A mixed-effects logistic regression model with random intercepts for each player was fitted using the lme4 package to examine whether excess match workload (match minutes or appearances) and travel distance were associated with the occurrence of the injury season (39). Regression coefficients (β) and corresponding odds ratios (ORs) with 95% confidence intervals were reported. Statistical significance was set at $p < 0.05$. All analyses were performed using RStudio (version 4.3.1

Results

Participant Characteristics

A total of 541 ACL-injured professional women footballers were initially identified (Figure 1). Match workload data were available for 417 players in the injury season, and complete workload data for both the injury and preceding (control) season were available for 375 players, who were included in subsequent analyses (mean age: 24.4 years, SD± 4.13). Of these, 259 injuries occurred during match

play, 68 during training, and 49 could not be classified. Eleven players in this sample experienced an ACL re-injury. At the time of injury, 209 players were competing in Tier 4 (55.7%), 98 in Tier 3 (26.1%), and 25 in Tier 5 (6.7%). 24 players transferred from Tier 3 to Tier 4 (6.4%), and 19 transitioned from Tier 4 to Tier 3 (5.1%) during the injury season (Table 1). Injured players were most commonly midfielders (34.6%), followed by defenders (31.5%) and forwards (26.4%), with goalkeepers accounting for 7.7% of injuries. The distribution of match types during the 90-day observation window was similar between injury and control seasons, including domestic league matches (71.3% vs. 69.1%), national team competitions (9.8% vs. 10.0%), domestic cup matches (9.3% vs. 12.2%), international club competitions (4.8% vs. 3.9%), and national team friendlies (4.8% vs. 4.4%). Club-friendly games were rare (0% vs. 0.4%). The proportion of home and away matches was comparable across seasons and time windows (30, 60, and 90 days), with approximately 51% away and 49% home matches.

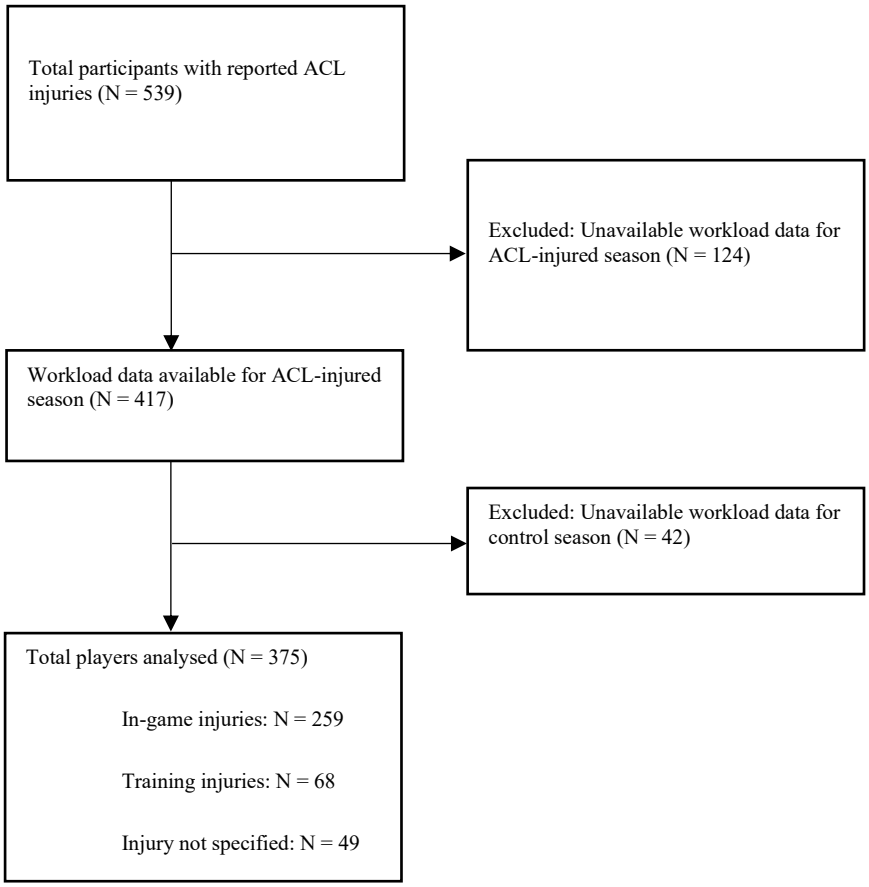


Figure 1: Flowchart of participant inclusion for ACL-injured and control seasons

Table 1: Player characteristics by position, ranking tier, and league

Variable	Category	n (%)
Position		
	Midfielder	129 (34.4%)
	Defender	118 (31.5%)
	Forward	99 (26.4%)
	Goalkeeper	29 (7.7%)
Ranking tier (control to injured season)		
	Tier 5	25 (6.7%)
	Tier 4	209 (55.7%)
	Tier 3	98 (26.1%)
	Tier 4 to 3	19 (5.1%)
	Tier 3 to 4	24 (6.4%)
League (injured year)		
	Liga F	40 (10.7%)
	English Women's Super League	36 (9.6%)
	Frauen Bundesliga	33 (8.8%)
	Other (each <5)	29 (7.7%)
	NWSL	27 (7.2%)
	Serie A	27 (7.2%)
	Arkema Première Ligue	22 (5.9%)
	Liga MX	19 (5.1%)
	Scottish Women’s Premier League	19 (5.1%)
	Toppserien	16 (4.3%)
	WE League	16 (4.3%)
	Brasileirão Feminino	15 (4%)
	Liga BPI	15 (4%)
	A-League Women	13 (3.5%)
	ÖFB Frauen Bundesliga	13 (3.5%)

