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Positional and Temporal Intermittency in Football: A Metabolic Model Approach

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ABSTRACT

This study examined positional differences in the intermittent nature of efforts during professional football matches and compared two analytical models: one using a fixed metabolic power threshold (Pmet20) and another based on the relationship between oxygen consumption and metabolic power (VO_2–Pmet). Data were collected from 24 First Division players in Cyprus across 50 matches during the 2022–2023 season using GPS technology (WIMU Pro System). High and low metabolic load efforts were analyzed. Results showed significant positional differences in both the duration and intensity of high metabolic load efforts and low metabolic load efforts. Compared to the Pmet20 model, the VO_2–Pmet method identified approximately twice longer high metabolic load effort durations (≈ 4.1 vs. 2.1 s) and about 70–150 % more detected efforts across positions, together with shorter recovery intervals. A notable decline in low metabolic load effort intensity between halves was linked to reduced performance. These findings highlight the dynamic interplay between aerobic and anaerobic systems in football and emphasize the need for position-specific training. Practical applications include designing training programs that reflect the unique intermittent demands of each position, focusing on both high-intensity efforts and recovery. This study provides a robust framework for understanding the football's intermittent nature and offers actionable strategies to enhance player performance through tailored conditioning.

Keywords Anaerobic capacity, GPS tracking, positional demands, training programmes, high-intensity efforts

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Introduction

Football is a complex and physically demanding team sport characterized by intermittent and unpredictable activity patterns that alternate between high-intensity efforts and periods of passive or active recovery of unknown duration.[1] Elite football players typically cover distances ranging from 10 to 12 km during official matches, maintaining an average intensity of approximately 80–90 % of their maximum heart rate,[1] and performing around 200 high-intensity actions.[2]

Despite the football's stochastic nature, there is a relative paucity of studies examining the specific characteristics of effort and recovery phases during a competitive play.[3] Previous research has reported that the duration of high-intensity actions ranges between 2.5 and 4 seconds,[4, 5] while recovery times between very high-intensity runs range from 48 to 72 seconds.[4, 6] As a result, it can be asserted that football performance is based on accumulated episodes of brief efforts. Nearly 90 % of all exertions and recovery periods last less than 15 seconds, after which the player either partially or fully recovers before engaging in a subsequent high-intensity action.[3]

Moreover, the physical demands of football are highly position-specific, as each role on the pitch entails distinct technical and tactical requirements intrinsically linked to various physical, physiological, energetic, and biomechanical components.[7] Typically, wide midfielders (WMFs) cover the greatest distances at high intensity during a match.[6, 8, 9] However, when data are normalized to the total distance covered, full-backs (FBs) exhibit the highest proportion of high-intensity runs. At the same time, central midfielders (CMFs) perform the most frequent efforts with limited recovery time.[10]

Player performance is also influenced by the tactical formation employed by the team.[11] Forward wide defenders (FWDs) operating in a 4-3-3 system tend to accumulate greater total running distances, including high- and very high-intensity efforts, than those in 4-4-2 and 4-5-1 formations. Similarly, defenders in a 4-4-2 formation demonstrate greater total and high-intensity running distances than their counterparts in 4-3-3 and 4-5-1 systems. A more detailed analysis of very high-intensity movement patterns indicates that players across all positions in 4-3-3 and 4-4-2 formations cover greater distances when their team has the ball, compared to players in a 4-5-1 system.[11]

In this context, metabolic power (Pmet) has emerged as a sensitive tool for quantifying exercise intensity and defining high-intensity efforts and repeated high-intensity activity bouts.[12] Using the approach that integrates a conventional speed threshold (14.4 km h⁻¹) with a corresponding Pmet value (20 W kg⁻¹), previous studies have shown that speed-based classifications tend to underestimate physical demands in football, particularly during training sessions or in playing positions characterized by lower-speed movements.[13] This suggests that substantial amounts of high-intensity activity occur at low speeds. Furthermore, the constant-speed equivalent of 20 W kg⁻¹ is in fact at 15.5 km h⁻¹,[14] indicating an even greater underestimation when the intensity is assessed solely via speed.

This discrepancy between internal and external load classifications is further illustrated in small-sided games, where players frequently attain high heart rates without covering large distances or reaching high running speeds,[15] highlighting yet another limitation in current evaluation methods of physical demands in team sports.

An alternative methodology approach enables the reasonably accurate estimation of the temporal evolution of both Pmet and modelled oxygen consumption (VO_2), offering detailed insights into the contributions of aerobic and anaerobic energy systems, as well as the duration and intensity of both high- and low-intensity bouts.[16] Compared to metrics based solely on speed and/or acceleration, this approach provides a more realistic representation of the metabolic load experienced during the football match play.

The estimation of VO_2 from GPS-derived data is based on the physiological relationship between Pmet output and the energetic cost, as first proposed by di Prampero et al. (2005) and later adapted to team sports by Osgnach et al. (2010). In this model, instantaneous VO_2 is inferred from the mechanical energy required to overcome both linear and gravitational components of acceleration, expressed relative to body mass. Consequently, the so-called 'VO_2–Pmet' method translates the external workload captured by GPS into an internally modeled oxygen demand, thereby bridging the gap between the mechanical output and the physiological response.

To date, positional analyses have not employed a model specifically designed to assess players' metabolic activity to characterize the intermittent nature of their movement patterns during matches. The primary objective of this study was to describe the intermittent activity profile of professional football players according to their positional roles within a specific and defined game model, using two distinct analytical approaches (Pmet20 and VO_2–Pmet). Complementary aims included examining differences in the duration, distance, intensity, and number of actions between the first and second halves of matches and evaluating the impact of threshold type – based on either VO_2 or absolute Pmet values – on the duration, distance, and metabolic intensity of actions, according to the playing position and effort type (low and high intensity).

