

Adaptive pacing and fatigue management in Thai premier league soccer: a GPS-based analysis of match demands

Wattana Nuttouch^{1ABCD}, Palakorn Nakarabandid^{2BC}, Pattarawut Khaosanit^{3BC},
Tachapon Tongterm^{4ACD}

¹ Division of Sports Science, Faculty of Science, Pitchaya bandit College, Thailand

² Division of Physical Education, Faculty of Education, Songkhla Rajabhat University, Thailand

³ Faculty of Sports Science, Chulalongkorn University, Thailand

⁴ Division of Sports Science, Faculty of Liberal Arts and Science, Sisaket Rajabhat University, Thailand

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Abstract

Background and Study Aim Soccer is characterized by continuous alternation between high-intensity efforts and recovery phases, requiring players to sustain repeated sprints, accelerations, and directional changes. Managing fatigue effectively during these demanding actions helps maintain performance throughout a match. Although Global Positioning System (GPS) technology is widely applied to quantify external workload in elite sports, its relative effectiveness in assessing pacing and match intensity under tropical conditions remains a subject of practical interest. The aim of this study was to examine half-time differences, analyze intensity-zone distribution, and test the adaptive pacing hypothesis in professional soccer players.

Material and Methods Sixteen male players from Rajpracha Football Club (N = 16; mean age = 27.7 ± 1.34 years; BMI = 21.1 ± 1.75 kg/m²) were monitored across 22 official matches. Variables included total distance covered (TDC), distances across five intensity zones (Zones 1–5), and sprint-related metrics. Paired t-tests and one-way ANOVA with Tukey's post hoc comparisons (p < 0.05) were applied. Effect sizes (Cohen's d) were calculated to assess practical significance.

Results The findings confirmed the adaptive pacing hypothesis. A large and significant reduction was observed in TDC and submaximal running (Zones 1–3) during the second half (Cohen's d ≈ 0.96), while high-speed running (Zones 4–5) and sprint metrics remained stable. Positional heat maps revealed distinct workload profiles corresponding to the tactical roles of defenders, midfielders, and forwards.

Conclusions Thai professional players demonstrated advanced behavioral and physiological adaptation by regulating effort to preserve decisive high-intensity performance under tropical fatigue conditions. These results provide baseline evidence for the Thai Premier League and highlight a pedagogical need for situational pacing instruction and position-specific conditioning programs. Such programs should emphasize the quality of high-intensity effort rather than total volume. Future studies should integrate internal physiological indicators and predictive analytics to optimize workload management in professional soccer.

Keywords: adaptive pacing, GPS-based workload, Thai Premier League, high-speed running, pedagogical application

Introduction

The modern game of soccer has evolved into a global cultural and athletic phenomenon that demands not only technical and tactical excellence but also well-developed physiological adaptability. Over the past two decades, the sport has shifted toward faster transitions, a higher tempo, and more dynamic phases of play. Players are required to repeatedly perform accelerations, sprints, and directional changes within limited recovery intervals. This intermittent physiological structure challenges both aerobic and anaerobic systems,

where efficient energy turnover and fatigue resistance are essential for sustaining performance [1, 2]. Continuous alternation between high- and low-intensity activities requires advanced neuromuscular coordination, metabolic flexibility, and cognitive anticipation, which together contribute to maintaining performance stability under competitive stress. Recent evidence also shows that seasonal variations in match intensity are closely linked to GPS-derived workload data, reflecting the evolving physiological demands of the modern game [3]. Therefore, the ability to monitor and manage these demands has become a central component of applied sports science, combining physical, psychological, and tactical data to optimize player development and match readiness.

In this context, Global Positioning System (GPS) technology has transformed performance analysis by providing a precise and objective method for quantifying physical workload in competitive soccer. Through continuous high-frequency data capture, GPS devices measure total distance covered, sprint frequency, and movement intensity across predefined velocity zones [4]. Recent advances in wearable sensor design and integration with video-tracking systems have improved the accuracy of movement detection and contextual interpretation [5, 6]. These external load parameters act as key indicators of physiological stress during match play, allowing practitioners to identify pacing strategies, fatigue accumulation, and movement efficiency. GPS data also serve as a pedagogical tool that supports evidence-based coaching. When interpreted appropriately, GPS-derived metrics help in individualized load planning, recovery optimization, and the development of tactical awareness through reflective feedback [7]. The integration of such data-driven approaches enhances athletes' ability to self-regulate effort and maintain performance quality in competitive settings.