Swiss Women's Super League	11 (2.9%)
Eredivisie Vrouwen	8 (2.1%)
Damallsvenskan	6 (1.6%)
A-Liga	5 (1.3%)
Belgian Women's Super League	5 (1.3%)

Match Workload Comparisons

Across all observation windows (30, 60, and 90 days), players accumulated greater match exposure in the ACL-injured season compared with the control season (Figure 2A and 2B). In the 30 days preceding injury (Table 2), the injury season was characterised by significantly greater match minutes (191 ± 145 min vs 157 ± 150 min), total match appearances (3.3 ± 2.0 vs 2.5 ± 2.0), and starting (2.5 ± 1.8 vs 1.8 ± 1.8), all with small effect sizes ($p < 0.001$, $d = 0.212$-0.370). No differences were observed in unused substitute appearances, rest days between matches, or the frequency of matches played with <3 or <5 days of recovery.

This trend persisted over the 60-day window (Table 3), with significantly greater match minutes (344 ± 247 min vs 290 ± 247 min), appearances (5.7 ± 3.3 vs 4.7 ± 3.4), and starting appearances (4.2 ± 3.0 vs 3.3 ± 2.9) with similar effect sizes ($p < 0.001$, $d = 0.217$-0.318). Matches played with <5 days of recovery were marginally more frequent in the injury season, but the associated effect size was negligible (2.4 ± 2.5 vs 2.1 ± 2.3, $p = 0.034$, $d = 0.128$). No differences were observed for unused substitute appearances, rest days, or matches played with <3 days of recovery.

Similarly, over the 90-day window (Table 4), players accumulated greater match minutes (470 ± 336 min vs 403 ± 323 min), appearances (7.8 ± 4.5 vs 6.6 ± 4.5), and starting appearances (5.7 ± 4.1 vs 4.5 ± 3.8) in the injury season compared with the control season, again with small effect sizes ($d = 0.212$–0.303). Matches played with <5 days of recovery were slightly more frequent in the injury season, though effect sizes remained negligible ($p = 0.039$, $d = 0.121$). No differences were observed for unused substitute appearances, rest days between matches, or the number of “critical zone” matches.

In the 90 days preceding injury, players who sustained match-related ACL injuries (N=233) accumulated significantly greater match minutes than their within-player controls (Table 5) (542 ± 335 min vs 444 ± 327 min, $p < 0.001$, $d = 0.321$). Players who changed teams during the injury season also had higher match minutes compared with their control season (441 ± 333 min vs 365 ± 284 min, $p = 0.041$, $d = 0.211$). No statistically significant differences were observed for training-related injuries or players who changed leagues, although small effect sizes were observed (d=0.324).

Table 2: Comparison of 30-Day Workload Variables Between Injury and Control Groups

Workload variables	Injury						Control					Injury versus control				
	n	Mean	SD	Median	IQR	CI	Mean	SD	Median	IQR	CI	MD	t	p	d	Interpretation
Minutes (min)	375	191	145	185	[63, 294]	[176, 205]	157	150	135	[0, 270]	[142, 172]	34 [49.8, 18.1]	4.20	<.001	0.212	Small
Appearances (n)	375	3.3	2.0	3.0	[2.0, 5.0]	[3.1, 3.5]	2.5	2.0	3.0	[0.0, 4.0]	[2.3, 2.7]	0.8 [1, 0.6]	6.92	<.001	0.358	Small
Appearances in the starting eleven (n)	375	2.5	1.8	2.0	[1.0, 4.0]	[2.3, 2.7]	1.8	1.8	1.0	[0.0, 3.0]	[1.6, 1.9]	0.7 [0.9, 0.5]	7.17	<.001	0.370	Small
Unused Substitute (n)	375	0.3	0.7	0.0	[0.0, 0.0]	[0.2, 0.4]	0.3	0.7	0.0	[0.0, 0.0]	[0.2, 0.4]	0 [0.1, -0.1]	0.38	0.707	0.019	Negligible
Rest days before match (n)	240	10.2	8.0	8.3	[6.2, 11.3]	[9.1, 11.2]	11.0	9.1	8.0	[6.2, 11.7]	[9.8, 12.2]	-0.8 [0.5, -2.2]	-1.19	0.235	-0.077	Negligible