Table 1 Descriptive data of the sample

Position	*n*	Age (y)	Height (cm)	Weight (kg)	BMI (kg/m²)
CD	4	30.0 ± 6.7	189.2 ± 3.6	79.4 ± 8.2	22.2 ± 3.0
FB	5	28.0 ± 4.4	177.0 ± 4.5	74.2 ± 9.2	23.6 ± 1.6
CMF	4	29.0 ± 6.2	178.8 ± 6.0	71.4 ± 1.2	22.4 ± 1.6
WMF	6	28.6 ± 5.2	178.6 ± 4.6	72.6 ± 5.5	22.8 ± 2.1
FWD	5	29.7 ± 4.9	183.8 ± 5.7	82.8 ± 5.8	24.5 ± 0.5

Abbreviations: BMI, body mass index; CD, central defender; CMF, central midfielder; FB, full back; FWD, forward wide defender; WMF, wide midfielder.

Materials and methods

An experimental approach to the problem

This study was a retrospective cohort analysis designed to test the hypotheses proposed in the Introduction, focusing on the intermittent nature of physical efforts in professional football. This study monitored 24 professional football players from a First Division club in Cyprus throughout the 2022–2023 season, using GPS devices to collect data on high and low metabolic load efforts (HMLE and LMLE). The independent variables include the playing position, match half, and the analytical approach (Pmet20 vs. VO_2–Pmet), while the dependent variables include the distance, duration, and average Pmet of efforts. The rationale for selecting these variables lies in their ability to capture the positional and temporal variations in physical demands, providing a comprehensive understanding of the interplay between aerobic and anaerobic systems. This approach allows for a detailed analysis of how different positions and match phases influence the intensity and duration of efforts, thereby validating the study's hypotheses on the intermittent demands of football.

Subjects

A cohort of 24 professional football players (mean age: 29.0 ± 4.98 y; mean weight: 76.1 ± 7.46 kg; and mean height: 181 ± 6.25 cm) from a First Division club in Cyprus were monitored throughout the 2022–2023 season. According to the Participant Classification Framework proposed by McKay et al.,[17] these players were classified as belonging to the second competition level, designated for highly trained or national-level athletes. The monitoring period included both the pre-season (June–July) and the competitive season (August–May). In addition to domestic competitions, the team participated in international tournaments, including the Champions League qualifying rounds, the Europa League group stage, and the Round of 16 of the Conference League.

This study received institutional approval from the club, and data collection was integrated into the players' regular employment conditions to assess their physical performance throughout the season.[18] As such, formal ethical approval was not required. All performance data were anonymized to ensure player confidentiality.

Data were collected over 36 domestic league matches (26 regular seasons and 10 playoff matches) and 14 European competition fixtures (four qualification phase, six Europa League group stage, and four conference league knockout stage matches), resulting in a total of 717 observations. Players were grouped into five positional categories based on their technical-tactical roles and predominant playing zones: central defenders (CDs = 4), FBs = 5, CMFs = 4, WMFs = 6, and FWDs = 5. To control performance variability between starting and substitute players, only those who completed at least 90 minutes of match play were included in the final sample, yielding a total of 276 valid observations: CD (*n* = 89), FB (*n* = 71), CMF (*n* = 67), WMF (*n* = 23), and FWD (*n* = 26; **Table 1**). Goalkeepers were excluded from the analysis due to the distinct nature of their physical demands compared to outfield players.[19]

Throughout the season, the team consistently employed a 4-4-2 formation, consisting of four defenders (two CD and two FB), two CMFs, two WMFs, and two FWDs. During the competitive phase, training microcycles were adapted according to the number and scheduling of official matches. In weeks with a single match, players typically trained five times in addition to the match. In weeks with two matches, training volume and frequency were adjusted based on the temporal distribution of the games. Training sessions followed the structure and guidelines described in previous literature.[20]

Procedures

Data were collected using 10 Hz GPS devices (WIMU Pro System; RealTrack Systems, Almería, Spain), operating with SPRO software (v989, RealTrack Systems, Almería, Spain), which have been validated and shown to be reliable for the analysis of performance-related variables.[21] These units are also certified by the FIFA Quality Programme.[22] GPS devices were calibrated and activated 15 minutes before data collection. To minimize inter-unit variability, each player used the same GPS unit for all training sessions and matches.

Following each match, data were downloaded using SPRO software (v989; RealTrack System, Almería, Spain), and raw data were exported in the .csv format. Data points recorded before kick-off, during halftime, and any instances where running speed exceeded 10 m s^{-1} or acceleration/deceleration surpassed 6 m s^{-2}[23] were excluded from the analysis, with such values removed from the data set (left blank) to avoid introducing artificial zero values that could bias Pmet calculations. This adjustment was implemented to ensure that missing or erroneous data points do not distort Pmet or VO_2 estimates. Given the analytical scope of this study, these adjustments were considered to have minimal impact on the overall data set for each match.

For further analysis, the exported data were processed using the custom code developed in RStudio (Version 2023.12.0 + 369). This code was specifically designed to extract key variables that characterize the intermittent nature of the match play. Player efforts were classified as either HMLE or LMLE based on two distinct analytical approaches:

1. Fixed threshold method (Pmet20): A high-intensity effort was defined as any instance in which the instantaneous Pmet exceeded 20 W kg^{-1} for at least 1 second. According to the model proposed by Di Prampero and Osgnach,[24] this value corresponds to an estimated oxygen consumption of 57 mL/kg/minute – representing the average VO_{2max} of a player with a body mass of 78 kg — and is equal to a constant running speed of 15.5 km h^{-1} or an acceleration of 2 m s^{-2} from an initial speed of 5.4 km h^{-1}.
2. Instantaneous oxygen consumption method (VO_2–Pmet): A high-intensity effort was defined as any period in which the estimated Pmet exceeded estimated oxygen consumption (VO_2) for at least 1 second. This approach accounts for the delayed kinetics of oxidative metabolism during transitions in exercise intensity. Due to the relatively slow response of oxidative pathways, the muscle-level adaptation to increased energy demands follows an exponential pattern with an estimated time constant of approximately 20 seconds.[16] As such, Pmet may be equal to, greater than, or less than VO_2 at any given moment.