Analysis of research findings has shown that physical workload monitoring through GPS technology provides valuable insights into the physiological and tactical dimensions of modern soccer. Researchers emphasize that understanding pacing behavior, fatigue regulation, and performance maintenance under varying environmental and competitive conditions remains essential for optimizing training processes. Despite growing attention to workload quantification, there is still a need to refine approaches that integrate external load metrics with behavioral and contextual factors influencing player performance. At the same time, despite substantial growth in GPS-based research, most evidence remains concentrated in European leagues, where environmental and tactical conditions differ markedly from those of tropical regions. This geographic imbalance limits the generalizability of findings and overlooks the unique physiological and cultural challenges inherent to Asian competitions. Professional soccer in Southeast Asia, particularly the Thai Premier League, is played under conditions of high temperature and humidity that intensify fatigue and influence pacing behavior [8]. Concurrently, the Thai league has undergone significant professionalization and commercial development in recent years [9], yet scientific analyses addressing its specific match demands remain scarce. Furthermore, methodological issues such as position-specific reference values and individualized load benchmarking, which are increasingly emphasized in elite contexts [10], have received little attention in Thai soccer research.

Given the specific climatic and tactical context of Thai professional soccer, a detailed assessment

of physical workload patterns can provide valuable insight into how players regulate intensity throughout a match. Building upon this perspective, the aim of this study was to examine half-time differences, analyze intensity-zone distribution, and test the adaptive pacing hypothesis in professional soccer players.

Materials and Methods

Participants

Sixteen professional male soccer players from Rajpracha Football Club were included in the study (mean age = 27.7 ± 1.34 years; BMI = 21.1 ± 1.75 kg/m²). The sample size ($n = 16$) and the number of monitored matches ($N = 22$) were consistent with methodological standards reported in previous elite-level team sport analyses [11]. The inclusion of a single club was justified as a robust case study because of the team's consistent tactical framework, competitive stability, and uniform data collection procedures. All players participated in the Thai national soccer league during the 2022 season. Each athlete provided written informed consent before participation. The study protocol was reviewed and approved by the Human Research Ethics Committee of Walailak University (WUEC-22-286-01), ensuring compliance with the Declaration of Helsinki and the ethical standards of human research integrity.

Study Design

Data Collection Procedure

This investigation used an observational and quantitative repeated-measures design to examine the physical demands of professional soccer under real competitive conditions. Match activity data were collected across twenty-two official fixtures of the Thai national soccer league during the 2022 season. This study involved a secondary analysis of a dataset previously collected for baseline positional profiling [12]. The primary aim was to analyze physical demands using Global Positioning System (GPS) technology and to compare performance variables between the first and second halves of matches, focusing on adaptive pacing strategies. The average environmental conditions across the twenty-two match days were recorded using official meteorological data. The mean ambient temperature was $30.2 \pm 2.1^\circ\text{C}$, and the relative humidity was $74 \pm 6\%$. These data confirmed that all matches were played in tropical, hot, and humid environments, consistent with evidence that heat stress can accelerate fatigue accumulation during soccer play [8].

Player movements were recorded using portable GPS devices (SPI HPU, GPSports Systems, Catapult Sports, Australia) operating at 5 Hz, with interpolation to 15 Hz via the manufacturer's cubic spline algorithm to improve the precision of

instantaneous velocity estimation [13]. Each GPS unit was placed in a specialized elastic vest (K-Shirt) to ensure stability during rapid movements. To maintain intra-individual reliability, each player used the same GPS unit throughout all monitored matches. The GPS system recorded total distance covered (TDC), total sprint distance (TSD), number of sprints (ToS), maximum speed (TMS), and distance covered across five predefined intensity zones: Zone 1 (1.0–5.99 km/h), Zone 2 (6.0–10.99 km/h), Zone 3 (11.0–15.49 km/h), Zone 4 (15.5–19.9 km/h), and Zone 5 (>20 km/h), following professional match analysis conventions (Bradley et al., 2009). A sprint was defined as any running action exceeding 20 km/h for at least one second with acceleration greater than 2 m/s² [14].