Less than 3 days between match (n)	240	0.5	0.8	0.0	[0.0, 1.0]	[0.4, 0.6]	0.5	0.9	0.0	[0.0, 1.0]	[0.4, 0.6]	-0.1	[0.1, -0.2]	-0.79	0.432	-0.051	Negligible
Less than 5 days between match (n)	240	1.4	1.7	1.0	[0.0, 2.2]	[1.2, 1.7]	1.2	1.5	1.0	[0.0, 2.0]	[1.0, 1.4]	0.2	[0.5, 0]	1.96	0.051	0.126	Negligible
Critical zone matches (n)	240	0.9	1.2	0.0	[0.0, 2.0]	[0.7, 1.0]	0.8	1.2	0.0	[0.0, 1.0]	[0.7, 1.0]	0.1	[0.2, -0.1]	0.53	0.595	0.034	Negligible

277 Abbreviations: MD, mean difference; d, effect size; SD, standard deviation; IQR, interquartile range;

278 CI, confidence interval. $p < 0.05$.

279 **Table 3:** Comparison of 60-Day Workload Variables Between Injury and Control Groups

Workload variables	**Injury**						**Control**					**Injury versus control**				
	n	**Mean**	**SD**	**Median**	**IQR**	**CI**	**Mean**	**SD**	**Median**	**IQR**	**CI**	**MD**	**t**	**p**	**d**	**Interpretation**
Minutes (min)	375	344	247	326	[145, 521]	[319, 369]	290	247	270	[44, 481]	[265, 315]	54.2 [79.6, 28.8]	4.20	<.001	0.217	Small
Appearances (n)	375	5.7	3.3	6.0	[3.0, 8.0]	[5.3, 6.0]	4.7	3.4	5.0	[2.0, 7.0]	[4.3, 5.0]	1 [1.3, 0.6]	5.58	<.001	0.288	Small
Appearances in the starting eleven (n)	375	4.2	3.0	4.0	[2.0, 6.0]	[3.9, 4.5]	3.3	2.9	3.0	[0.0, 5.5]	[3.0, 3.6]	1 [1.3, 0.6]	6.16	<.001	0.318	Small
Unused Substitute (n)	375	0.6	1.1	0.0	[0.0, 1.0]	[0.4, 0.7]	0.6	1.3	0.0	[0.0, 1.0]	[0.5, 0.7]	0 [0.1, -0.2]	-0.37	0.708	-0.019	Negligible
Rest days before match (n)	276	10.0	7.8	8.0	[6.8, 10.5]	[9.1, 11.0]	10.1	8.0	8.2	[6.5, 10.5]	[9.1, 11.0]	0 [1.1, -1.2]	-0.08	0.938	-0.005	Negligible
Less than 3 days between match (n)	276	0.9	1.2	0.0	[0.0, 1.0]	[0.7, 1.0]	0.9	1.3	0.0	[0.0, 2.0]	[0.8, 1.1]	-0.1 [0.1, -0.3]	-0.89	0.376	-0.053	Negligible
Less than 5 days between match (n)	276	2.4	2.5	2.0	[0.0, 4.0]	[2.1, 2.7]	2.1	2.3	2.0	[0.0, 3.0]	[1.8, 2.3]	0.3 [0.7, 0]	2.13	0.034	0.128	Negligible

Critical zone matches (n)	276	1.6	1.9	1.0	[0.0, 2.0]	[1.4, 1.8]	1.4	1.7	1.0	[0.0, 2.0]	[1.2, 1.6]	0.2 [0.5, 0]	1.71	0.088	0.103	Negligible

Abbreviations: MD, mean difference; d, effect size; SD, standard deviation; IQR, interquartile range; CI, confidence interval. $p < 0.05$.

Table 4: Comparison of 90-Day Workload Variables Between Injury and Control Groups

Workload variables	**Injury**						**Control**					**Injury versus control**				
	n	**Mean**	**SD**	**Median**	**IQR**	**CI**	**Mean**	**SD**	**Median**	**IQR**	**CI**	**MD**	**t**	**p**	**d**	**Interpretation**
Minutes (min)	375	470	336	448	[194, 720]	[436, 505]	403	323	360	[115, 638]	[370, 436]	67.6 [100, 35.2]	4.10	<.001	0.212	Small
Appearances (n)	375	7.8	4.5	8.0	[4.0, 11.0]	[7.3, 8.2]	6.6	4.5	7.0	[3.0, 10.0]	[6.1, 7.0]	1.2 [1.7, 0.8]	5.42	<.001	0.280	Small
Appearances in the starting eleven (n)	375	5.7	4.1	5.0	[2.0, 9.0]	[5.2, 6.1]	4.5	3.8	4.0	[1.0, 7.0]	[4.1, 4.9]	1.1 [1.5, 0.8]	5.86	<.001	0.303	Small
Unused Substitute (n)	375	0.9	1.5	0.0	[0.0, 1.0]	[0.7, 1.0]	0.8	1.6	0.0	[0.0, 1.0]	[0.7, 1.0]	0 [0.2, -0.2]	0.06	0.956	0.003	Negligible
Rest days before match (n)	290	9.1	4.9	8.0	[6.5, 10.0]	[8.6, 9.7]	9.1	5.8	7.7	[6.5, 10.1]	[8.4, 9.8]	0 [0.8, -0.8]	0.05	0.957	0.003	Negligible
Less than 3 days between match (n)	290	1.1	1.4	1.0	[0.0, 2.0]	[1.0, 1.3]	1.2	1.5	1.0	[0.0, 2.0]	[1.1, 1.4]	-0.1 [0.1, -0.3]	-0.97	0.333	-0.057	Negligible
Less than 5 days between match (n)	290	3.1	3.3	2.0	[1.0, 5.0]	[2.8, 3.5]	2.7	2.9	2.0	[0.0, 4.0]	[2.4, 3.1]	0.4 [0.8, 0]	2.07	0.039	0.121	Negligible
Critical zone matches (n)	290	2.0	2.4	1.0	[0.0, 3.0]	[1.7, 2.3]	1.8	2.1	1.0	[0.0, 3.0]	[1.5, 2.0]	0.2 [0.5, -0.1]	1.38	0.167	0.081	Negligible