In both methods, when two HMLE bouts were separated by less than 0.5 seconds, they were considered part of the same effort. All remaining periods not classified as HMLE were categorized as LMLEs, for which intensity and duration were also computed.

In addition to distance, duration, and average Pmet (AvgPmet), two energy cost metrics were calculated for each effort: an average energy cost (AvgEC, J kg^{-1}) and a total energy cost (TotalEC, J kg^{-1}). AvgEC represents the mean energetic expenditure per unit of body mass during an effort, while TotalEC corresponds to the cumulative energy cost of the entire effort. Both metrics were derived from the Pmet model proposed by di Prampero et al.[24] and expressed relative to body mass to allow inter-individual comparisons.

Statistical analysis

The data set was structured such that each observation represented a single effort performed by a player, categorized as either a HMLE or a LMLE, based on two physiological thresholds: Pmet20 and VO_2–Pmet. Two distinct analyses were performed for each threshold.

The first analysis aimed to compare performance variables across playing positions (e.g., CDs, midfielders, and FWD) for both effort types (HMLE and LMLE) and each threshold (Pmet20 and VO_2–Pmet). The second analysis evaluated differences between the first and second halves of matches, regardless of the playing position, again separately for each threshold.

Descriptive statistics were computed using the median and interquartile range (IQR), given that the data did not meet the assumption of normality. The distribution of the data was assessed through visual inspection and the Kolmogorov–Smirnov test. The performance variables analyzed included the distance covered during each effort (distance), duration of the effort (duration), average Pmet (AvgPmet), average energy cost (AvgEC), and total energy cost (TotalEC). Additionally, the number of efforts per player per match (*n*) was calculated, representing the total count of HMLE or LMLE events per player per game.

Due to the non-normal distribution of the data, non-parametric tests were used. The Kruskal–Wallis test was applied to identify significant differences across groups. When significant main effects were detected, post-hoc pairwise comparisons were conducted using the Wilcoxon rank-sum test, with Holm's correction applied to control for multiple comparisons.

To examine the effects of threshold type (Pmet20 and VO_2–Pmet), effort type (HMLE and LMLE), playing position, and match half on external load metrics, separate linear mixed-effect models (LMMs) were fitted for each dependent variable: distance, duration, and AvgPmet. For the LMM, each observation represented the total value for each player per match, based on the threshold type (VO_2–Pmet and Pmet20), activity (HMLE and LMLE), and match half (first and second). Thus, each player included in the analysis had eight observations per match. Each model included the interaction terms threshold type × activity and playing position × activity, as well as the main effect of match half. These interaction terms allowed us to assess whether the influence of threshold type or playing position varied depending on whether the activity was classified as high (HMLE) or low (LMLE) metabolic load.

The structure of the models was identical across dependent variables and included random intercepts for the player identity and the observation date to account for repeated measures and potential temporal dependency:

$$Y \sim threshold\ type\ \times activity + playing\ position\ \times activity$$

$$+ match\ half + \ (1 \mid player\ identity) + (1 \mid observation\ date)$$

where Y represents each of the dependent variables in turn (distance, duration, AvgPmet, AvgEC, and TotalEC). The reference levels for the fixed effects were as follows: threshold type = Pmet20, activity = HMLE, position = CD, and match half = first half. Based on these reference categories, the model intercept represents the estimated value of the dependent variable for a CD during a HMLE, in the first half of the match, using the Pmet20 threshold method.

Model diagnostics were performed for each fitted model. Residuals were extracted and evaluated to verify the assumption of normality. Visual inspection was conducted using histograms and Q–Q plots. Additionally, a formal normality test was applied (Jarque–Bera test). These procedures ensured that residual distributions approximated normality, thereby supporting the validity of the inferential results obtained from the models. Furthermore, the explanatory power of the models was assessed using the marginal and conditional R^2 values (R^2m and R^2c). When significant effects were detected, estimated marginal means (EMMs) were computed for relevant interaction terms, and pairwise comparisons were conducted using Holm's correction to account for multiple testing.

All statistical analyses were conducted using R software (version 4.4.2) and RStudio (version 2024.12.0 + 467).

Results

Fig. 1 represents the distribution for each playing position. For improved visual representation, outlier points were not displayed in the boxplots, as the distributions were positively skewed with long tails.

Table 2 presents the median and IQR values for the distance, duration, AvgPmet, and number of HMLE & LMLE across different playing positions. Using the Pmet20 approach, during the HMLE, WMFs consistently exhibited higher values of AvgPmet, distance, and number of actions compared to other positions. Notably, CMFs showed higher AvgPmet ($p < 0.05$) than all other roles using the VO_2–Pmet approach. In the LMLE, similar trends were observed, with CMFs maintaining an elevated work rate and engagement. For both Pmet20 and VO_2–Pmet measures, significant differences were found across positions, particularly between CDs, FBs, and WMFs, as indicated by the superscript letters denoting pairwise comparisons.

Table 3 summarizes the median and IQR values for the distance, duration, AvgPmet, and number of actions during the HMLE and LMLE, comparing the first and second halves. Across both Pmet20 and VO_2–Pmet estimations, performance metrics were generally lower in the second half, particularly during the LMLE. Specifically, AvgPmet and the number of actions decreased significantly from the first to the second half in the HMLE for both methods ($p < 0.05$). These findings indicate that distance and duration of the LMLE increased in the second half while the intensity (AvgPmet) decreased.