After each match, raw GPS data were downloaded and processed using Team AMS software (Catapult Sports, Australia). Data were excluded if the Horizontal Dilution of Precision (HDOP) exceeded 1.5 or if signal loss occurred. Valid datasets were retained for analysis, and positional spatial distributions were generated using the Field Viewer module (Catapult Sports, Australia) with a grid resolution of 5 m × 5 m to ensure consistent visualization quality across all matches.

Statistical Analysis

All statistical analyses were conducted using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were expressed as mean ± SD. Data normality was assessed using the Shapiro–Wilk test, and extreme values were managed by the winsorization method (±3 SD). Paired t-tests were used to compare first- and second-half performance variables, including total distance, sprint distance, sprint frequency, and maximum speed. One-way analysis of variance (ANOVA) with Tukey’s post

hoc test was applied to examine differences across intensity zones (Zones 1–5). Statistical significance was set at $p < 0.05$ with 95% confidence intervals. Effect sizes (Cohen’s d) were calculated to determine the magnitude of meaningful differences and to support the interpretation of practical significance. The anonymized raw and processed GPS dataset supporting this study’s findings is available upon reasonable request from the corresponding author in .csv format for verification and replication.

Results

The analysis revealed consistent physiological and workload patterns across all observed matches. Statistical comparisons showed significant reductions in total and submaximal running distances between halves, while sprint-related variables remained stable. These findings indicate an adaptive pacing mechanism characterized by selective regulation of physical effort under tropical match conditions. Detailed results are presented in Tables 1–3 and Figures 1–3, which illustrate the distribution of workload intensity, spatial movement patterns, and positional adaptations across match halves.

1. Total Distance Covered and Sprint-Related Variables

A significant reduction in total distance covered (TDC) was observed between halves ($p = 0.03$), as shown in Table 1 and Figure 1. The effect size was large (Cohen’s $d = 0.96$), confirming a meaningful reduction in overall running volume. Conversely, no significant changes were found in high-intensity metrics, including total sprint distance (TSD), number of sprints (ToS), and maximum speed (TMS) (all $p > 0.05$). These findings indicate that while total workload decreased, players successfully maintained

Table 1. Comparison of total and sprint-related variables between match halves.

| Variable | First half (Mean ± SD) | Second half (Mean ± SD) | p-value |
|---------------------------------|------------------------|-------------------------|---------|
| Total distance covered (TDC, m) | 4,070.24 ± 856.86 | 3,270.99 ± 805.50 | 0.03* |
| Total sprint distance (TSD, m) | 32.19 ± 15.77 | 31.08 ± 15.81 | 0.35 |
| Number of sprints (ToS) | 11.11 ± 3.95 | 10.87 ± 2.81 | 0.14 |
| Maximum speed (TMS, km/h) | 26.66 ± 3.39 | 25.63 ± 4.91 | 0.14 |

Note: Values are Mean ± SD. * $p \leq 0.05$ indicates a statistically significant difference between halves. TDC = total distance covered; TSD = total sprint distance; ToS = number of sprints; TMS = total maximum speed.

Table 2. Overall distribution of running distances by intensity zone.

| Zone of intensity | Distance (m, Mean ± SD) | Relative distance (m/min, Mean ± SD) |
|-------------------|-------------------------|--------------------------------------|
| Zone 1 | 2,779.00 ± 459.36 | 20.14 ± 2.99 |
| Zone 2 | 2,384.38 ± 289.24 | 26.68 ± 3.09 |
| Zone 3 | 773.15 ± 136.56 | 6.02 ± 1.07 |
| Zone 4 | 254.52 ± 74.60 | 2.20 ± 0.64 |
| Zone 5 | 57.31 ± 26.64 | 0.07 ± 0.02 |

Note: Values are Mean ± SD. Running distances are reported across five intensity zones. $p \leq 0.05$.