283 Abbreviations: MD, mean difference; d, effect size; SD, standard deviation; IQR, interquartile range;
284 CI, confidence interval. $p < 0.05$.

285 **Table 5:** Comparison of 90-Day Minutes Played Between Injury and Control Groups Across Specific
286 Subgroups

Workload variables	Injury						Control					Injury versus control				
	n	Mean	SD	Median	IQR	CI	Mean	SD	Median	IQR	CI	MD	t	p	d	Interpretation
Game related	233	542	335	518	[277, 759]	[498, 585]	444	327	423	[180, 660]	[402, 487]	97 [58, 136]	4.9	<.001	0.321	Small
Training related	78	345	306	283	[72, 543]	[276, 414]	322	314	225	[50, 548]	[251, 392]	23 [-50, 96]	0.64	0.526	0.072	Negligible
Changing teams	96	441	333	414	[180, 667]	[373, 508]	365	284	318	[129, 576]	[308, 423]	76 [3, 148]	2.07	0.041	0.211	Small
Changing leagues	129	472	393	364	[148, 694]	[322, 622]	351	261	360	[99, 546]	[252, 451]	121 [-21, 263]	1.75	0.092	0.324	Small

287 Abbreviations: MD, mean difference; d, effect size; SD, standard deviation; IQR, interquartile range;
288 CI, confidence interval. $p < 0.05$.

289 Travel Workload Comparisons

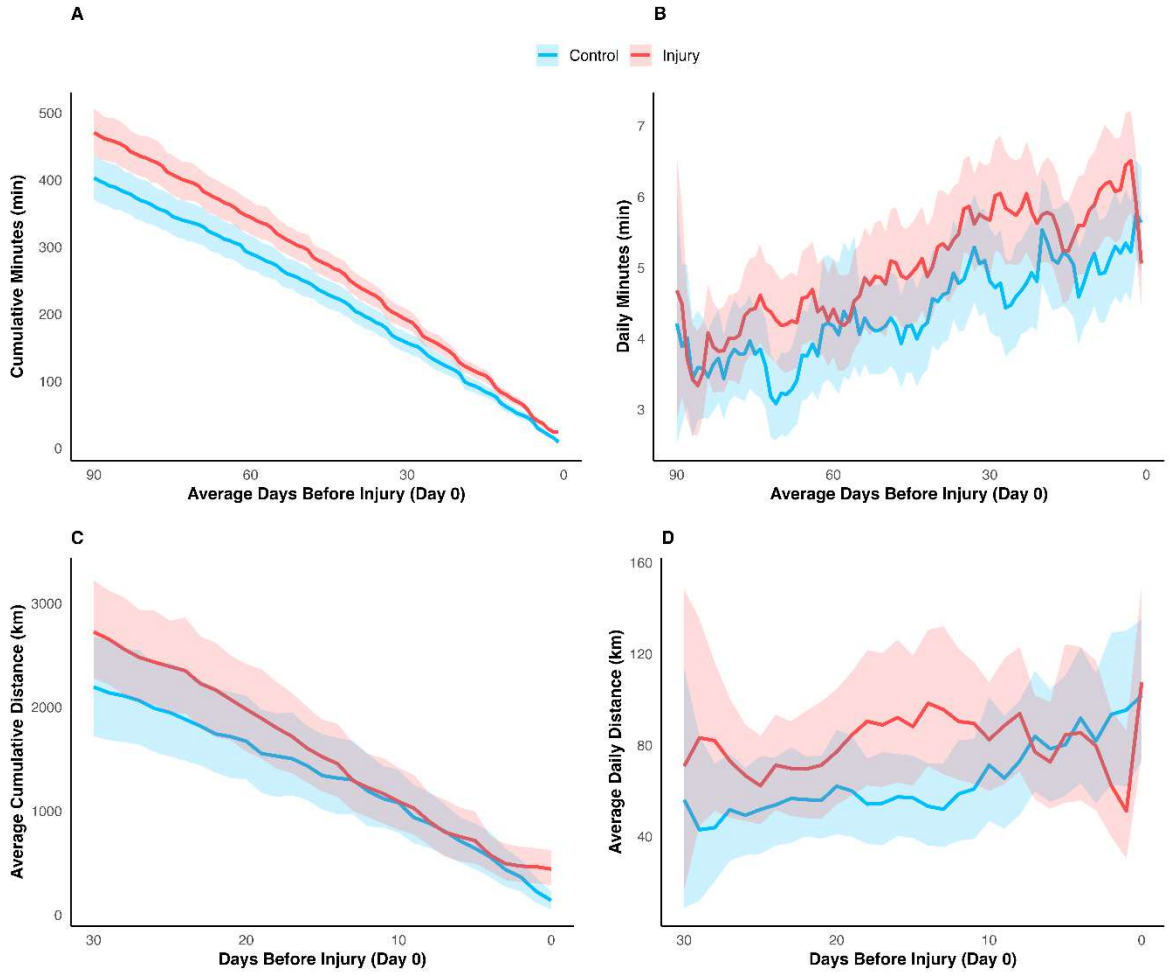
290 During the 30-days preceding ACL injury, cumulative travel distance was significantly greater in the
291 injury season compared with the control season (2724 ± 4821km vs 2194 ± 4624 km, $p < 0.001$)
292 (Table 6; Figure 2C-D). However, the effect size was negligible (d=0.106). The number of time zones
293 crossed did not differ significantly between seasons (MD = 0.2 for both seasons; $p = 0.106$, $d =$
294 0.056).