Significant differences were also observed for AvgEC and TotalEC across positions and effort types. Using the Pmet20 approach, FWDs exhibited the highest AvgEC values during the HMLE, while CDs recorded the lowest. TotalEC during the HMLE was markedly greater for FWDs compared to other positions, reflecting their involvement in longer or more energetically demanding sequences. For the LMLE, AvgEC differences were less pronounced, although CMFs consistently displayed slightly higher values than CDs and FBs, suggesting greater energetic turnover even during lower-intensity phases. TotalEC during the LMLE was substantially higher for WMFs and FWDs, indicating prolonged recovery periods combined with intermittent activity. When using the VO_2–Pmet approach, AvgEC and TotalEC values increased across all positions compared to Pmet20, confirming that this method captures a broader spectrum of metabolic stress. Positional trends remained similar, with FWDs and CMFs showing the greatest energetic cost per effort.

LMM results for all dependent variables revealed significant differences for the fixed effects included (**Table 4**). Estimated marginal means for the fixed effects are provided in Supplementary File S1 (available in the online version only). The fixed effects explained 97, 99, and 92 % of the variance (R^2 marginal), while the full model, including random effects, explained 98, 99, and 95 % (R^2 conditional) for the variable distance, duration, and AvgMetPow, respectively.

Discussion

The primary aim of this study was to examine the positional differences in the intermittent nature of physical efforts during professional football match play and to compare two analytical approaches: one based on a fixed Pmet threshold (Pmet20), and another derived from the relationship between instantaneous oxygen consumption (VO_2–Pmet) and Pmet. The features defining the intermittent activity profile were characterized by the duration and intensity of both active efforts and recovery periods, which varied depending on the analytical method employed.

Traditionally, GPS-based tracking systems have utilized a fixed threshold of 25.5 W kg^{-1} to identify high-intensity efforts. This benchmark corresponds to running at a constant speed of 5.5 m s^{-1} (19.8 km h^{-1}) on grass and is widely recognized in the literature as a reference for high-speed running.[25] Moreover, high-magnitude accelerations and decelerations – such as an increasing speed from 2 to 4 m s^{-2} within 1 second — are typically included in high metabolic load distance analyses under this threshold.[26]

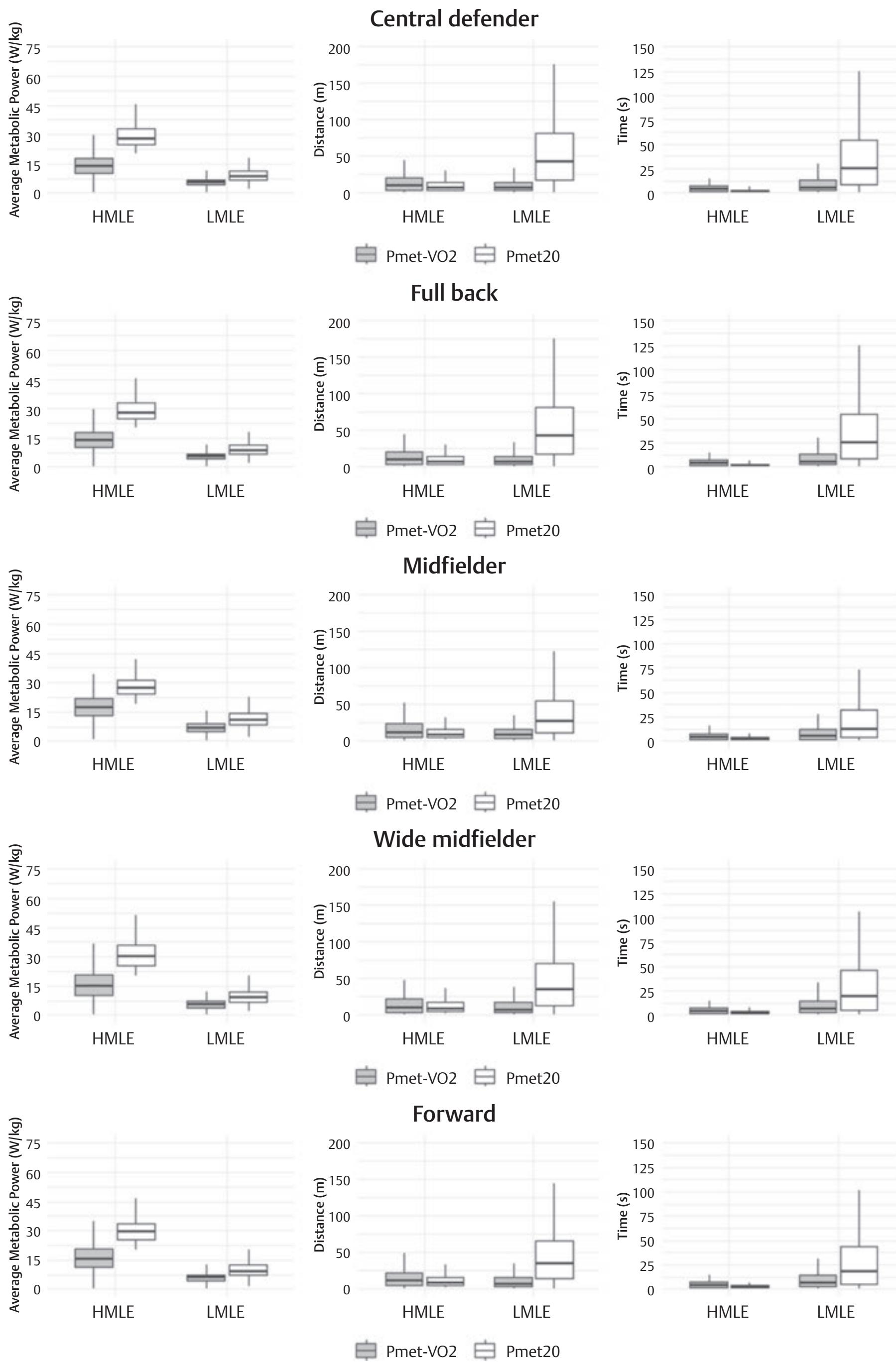

Fig. 1 Boxplots of the average metabolic power, distance, and duration for high and low metabolic load efforts across playing positions.