Table 3. Comparison of distances across intensity zones between halves.

| Zone of intensity | First half (Mean ± SD) | Second half (Mean ± SD) | p-value | 95% CI (Lower–Upper) |
|-------------------|------------------------|-------------------------|---------|----------------------|
| Zone 1 (m) | 1,777.00 ± 85.51 | 1,487.00 ± 80.38 | 0.02* | -526.90 – -53.25 |
| Zone 2 (m) | 1,608.00 ± 71.56 | 1,201.00 ± 61.83 | 0.00* | -597.60 – -215.90 |
| Zone 3 (m) | 495.60 ± 24.34 | 410.60 ± 23.53 | 0.02* | -153.30 – -16.63 |
| Zone 4 (m) | 156.40 ± 10.72 | 140.20 ± 10.12 | 0.28 | -45.98 – 13.74 |
| Zone 5 (m) | 33.79 ± 3.49 | 32.38 ± 3.46 | 0.78 | -11.33 – 8.52 |

Note: Values are Mean ± SD. CI = confidence interval. *p ≤ 0.05 indicates a statistically significant difference between halves.

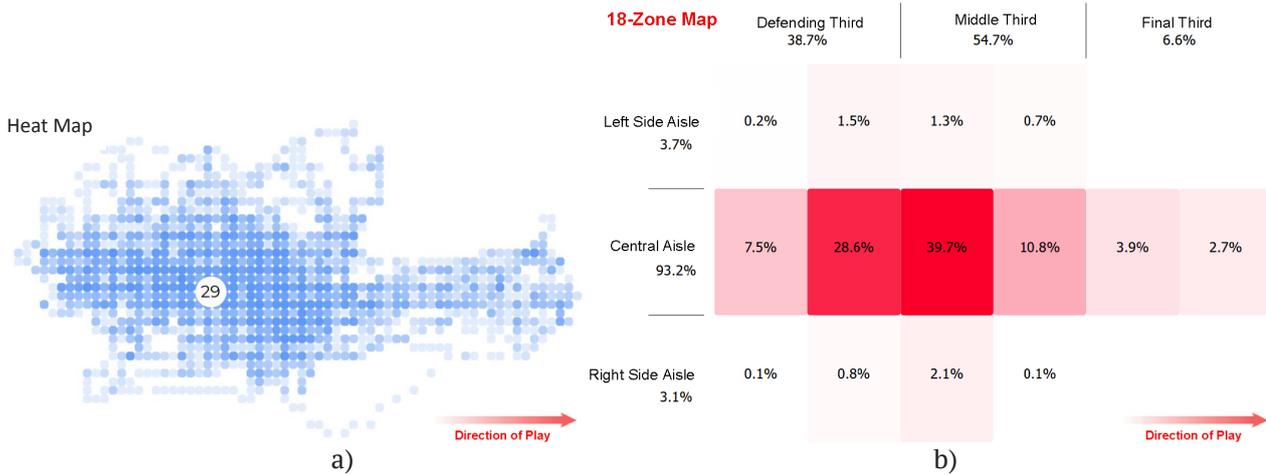


Figure 1. Heat map and 18-zone activity distribution of defenders, showing high concentration in the defensive and central thirds of the field.