295 **Table 6:** Comparison of 30-Day Travel-Related Workload Variables Between Injury and Control
296 Groups

	Injury	Control	Injury versus control

Workload variables	n	Mean	SD	Median	IQR	CI	Mean	SD	Median	IQR	CI	MD	V	p	d	Interpretation
Distance (km)	375	2724	4821	944	[120, 3176]	[2235, 3214]	2194	4625	480	[0, 1959]	[1724, 2663]	530.1 [1187.9, 80.3]	22184	<0.001	0.106	Negligible
Time zones crossed (n)	375	1.2	2.9	0.0	[0.0, 1.0]	[0.9, 1.5]	1.0	3.1	0.0	[0.0, 0.0]	[0.7, 1.3]	0.2 [0.5, -0.2]	2965.00	0.106	0.056	Negligible

297 Abbreviations: MD, mean difference; V, Wilcoxon signed-rank test statistic; d, effect size; SD,
298 standard deviation; IQR, interquartile range; CI, confidence interval.



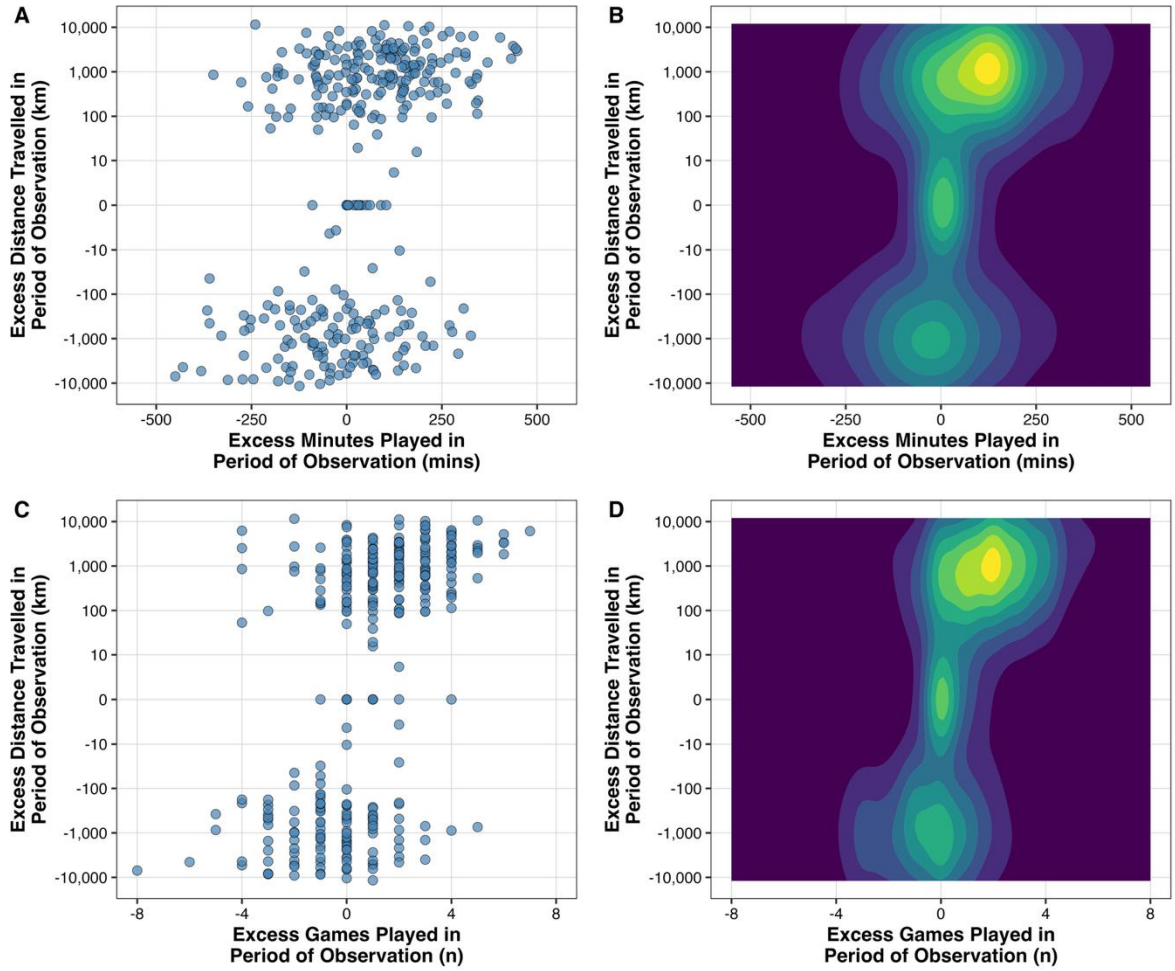
299

300 **Figure 2:** Training load and travel distance before ACL injury. Each figure shows the average
301 differences between the injury season and the previous season for (A) cumulative match minutes over