Beyond the Pmet, the inclusion of AvgEC and TotalEC provides additional insights into the energetic demands of match play. AvgEC reflects the intensity of individual efforts, while TotalEC captures the cumulative energy expenditure across sequences. Our findings indicate that FWDs and WMFs consistently exhibited the highest TotalEC values, suggesting greater overall energetic load despite similar or shorter durations compared to other positions.[27, 28] Conversely, CMFs displayed elevated AvgEC even during the LMLE, reinforcing their role in sustaining intermittent activity under moderate metabolic stress.[10] These metrics complement traditional power-based measures by highlighting not only the peak intensity but also the accumulated cost of repeated efforts, which has direct implications for recovery strategies and nutritional planning.[12, 24]

The present study employed more refined detection strategies to identify both high- and low-intensity efforts. The first approach

Table 2 Positional differences in distance, duration, AvgPmet and actions by the threshold type and the intensity of the actions

		HMLE										LMLE									
		CD		FB		MF		WMF		FWD		CD		FB		MF		WMF		FWD	
		Med	IQR	Med	IQR	Med	IQR	Med	IQR	Med	IQR	Med	IQR	Med	IQR	Med	IQR	Med	IQR	Med	IQR
Pmet20	Distance (m)	7.7	10.5	8.4[a]	12.3	8.1[a,b]	11.1	8.7[a,c]	12.7	8.5[a]	11.7	45.3	66.4	32.8[a]	51.8	27.3[a,b]	44.8	35.4[a,b,c]	59.3	35.1[a,b,c]	53.4
	Duration (s)	2.0	2.1	2.1[a]	2.3	2.1[a,b]	2.3	2.2[a,b,c]	2.3	2.1[a,c,d]	2.2	26.8	50.2	18.8a	39.4	12.1[a,b]	28.7	19.7[a,c]	43.3	18.6[a,c]	40.0
	AvgPmet (W/kg)	28.1	8.4	29.1[a]	8.8	27.4[a,b]	6.9	30.1[a,b,c]	10.2	29.3[a,c,d]	8.5	8.6	4.4	8.8[a]	5.2	11.1[a,b]	5.8	9.0[a,b,c]	5.2	9.3[a,b,c,d]	5.5
	Actions (n)	130.0	22.0	168.0[a]	20.5	217.0[a,b]	29.0	152.0[a,b,c]	17.0	150.0[a,c]	31.2	132.0	22.0	170.0[a]	20.5	219.0[a,b]	29.0	154.0[a,b,c]	18.0	152.0[a,c]	30.5
	AvgEC ($J\,kg^{-1}$)	5.30	2.21	5.48[a]	2.25	5.24[a,b]	2.03	4.91[a,b,c]	2.24	5.78[a,b,c,d]	2.24	4.81	1.34	4.84	1.33	4.87[a,b]	1.39	5.00[a,b,c]	1.53	4.78[a,b,c,d]	1.23
	TotalEC ($J\,kg^{-1}$)	50.2	79.4	51.7	82.6	50.4	79.9	49.8	77.3	56.2[a,b,d]	90.0	56.4	112.0	56.8	103.3	57.3	103.5	59.9	111.2	55.4[a,c,d]	100.2
VO_2–Pmet	Distance (m)	10.0	16.0	10.6[a]	16.9	11.9[a,b]	19.2	10.7[a,c]	17.4	11.2[a,b,c,d]	17.7	7.1	12.0	7.5[a]	12.5	8.0[a,b]	12.5	7.6[a,c]	13.8	7.8[a,c]	12.7
	Duration (s)	4.1	5.0	4.1	4.9	4.1	5.3	4.2	4.9	4.3[a,b]	5.1	5.7	11.0	6.1[a]	11.6	5.1[a,b]	9.9	6.3[a,c]	12.1	6.1[a,c]	11.5
	AvgPmet (W/kg)	14.0	7.8	15.7[a]	9.5	17.5[a,b]	8.4	15.2[a,b,c]	10.5	15.5[a,b,c,d]	9.4	5.5	2.9	5.6[a]	2.9	6.9[a,b]	4.1	5.7[a,c]	3.2	5.9[a,b,c,d]	3.3
	Actions (n)	377.0	25.0	367.0[a]	25.5	386.0[a,b]	35.0	353.0[a,b,c]	32.5	359.0[a,c]	28.2	377.0	24.0	367.0[a]	25.0	386.0[a,b]	34.5	354.0[a,b,c]	32.0	360.0[a,c]	27.8
	AvgEC ($J\,kg^{-1}$)	5.95	1.41	6.20a	1.59	6.09[a,b]	1.45	6.03[a,b]	1.70	6.04[a,b,c,d]	1.55	4.40	0.59	4.43	0.57	4.38[b]	0.70	4.45[a,b,c]	0.57	4.30[a,c,d]	0.56
	TotalEC ($J\,kg^{-1}$)	63.7	96.8	71.2[a]	108.1	78.3[a,b]	115.4	70.0[a,c]	113.1	73.3[a,c]	110.2	30.5	55.7	33.0[a]	58.9	34.1[a,b]	59.1	33.3[a]	65.1	33.6[a,c,d]	59.1

Abbreviations: AvgEC, average energy cost; AvgPmet, average metabolic power; CD, central defender; CM, central midfielder; FB, full back; FWD, forward wide defender; HMLE, high metabolic load efforts; IQR, interquartile range; LMLE, low metabolic load efforts; Med, median; MF, midfielder; Pmet20, the time integral of the power metabolic curve exceeded the threshold of 20 W/kg for at least 1 second; TotalEC, total energy cost; VO_2–Pmet, power metabolic requirements were higher than actual VO_2 consumption; WMF, wide midfielder.

[a]Significant differences ($p < 0.05$) with CDs.

[b]Significant differences ($p < 0.05$) with FBs.