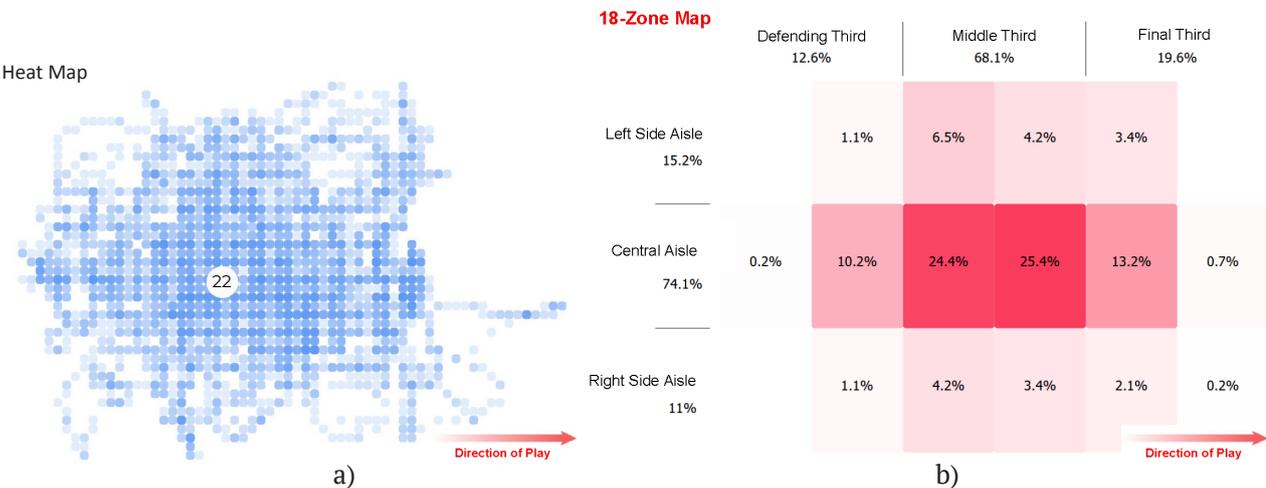


Figure 2. Heat map and 18-zone activity distribution of midfielders, with dominant movement in the middle third and balanced coverage across lateral corridors.

sprint capacity and peak speed, suggesting efficient energy management under competitive conditions.

2. Adaptive Pacing Strategy Across Intensity Zones

The distribution of running distances across five predefined intensity zones is summarized in Table 2, with half-time comparisons presented in Table 3 and visualized in Figures 2–3. Most activity occurred in low-intensity zones (Zones 1–2), accounting for nearly 80% of total movement and confirming

the predominance of aerobic metabolism during match play. Significant reductions were observed in the lower intensity zones (Zones 1–3), while no significant differences were found in higher intensity zones (Zones 4–5). This indicates that players selectively reduced low-to-moderate intensity efforts while maintaining high-speed running, reflecting an adaptive pacing response to accumulated fatigue and environmental stress. As shown in Figures 1–3, the spatial and intensity-

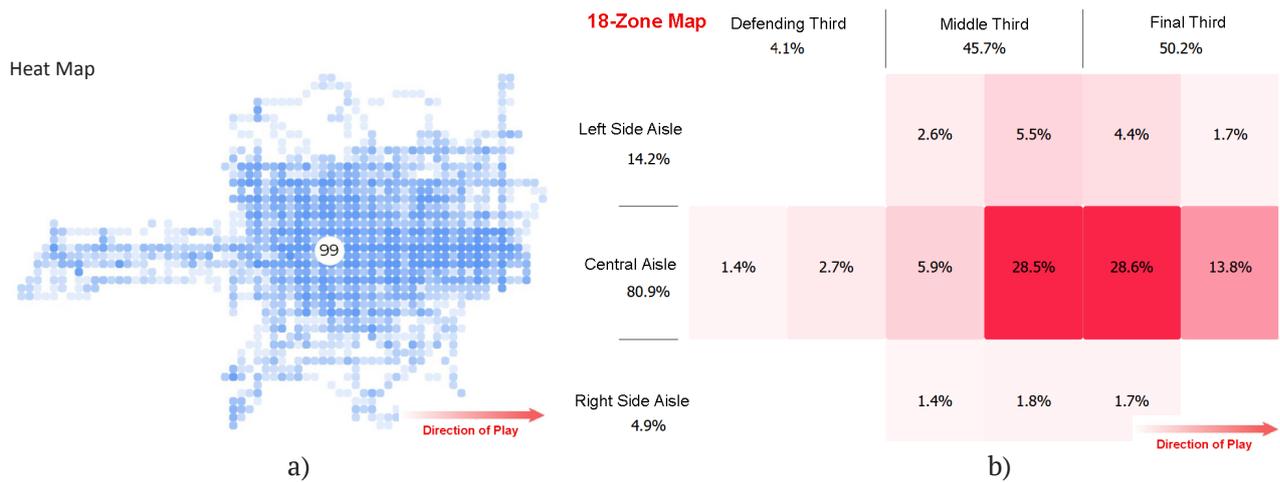


Figure 3. Heat map and 18-zone activity distribution of forwards, indicating activity focused in the attacking and wide areas.