90 days, (B) average daily match minutes over 90 days, (C) cumulative travel distance over 30 days and (D) average daily travel distance over 30 days. Values were averaged across participants at each time point and subsequently smoothed using a rolling mean.

Relationship Between Match Exposure and Travel Distance

Excess travel distance was moderately correlated with excess match minutes ($\rho = 0.399$, $p < 0.001$; Figure 3A and 3B) and more strongly correlated with excess matches attended ($\rho = 0.556$, $p < 0.001$; Figure 3C and 3D). In mixed-effects logistic regression analyses, the interaction between match appearances and travel status indicated that not travelling was associated with significantly lower odds of being in the injury season compared with any travel ($\beta = -0.64$, OR = 0.53, $p = 0.024$), although this effect diminished as match appearances increased ($\beta = -0.47$, $p=0.056$). In contrast, when assessing match minutes ($\beta = 0.09$, $p = 0.111$) and match appearances ($\beta = 0.19$, $p = 0.235$) were positively but not significantly associated with the injury season.



314

315 **Figure 3:** Relationship between excess minutes played and excess distance travelled in the 30 days
316 preceding ACL injury compared with the previous season. (A) Scatterplot displaying individual
317 player data for excess match minutes (min) and travelled distance (km). (B) Heat map illustrating the
318 distribution of data clusters across excess match minutes (min) and travel distance (km). (C)
319 Scatterplot displaying individual player data for excess games played (n) and travelled distance (km).
320 (D) Heat map illustrating the distribution of data clusters across excess games played (n) and travel
321 distance (km). For all panels, the y-axis (excess distance travelled, km) is log-transformed.

322 Visual inspection of workload and travel distributions across competitive tiers (Figure 4) indicated
323 that a large proportion of players transitioning from Tier 3 to Tier 4 experienced concurrent increases
324 in both match exposure and travel distance relative to their control season. Tier 5 players

demonstrated a similar pattern, with notable proportions exposed to elevated match and travel demands compared with the previous season.