[c]Significant differences ($p < 0.05$) with MFs.

[d]Significant differences ($p < 0.05$) with WMFs.

Table 3 Half differences in the distance, duration, AvgPmet and actions by the threshold type and the intensity of the actions

	Half	HMLE				LMLE			
		First		Second		First		Second	
		Med	IQR	Med	IQR	Med	IQR	Med	IQR
Pmet20	Distance (m)	8.2	11.5	8.1	11.4	33.4	51.9	35.5*	57.7
	Duration (s)	2.1	2.3	2.1	2.3	17.5	36.8	19.4*	42.9
	AvgMetPow (W/kg)	28.4	8.2	28.2*	8.1	9.6	5.5	9.3*	5.7
	Actions (n)	81.0	27.2	76.0*	27.0	82.0	27.2	77.0*	27.0
	AvgEC (J kg⁻¹)	5.4	2.2	5.4	2.2	4.9	1.4	4.8	1.4
	TotalEC (J kg⁻¹)	50.9	81.8	51.5	80.7	56.9	105.1	57.1	105.4
VO_2–Pmet	Distance (m)	11.1	17.4	10.4*	17.1	7.9	12.6	7.2*	12.3
	Duration (s)	4.1	5.0	4.0*	5.1	5.7	10.9	5.7*	11.2
	AvgMetPow (W/kg)	16.0	8.8	15.0*	9.3	6.1	3.3	5.6*	3.3
	Actions (n)	185.0	19.0	187.0	21.0	185.0	19.0	187.0	21.0
	AvgEC (J kg⁻¹)	6.1	1.5	6.0*	1.5	4.4	0.6	4.5*	0.6
	TotalEC (J kg⁻¹)	73.6	108.0	67.5*	106.2	34.3	59.1	30.7*	57.7

Abbreviations: AvgEC, average energy cost; AvgPmet, average metabolic power; HMLE, high metabolic load efforts; IQR, interquartile range; LMLE, low metabolic load efforts; Med, median; Pmet20, the time integral of the power metabolic curve exceeded the threshold of 20 W/kg for at least 1 second; TotalEC, total energy cost; VO_2–Pmet, power metabolic requirements were higher than actual VO_2 consumption.
*$p < 0.05$.

adopted a lower fixed threshold of 20 W kg^{-1}, which corresponds to an estimated VO_2 of approximately 57 ml kg^{-1} min^{-1} above resting values.[27] This threshold approximates the maximal oxygen uptake of a player weighing around 78 kg.[29] The second approach was based on the ratio of Pmet and instantaneous oxygen consumption (VO_2), offering insights into the predominant energy system (aerobic or anaerobic) supporting each activity.[16]

In both approaches, Pmet represents the total energy required per unit of time to resynthesize adenosine triphosphate (ATP), while instantaneous VO_2 reflects the oxidative (aerobic) contribution to ATP production. At any given time, VO_2 may exceed, match, or lag behind Pmet, as the kinetics of oxidative metabolism respond more slowly to changes in exercise intensity, following an exponential time course. Moreover, VO_2 can remain elevated during recovery due to phosphocreatine resynthesis (i.e., repayment of the oxygen debt), rather than being solely a consequence of this temporal lag. Consequently, when the Pmet exceeds VO_2, energy demands are primarily met through anaerobic pathways. Conversely, when VO_2 surpasses Pmet, aerobic metabolism is the dominant contributor.[16] This dual approach thus provides a more comprehensive depiction of energy system contributions and enables a more precise temporal analysis of metabolic load fluctuations throughout a football match.

Positional profiles based on the fixed Pmet20 model

When applying the fixed 20 W kg^{-1} threshold, the model selectively identifies actions that exceed a relatively high absolute metabolic limit. As a result, it primarily captures brief, high-intensity movements characterized by elevated running speeds or accelerations, which are inherently difficult to sustain over time or may be tactically unnecessary in certain phases of play.

Within this analytical framework, players spent between 7 % (CD) and 15 % (CMF) of the total match time performing high-intensity efforts, covering 14–23 % of the total distance during these periods. These values are notably lower than those reported by Osgnach et al.,[27] who estimated that high-intensity efforts accounted for 26 % of the total distance and 42 % of the overall energy cost. HMLE durations were relatively homogeneous across positions (~2.00–2.20 s). However, the intensity of these efforts varied, with WMFs displaying the highest average value (30.10 W kg^{-1}) and CMFs displaying the lowest value (27.40 W kg^{-1}), likely reflecting differences in tactical responsibilities or individual physical capacity. WMFs and FWDs covered the greatest distance per action, whereas CDs covered the least, consistent with previous findings.[30–32]

During lower-intensity phases, positional differences became even more pronounced. CDs recorded the longest average duration per LMLE (26.80 s), while CMFs exhibited the shortest (12.10 s), aligning with the findings of Carling et al.[10] Notably, CMFs also demonstrated the highest LMLE intensities (11.10 W kg^{-1}), whereas FBs and CDs showed the lowest values (8.59–8.83 W kg^{-1}). These results suggest that CMFs experience greater energetic demands even during lower-intensity phases, likely due to their dual role in both offensive and defensive transitions.