related analyses provide visual confirmation of the quantitative results. The 18-zone maps (Figures 1a, 2a, and 3a) demonstrate that player activity was primarily concentrated in the central and middle thirds of the field, highlighting controlled positional play and efficient use of space. Corresponding heat maps (Figures 1b, 2b, and 3b) reveal dense activity clusters within these areas, reflecting players' tendency to conserve energy by limiting unnecessary off-ball movement while maintaining tactical balance. Collectively, these spatial patterns illustrate an adaptive pacing response under tropical match conditions, where players strategically adjusted movement intensity to preserve high-speed performance and sustain overall effectiveness throughout the match.

Overall, the findings revealed a significant reduction in total distance and low-to-moderate intensity activity between halves, while sprint-related and high-speed efforts were maintained. These outcomes confirm that players used adaptive pacing, strategically adjusting workload to sustain decisive actions despite accumulating fatigue. The evidence shows that Thai professional players effectively managed physical and cognitive demands under tropical environmental stress, providing a solid empirical basis for further pedagogical and physiological interpretation.

Discussion

The present study aimed to examine half-time differences, analyze intensity-zone distribution, and test the adaptive pacing hypothesis in professional soccer players competing under tropical environmental conditions. The analysis revealed significant reductions in total and submaximal running distances between halves, while sprint-related and high-speed efforts were maintained. These results confirm the presence of an adaptive pacing mechanism, indicating

that players strategically regulated their physical output to preserve decisive actions despite fatigue accumulation. The observed spatial and intensity-related patterns further demonstrated that Thai professional players effectively managed physical and cognitive demands, maintaining tactical stability and performance efficiency throughout the match.

The significant reduction in total distance covered during the second half (Cohen's $d \approx 0.96$) confirms that Thai professional players experienced progressive fatigue over the course of the match. However, the stability of sprint distance, sprint frequency, and maximum speed indicates that players maintained their ability to perform decisive high-intensity actions even under fatigue. This reflects a deliberate redistribution of physical effort rather than a simple physical decline. In line with the adaptive pacing model, athletes appear to regulate running intensity strategically, reserving metabolic energy for critical phases of the game [15]. From a physiological perspective, this balance between conserving energy and producing explosive actions demonstrates effective self-regulation of aerobic and anaerobic systems, allowing players to sustain performance efficiency throughout the match.

When compared with international standards, the total running distance recorded in this study was lower than values typically reported in European professional leagues [16]. However, this should not be interpreted as evidence of inferior physical conditioning but rather as a rational adjustment to local environmental and tactical contexts. Matches were played under tropical heat averaging 30.2 °C and humidity exceeding 70%, conditions known to accelerate cardiovascular strain and glycogen depletion [8]. Under such circumstances, players likely adapt by minimizing unnecessary low-intensity movements to prevent early exhaustion

while maintaining energy reserves for high-speed play. The pattern observed in this dataset therefore represents optimized pacing behavior shaped by the climatic and tactical realities of Thai soccer.

The analysis across intensity zones supports the existence of the adaptive pacing mechanism. Distances in Zones 1–3 declined significantly between halves, while Zones 4 and 5, representing high-speed and sprint activities, remained statistically unchanged. This selective adjustment suggests that players consciously reduced submaximal efforts to preserve the physiological and cognitive resources necessary for sprinting. In modern soccer, this reflects a dynamic interaction between physical capacity and tactical decision-making, where players continuously assess energy expenditure in relation to situational demands [17]. Rather than representing fatigue-induced decline, this controlled modulation of pace reveals an advanced behavioral adaptation that enables players to sustain performance quality throughout the match.

From a pedagogical perspective, these findings emphasize the importance of incorporating pacing education into training programs. Coaches and conditioning staff should use GPS-derived data not only as performance tracking tools but also as instructional resources to teach players energy regulation and situational awareness. Training should prioritize the quality of effort over total volume, replicating match-specific fatigue profiles to build tolerance for maintaining sprint output under constrained conditions. Periodization strategies should include sessions that reproduce the physical decay observed after halftime while reinforcing the cognitive skills required to judge when and how to perform high-intensity actions [18]. This approach aligns with the pedagogical trend toward ecologically valid training design, where the objective is to simulate realistic decision–action couplings rather than isolated physical drills.