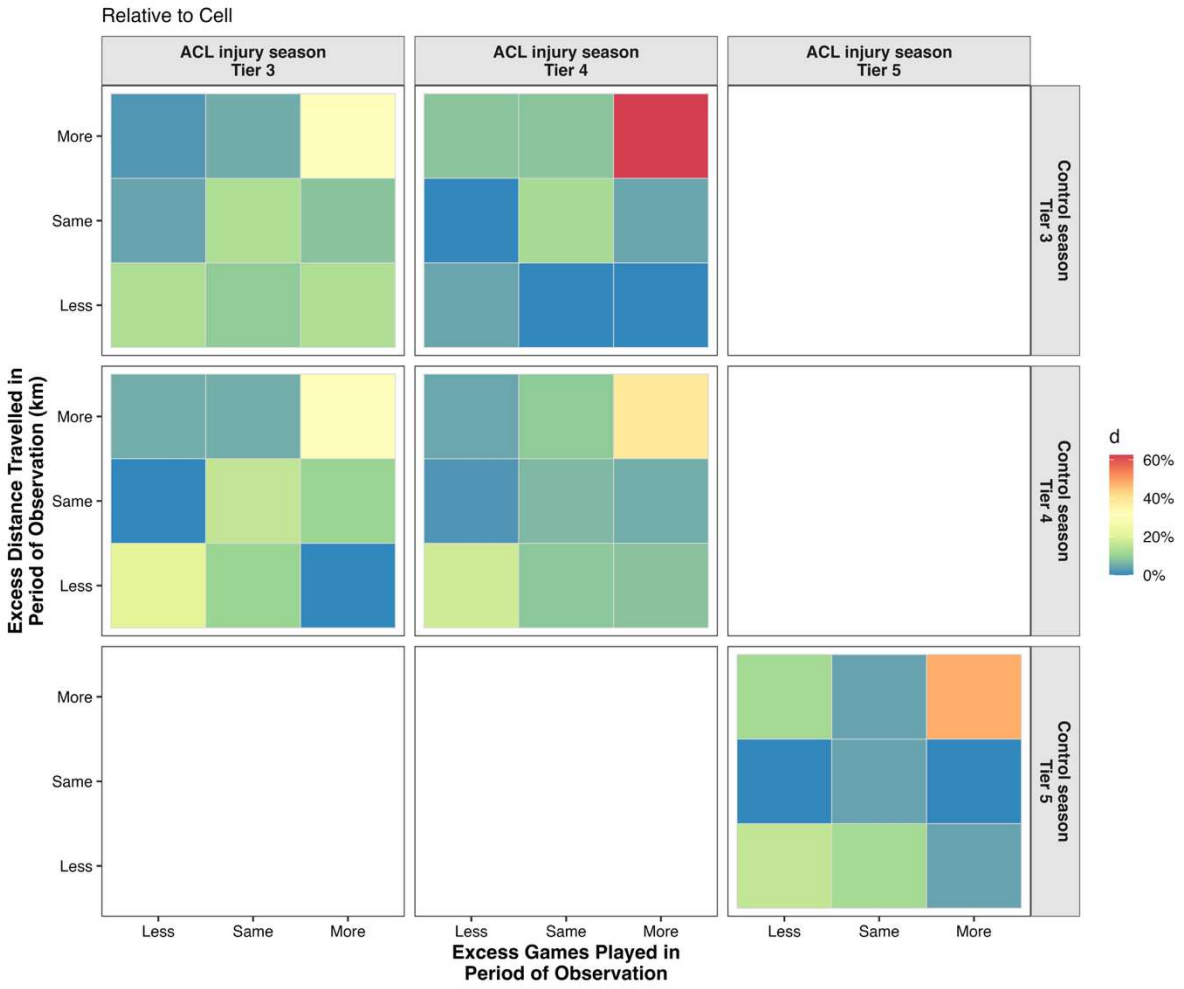


Figure 4: Distribution of excess match exposure (x-axis) and excess travel load (y-axis) across league tiers. The vertical axis represents the player's competitive tier in the previous (control) season, and the horizontal axis represents the tier in which the ACL injury occurred. Values are shown relative to the sample in each tier-to-tier cell. Colour scale (d) represents the density of observations within each cell.

Discussion

This study compared pre-injury match exposure and travel workload in professional women footballers who sustained ACL injuries, using a within-player, season-matched period from the preceding year. The main observations were: (1) match exposure (match minutes, total appearances, and starting appearances) was consistently higher in the injury season compared with the within-player control season across 30-,60-, and 90-day windows, although effect sizes were small; (2) Travel distance in the 30 days preceding injury was significantly higher in the injury season, but the effect size was negligible due to substantial inter-individual variability; (3) Increases in match exposure relative to the control season were moderately associated with increased travel distance, indicating that these demands co-occur; (4) In mixed effects modelling, travel distance was the only workload variable statistically associated with ACL injury status, with no increase in travel linked to lower odds of injury compared with any change; and (5) concurrent increases in match and travel exposure were most evident among players transitioning from Tier 3 to Tier 4 and among those competing at Tier 5.

Impact of Match Workload on ACL Injuries

Across all time windows, the injury season was characterised by generally higher, but variable, match involvement (minutes, appearances and appearances in the starting eleven) relative to each player's preceding season. These observations extend the preliminary findings in elite women's football reporting higher match exposures among ACL-injured players compared with league-based controls ($n = 12$; moderate effect size: $\eta^2 = 0.08$) over a similar period (28 days) (18). Importantly, the within-player design used here provides a more robust approach to addressing heterogeneity in intrinsic characteristics and contextual factors that may confound between-player comparisons, and the larger sample size improves precision and generalisability across Tier 3-5 competitions. Notably, increased match exposure in the injury season was not accompanied by consistent differences in recovery time between matches or the frequency of congested fixtures. This contrasts with the findings of den Hollander and colleagues, who suggested shorter recovery intervals as a distinguishing feature of injury (18). Differences may reflect study design (within-player vs. between-player controls), cohort composition (Tier 3-Tier 5 vs. exclusively elite) or size (n= 240 vs. 12). Together, the findings

suggest that absolute match volume may be a more consistent marker than fixture congestion indicators for distinguishing injury seasons from within-player controls.

Extending the exposure window beyond 30 days demonstrated that the pattern of higher match exposure (match minutes and appearances) persisted across 60 and 90 days, but effect sizes remained similar (*d*=0.217-0.318). From a surveillance perspective, this supports the practicality of a 30-day window for monitoring relative changes in match involvement, as longer windows may introduce additional confounding due to seasonal variation, injuries, selection changes and competition phase effects without substantially strengthening the observed association. However, the small effect sizes and large inter-individual variability reinforce that match exposure represents only one component within a multifactorial injury landscape.

Impact of Travel Workload on ACL Injuries

Players accumulated significantly greater travel distance in the 30 days preceding ACL injury relative to the within-player control season, although variability was substantial and the effect size was negligible. This broadly aligns with preliminary evidence that ACL-injured players had greater travel exposure than league-based controls (18). However, the magnitude and variability of travel load are likely strongly influenced by the competition structure and the proportion of international fixtures, which may explain differences in average travel distance across cohorts (5,012 ± 5,651 km vs. 2,724 ± 4,821 km).