Overall, CMFs exhibited the most intermittent activity profile, recording 219 efforts per match (~2.43 actions/min), likely due to their strategic role in linking play and managing transitions. In contrast,

Table 4 Linear mixed model results for the distance, duration, and average Pmet

	Distance (*m*)					Duration (*s*)					Avg Met Pow (W/kg)				
	Estimate	Std error	df	*t* Value	*p*-Value	Estimate	Std error	df	*t* value	*p*-value	Estimate	Std. Error	df	*t* value	*p*-value
Intercept	795.66	51.42	15.31	15.48	<0.001***	162.30	5.16	563.71	31.49	<0.001***	2093.83	70.15	12.05	29.85	<0.001***
Type: VO_2–Pmet	1875.02	10.29	2105.09	182.23	<0.001***	771.74	4.35	2120.95	177.35	<0.001***	556.70	13.15	2099.52	42.35	<0.001***
Activity: LMLE	3183.33	14.82	2105.33	214.74	<0.001***	2503.59	6.27	2121.93	399.39	<0.001***	−1360.00	18.94	2099.77	−71.80	<0.001***
Position: FB	249.51	63.10	13.57	3.95	0.002**	12.77	5.79	2148.84	2.21	0.027*	432.54	86.50	10.89	5.00	<0.001***
Position: MF	593.79	65.99	13.55	9.00	<0.001***	89.87	5.89	2144.83	15.27	<0.001***	929.68	90.47	10.88	10.28	<0.001***
Position: WMF	110.68	73.43	15.41	1.51	0.152	−1.59	8.60	2166.17	−0.18	0.854	235.80	100.24	12.25	2.35	0.036*
Position: FWD	230.48	63.50	15.57	3.63	0.002**	22.28	8.22	2169.51	2.71	0.007**	376.59	86.66	12.32	4.35	0.001***
Match half: Second half	−53.44	7.30	2105.46	−7.32	<0.001***	82.74	3.09	2122.51	26.80	<0.001***	−152.34	9.33	2099.91	−16.33	<0.001***
Threshold type (VO_2–Pmet): Activity (LMLE)	−3752.73	14.60	2105.23	−257.07	<0.001***	−1537.79	6.17	2121.51	−249.10	<0.001***	−259.36	18.65	2099.66	−13.91	<0.001***
Activity (LMLE): Position (FB)	−260.10	19.24	2105.08	−13.52	<0.001***	−25.29	8.14	2120.92	−3.11	0.002**	−328.57	24.58	2099.52	−13.37	<0.001***
Activity (LMLE): Position (MF)	−236.92	19.67	2105.22	−12.05	<0.001***	−182.54	8.32	2121.44	−21.95	<0.001***	−422.29	25.13	2099.66	−16.81	<0.001***
Activity (LMLE): Position (WMF)	−132.83	28.42	2105.10	−4.68	<0.001***	6.83	12.02	2120.97	0.57	0.570	−224.35	36.31	2099.53	−6.18	<0.001***
Activity (LMLE): Position (FWD)	−185.95	27.01	2105.11	−6.89	<0.001***	−48.74	11.42	2120.90	−4.27	<0.001***	−222.71	34.51	2099.55	−6.45	<0.001***

Abbreviations: AvgPmet, average metabolic power; CM, central midfielder; df, degrees of freedom; FB, full back; FWD, forward wide defender; LMLE, low metabolic load efforts; Std error, standard error; VO_2–Pmet, power metabolic requirements were higher than actual VO_2 consumption; WMF, wide midfielder.

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

CDs recorded the fewest efforts per minute (1.46), consistent with their more static positional role and primarily reactive demands.

HMLE distances declined slightly from 8.21 to 8.05 m in the second half, primarily due to a minor reduction in intensity (28.40 to 28.20 W kg^{-1}), while effort durations remained stable (~2.10 s). Conversely, LMLE distances increased (33.40 m to 35.50 m), attributed to prolonged durations (17.50 to 19.40 s) and marginally decreased intensities (9.62 to 9.25 W kg^{-1}). This pattern may reflect players' self-regulation strategies to conserve energy and mitigate fatigue, as proposed by Edwards and Noakes,[33] but also underlying physiological fatigue mechanisms. Depletion of muscle glycogen and central fatigue could contribute to the observed decreases in effort intensity and number of actions, limiting the ability to sustain repeated high-intensity efforts over time. A decline in the total number of efforts, from 81 to 76, further supports the notion of reduced high-intensity output over time.

Positional profiles based on the VO_2–Pmet model

Using the VO_2–Pmet approach, HMLEs were considerably longer (~4.1–4.3 s) compared to those identified using the fixed threshold model. CMFs recorded the highest average intensities (17.50 W kg^{-1}), while CDs recorded the lowest value (14.00 W kg^{-1}). Distance covered during these efforts followed a similar trend, with CMFs leading (11.90 m) and CDs trailing (9.98 m).

Regarding the LMLE, durations ranged from 5.10 seconds (CMF) to 6.30 seconds (WMF), potentially reflecting distinct recovery needs or tactical involvement. CMFs again demonstrated the highest intensities during the LMLE (6.86 W kg^{-1}), whereas CDs showed the lowest value (5.52 W kg^{-1}), reinforcing the notion that midfield roles require elevated energetic and spatial demands.

The frequency of the HMLE further supports these patterns: CMFs averaged 386 actions per match (~4.28 actions/min), closely followed by CDs (377; ~4.18/min). WMFs recorded the lowest frequency (~3.92/min), likely due to longer recovery times between high-intensity efforts. These findings are consistent with those of Bortnik et al.,[34]

Both HMLE and LMLE durations remained stable between halves (~4.10 s and ~5.70 s, respectively), with the total number of actions unchanged (185 in each half). However, intensities decreased in both phases: from 16.00 to 15.00 W kg^{-1} (HMLE) and 6.08 to 5.61 W kg^{-1} (LMLE), leading to reduced distance covered (11.10 to 10.40 m in the HMLE and 7.94 to 7.15 m in the LMLE). Although these data suggest a slight decline in match intensity, further analysis — including technical actions such as passes or shots — is needed to fully interpret performance dynamics.[35]

Interpretation of the analytical approaches and methodological considerations

When comparing both analytical models, clear methodological and practical differences emerge. The Pmet20 method, by setting a fixed metabolic threshold, selectively identifies brief and intense actions involving higher running speeds or accelerations. In contrast, the VO_2–Pmet approach captures a broader spectrum of efforts that reflect the fluctuating aerobic–anaerobic interplay characteristic of football.