The heat maps revealed clear positional differences consistent with tactical specialization. Defenders primarily operated within the defensive and middle thirds, engaging in short, controlled movements associated with positional discipline and recovery actions. Midfielders displayed broader spatial coverage across central corridors, reflecting their transitional role in linking defense and attack, while forwards concentrated their activity in attacking zones, executing repeated high-speed actions near the opponent's goal. These spatial distinctions confirm that physical demands are role-dependent and cannot be generalized across positions. Recognizing these unique movement patterns enables coaches to design position-specific conditioning programs that replicate the

physiological load and tactical responsibilities of each role [12].

The practical value of these results lies in their application to tactical organization and match management. Knowledge of where and when players engage in high-intensity actions helps coaches plan substitutions more effectively, structure recovery periods, and balance training loads according to positional roles. Using GPS data alongside tactical observations allows for a more precise interpretation of player activity during different phases of the game. In the context of Thai professional soccer, such data serve as a starting point for building practical models that reflect real playing conditions and support informed coaching decisions.

The study confirmed that Thai professional soccer players adjust their pacing according to the tactical flow of the game and the challenges of a tropical environment. Despite a reduction in total running distance, the players maintained sprint capacity and high-intensity actions, demonstrating an effective balance between effort and recovery. These outcomes highlight a functional adaptation that allows athletes to sustain performance quality under heat stress. The findings can be used by coaches to design training sessions that reflect match-specific fatigue patterns and promote efficient energy management throughout competition.

Limitations and Future Research

While the findings provide valuable insights, certain limitations should be acknowledged. The study involved a single professional team of sixteen players, which limits generalization to the broader Thai Premier League. In addition, the analysis focused solely on external workload variables, excluding internal indicators such as heart rate, perceived exertion, or hormonal markers that could clarify the physiological mechanisms underlying adaptive pacing. These limitations restrict the interpretation of whether the observed behaviors were primarily influenced by thermoregulatory stress or tactical intent.

Future studies should address these constraints by including multi-team and multi-season datasets that combine both internal and external load parameters. Such approaches would enhance ecological validity and support the creation of predictive performance models. The use of machine learning with GPS data could also allow early identification of overtraining or injury risk, aiding data-driven decisions in training management [19]. Moreover, examining psychological factors such as self-regulation, perceived effort, and tactical awareness under environmental stress may provide a more integrated view of adaptive pacing as a combined physiological and cognitive process in professional soccer.

Conclusions

The study confirmed that Thai professional soccer players regulate their pacing to maintain performance efficiency under tropical match conditions. Although total and submaximal running distances decreased in the second half, players sustained sprint capacity and high-speed actions. This indicates a controlled distribution of effort that reflects physiological and tactical adaptation to heat and fatigue. The results support the adaptive pacing model, showing that players balance endurance and decision-making demands to preserve effective performance. From a practical perspective, these findings emphasize the importance of situational pacing and position-specific conditioning that prioritize the timing and quality of high-intensity actions rather than total running volume.

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Conflict of Interest

The authors declare no conflicts of interest related to this study.

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Information about the authors:

Wattana Nuttouch; <https://orcid.org/0000-0003-3964-8560>; wattanajae12@gmail.com; Division of Sports Science, Faculty of Science, Pitchaya bandit College; Nong Bua Lamphu; Thailand.

Palakorn Nakarabandid; <https://orcid.org/0009-0005-1645-188X>; palakorn.na@skru.ac.th; Division of Physical Education, Faculty of Education, Songkhla Rajabhat University; Songkhla, Thailand.

Pattarawut Khaosanit; <https://orcid.org/0000-0003-1023-6992>; pattarawut.k@chula.ac.th; Faculty of Sports Science, Chulalongkorn University; Bangkok; Thailand.

Tachapon Tongterm; (Corresponding author); <https://orcid.org/0000-0001-7874-4948>; tachapon.t@sskru.ac.th; Division of Sports Science, Faculty of Liberal Arts and Science, Sisaket Rajabhat University; Si Sa Ket; Thailand.

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