The substantial variability observed here likely reflects the fact that travel exposure may be concentrated within specific subgroups (e.g., players in international competitions, transitioning to higher competitive tiers, or those experiencing rapid changes in competitive demands), where progression is often accompanied by more demanding fixtures, increased match intensity, and expanded travel requirements. These combined demands may increase both physical and cognitive load, which may influence fatigue and recovery (20). This may also help explain discrepancies with earlier research in men's rugby and football, reporting limited associations between travel and overall

injury incidence (19, 40, 41). However, these previous studies often examined overall injury burden (rather than ACL-specific events) or may have been underpowered to detect relationships for low-frequency outcomes such as ACL injury.

Concurrent Match and Travel Demands

Excess match exposure (match appearances and minutes played) relative to the control season was moderately associated with higher travel, indicating that increases in match involvement often coincide with increased travel. In mixed-effects modelling, travel distance (rather than match exposure) was associated with ACL injury seasons. We caution against interpreting this finding as travel acting in isolation; rather, travel distance may serve as a proxy for the clustered demands that accompany increased match exposure and the associated logistical burden.

Consistent with this observation, the strongest clustering of increased match and travel demands appeared among players transitioning from Tier 3 to Tier 4, and those competing at Tier 5. Progression to higher competitive levels typically involves greater match frequency, broader competition participation, and increased travel, often occurring concurrently. Although these tier-based patterns were descriptive and not formally tested, they highlight competitive progression as a plausible context in which demands may increase more rapidly than players' capacity to adapt. Within a workload progression and adaptive capacity framework, simultaneous increases in match exposure and travel distance may contribute to cumulative physiological strain, potentially through mechanisms such as travel-related sleep disruption, circadian misalignment, and impaired recovery (20, 26-28). Such strain may transiently reduce neuromuscular readiness, impair player readiness and football-specific performance capacities, including sprint speed, rapid force generation, decision-making, and technical execution (21, 25, 42). These capacities may be considered paramount for tolerating rapid, high-magnitude mechanical loads during dynamic match movements (43, 44) such as cutting, deceleration and landing tasks. A transient reduction in readiness during periods of elevated cumulative demand may therefore represent one plausible pathway through which early-phase match

actions, where ACL injuries are frequently reported in professional women's football (33), become more hazardous. These proposed mechanisms remain speculative in the present study but offer testable hypotheses for future prospective and mechanistic research.

Practical Implications

From an applied perspective, the findings suggest that periods characterised by concurrent increases in match exposure and travel demands may warrant heightened monitoring and targeted risk mitigation in professional women's football. Practical strategies may include proactive planning around competition transitions (e.g. Tier 3 to Tier 4 progression), staged exposure to increased match involvement, and systemic monitoring of fatigue, recovery and neuromuscular readiness during periods of intensified travel.

Given the observed association between increased travel distance and injury season workload, attention to travel logistics may also be warranted. Although this study cannot establish causality, optimising travel planning, such as minimising unnecessary long-haul transit, allowing adequate arrival time before competition, and implementing strategies to reduce circadian and sleep disruption, may help mitigate cumulative strain during congested competitive periods. For Tier 5 players, where cumulative exposure and international travel are consistently high, integrating travel-aware recovery protocols and readiness monitoring may be particularly relevant.

Importantly, given the substantial inter-individual variability observed, these factors should be viewed as context-dependent risk markers rather than universal predictors of ACL injury. Workload and travel demands likely interact with multiple intrinsic and extrinsic factors, underscoring the need for individualised and context-sensitive management approaches.

Limitations

This study is exploratory and cannot support causal inference. The cohort was defined by ACL injury occurrence and lacked a non-injured comparison group to estimate injury probability, so associations should be interpreted as hypothesis-generating risk markers (17). Reliance on publicly available data introduces potential inaccuracies and incomplete capture of match exposure, particularly for friendly fixtures. Travel distances were estimated using the Haversine formula and may not reflect true routes, transport modes, or travel duration. Assigning 0 km for home matches and intra-tournament movement likely underestimates total travel, and east-west travel direction, which may be relevant to circadian disruption (25), could not be operationalised reliably with available data. The dataset did not include training load, internal load, match-intensity metrics, or detailed injury mechanism classification (e.g. contact vs. non-contact), limiting mechanistic interpretation. Finally, congestion-related metrics were derived from smaller subsamples because not all players accumulated sufficient match exposure within the relevant windows.

Conclusion

Professional women football players who sustained ACL injuries demonstrated modestly higher match exposure and travel distance in the injury season relative to their own within-player control season. Although effect sizes were small and variability across players and competitions was substantial, concurrent increases in match and travel demands appeared more evident among players transitioning to higher competitive tiers and those competing at elite levels. These findings highlight the potential value of future research examining how competition scheduling and travel demands intersect with player readiness, recovery, and ACL injury risk in professional women's football.

Author contributions:

- **WH:** Conceptualisation, data collection, data analysis, and drafting of the manuscript.
- **EP, MW, RL:** Conceptualisation and critical revision of the manuscript.
- **BW:** Statistical analysis and critical revision of the manuscript.
- **VC:** Data collection and critical revision of the manuscript.

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Ethics Approval: All the substitution minutes we accessed are publicly available, data were treated confidentially, and no personal player information was accessed; therefore, ethics were exempt.

Provenance and review: Not commissioned, externally peer reviewed

Data Availability Statement: All data relevant to the study are included in the article or uploaded as supplementary information.

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