The VO_2–Pmet model yielded approximately twice longer HMLE durations (~4.1 s vs. ~2.1 s) and a greater total time spent in high-intensity activity (≈ 58–60 % of match time) compared to the Pmet20 method (7–15 %). These discrepancies underscore how threshold selection substantially influences the interpretation of match demands. The VO_2–Pmet approach suggests that players operate under sustained metabolic stress even at moderate speeds, due to frequent accelerations and decelerations.

This broader detection aligns with research showing that anaerobic pathways contribute significantly to the total match expenditure,[28] reinforcing the importance of conditioning programs that integrate both high-intensity efforts and recovery strategies. These results emphasize the importance of carefully defining 'high-intensity' activity. Just as traditional metrics based on speed alone may underestimate certain game actions, the VO_2–Pmet approach — because it accounts for frequent accelerations and decelerations — may classify certain moderate-intensity actions as metabolically demanding. Previous research[12,16] has noted that this method can sometimes attribute higher energetic cost to actions with repeated changes of direction, which might not fully correspond to actual anaerobic contribution. Therefore, this should be considered a potential limitation when interpreting results.

Given the variability in tactical formations and in-game strategies, analyzing intermittent match demands by positional roles within different tactical contexts may enable practitioners to better tailor training loads.[28] It is important to note, however, that Pmet calculations only account for horizontal locomotion and exclude vertical movements. For example, although CDs displayed the lowest distances during high-intensity phases, their match activity includes non-locomotor actions — such as aerial duels, physical challenges, and technical interventions — that contribute significantly to the energy expenditure but remain unaccounted for in current Pmet models.[36] The same limitation applies when performance is described solely through distance- or speed-based metrics, which also fail to capture the energetic cost of these non-locomotor actions.

Moreover, due to the inherently intermittent nature of team sports,[37,38] relying solely on average values may underestimate true match demands. Designing training tasks based on such averages may result in under-preparation. Considering that peak load periods may comprise a combination of both HMLE and LMLE characteristics, identifying and replicating that these most demanding phases are crucial for the development of ecologically valid training scenarios.[39]

Finally, while this study provides a novel and detailed analysis of intermittent match profiles, it is not without limitations. The sample size was relatively small and drawn from a single First Division club in Cyprus, which may limit the generalizability of the findings to other contexts. This study was also limited to a single season, which might not reflect variability in physical demands across different competitive periods or long-term adaptations. In addition, the number of valid observations differed across playing positions, reflecting the natural variability in player availability and match participation throughout the season. This unbalanced distribution may have influenced the statistical power of some positional comparisons, and this limitation should be considered when interpreting the results. It is also important to note that, although the selected thresholds for Pmet and VO_2–Pmet are supported by previous research, they may not precisely reflect individual physiological profiles, and alternative thresholds could produce different outcomes. Contextual variables — such as the match outcome, opponent strength, or match location — were not considered in the present study; yet, they may substantially influence intermittent performance.[2] Similarly, tactical variability, such as employing a high-pressing versus a low-block strategy, can affect the frequency, duration, and intensity of HMLE and LMLE. Together, these factors highlight that match demands are context-dependent, and the observed profiles may differ under alternative competitive or tactical scenarios. Moreover, the findings are specific to professional male players in the First Division. Future research should investigate how these intermittent profiles evolve throughout a season and whether they reflect training adaptations, competitive context, or tactical models. It is important to note that missing data points were excluded rather than replaced with zeros, as even a single erroneous value can substantially affect average Pmet calculations in high-frequency datasets.

Conclusions

This study provides valuable insights into the intermittent nature of physical efforts in professional football, emphasizing significant positional differences and the influence of analytical methodology on performance interpretation. Importantly, the findings highlight the critical role of both aerobic and anaerobic systems in football performance. This integrative approach can provide a more complete picture of a player's conditional performance, extending beyond traditional external load metrics. Moreover, the findings suggest that training should not only focus on average demands but also consider peak efforts and the most demanding passages of play. This approach ensures that players are adequately prepared for the highest-intensity periods of a match, reducing the risk of fatigue and injury. Beyond Pmet, incorporating energy cost metrics (AvgEC and TotalEC) provides a more comprehensive understanding of match demands. AvgEC reflects the intensity of individual efforts, while TotalEC captures the cumulative energetic load, which is essential for optimizing recovery and nutritional strategies.

Practical applications

From a practical perspective, the results can be directly applied to the development of training programs tailored to the specific intermittent profiles of each playing position. For instance, CMFs displayed the highest number of HMLEs (~386 actions per match, VO_2–Pmet), corresponding to ~4.0–4.2 actions per minute. Training for this position should emphasize repeated sprint drills with short recovery (~1:1 work-to-rest ratio) to reflect the frequent high-intensity efforts and rapid recovery required in match play. In contrast, CDs performed a similar total number of LMLEs (~377 actions), but with longer durations per effort (~5.7 s), suggesting that drills for defenders should include longer, moderate-intensity efforts with slightly extended recovery periods to mimic sustained defensive actions. These examples illustrate how applying either HMLE or LMLE data from the VO_2–Pmet model allows coaches to structure drills that are more representative of position-specific demands. Furthermore, the data suggest that training prescription should not rely solely on average match demands but should also take into account periods of peak effort and the most demanding phases of play. This applies not only to traditional physical metrics, but also to intermittent activity profiles, which capture the duration, frequency, and distribution of both high- and low-intensity efforts. Preparing players for these high-intensity episodes can help reduce the risk of fatigue and injury while optimizing performance during decisive moments. In summary, this study provides a robust framework for characterizing the intermittent demands of match play and presents actionable recommendations for tailoring training loads based on the position, intensity, and metabolic profile. Such an approach may help practitioners design more effective and individualized training programs that better reflect the true demands of competition. Using AvgEC and TotalEC can help practitioners adjust training loads not only based on the intensity but also on the accumulated energetic cost, guiding session design, energy replenishment, and fatigue management.

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Statements and Additional Information

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