Heliyon 10 (2024) e27014

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Temporal features of goals, substitutions, and fouls in football games in the five major European league from 2018 to 2021

Rongkun Sun [a], Changquan Wang [a,**], Zhe Qin [a,b], Chuanliang Han [c,*]

[a] College of P.E. and Sports, Beijing Normal University, Beijing, 100875, China
[b] College of Physical Education Northwest Normal University, Lanzhou, 730070, China
[c] School of Biomedical Sciences and Gerald Choa Neuroscience Institute, The Chinese University of Hong Kong, Hong Kong SAR, China

ARTICLE INFO

Keywords:
Football
Mathematical model
Goal
Substitution
Yellow card

ABSTRACT

The “Big Five” European football leagues, comprising England’s Premier League, Germany’s Bundesliga, Spain’s La Liga, Italy’s Serie A, and France’s Ligue 1, command significant attention. While the occurrence of goals, substitutions, and fouls in football games is often considered random, of the presence of an inherent inevitability is unclear. To investigate, we analyzed a public dataset detailing timing of goals, substitutions, and yellow cards in regular time from WhoScored across three seasons (2018–2019, 2019–2020, 2020–2021) in the top five European football leagues. We employed various mathematical descriptive models (including linear, sigmoid, and gaussian functions) to measure the temporal tendency of goals, substitutions, and yellow cards. Our results indicate that, whether in the first or second half of the match, the temporal distribution of these elements exhibits evenness a (indicative of randomness). However, specific characteristics were discerned through distinct model parameters, capturing novel phenomena that were intuitively illustrated. Furthermore, we explored the interaction of the timing of goals, substitutions, and yellow cards. In this analysis we found that scoring in the second half leads to more substitutions and yellow cards. Changing players in the second half corresponded with more goals, while the impact of yellow card fouls showed no differences in goals in the first and second halves. Our research is the first to systematically study the laws of modern football matches, providing valuable guidance and reference for many football coaches.

1. Introduction

Football is a sports event in which two teams of 11 players each control a ball, and two teams engage in offensive and defensive confrontations on a rectangular field while adhering to specific rules [1] [–] [5], with the aim of scoring in the opposing team’s goal. Due to its intense adversarial nature, diverse tactics, and large number of onlookers, football is known as the "world’s number one sport". In a football game, effective goals [6] [–] [10], substitutions [11–18] arranged by the coach, and yellow or red cards [19–22] for fouls are pivotal match events. The timing of players scoring goals, substitutions, and receiving yellow cards is theoretically considered random [23] [–] [25] and, without additional assumptions, should follow a uniform distribution. However, due to various complex factors, this distribution may fluctuate [26,27]. To date, there has been no detailed quantitative description of football match

* Corresponding author.
** Corresponding author.
E-mail addresses: Wangchangquan@vip.163.com (C. Wang), hanchuanliang2014@163.com (C. Han).

https://doi.org/10.1016/j.heliyon.2024.e27014
Received 23 July 2023; Received in revised form 22 February 2024; Accepted 22 February 2024
Available online 28 February 2024

information (goals, substitutions, and yellow cards), and trends in the interaction between goals, substitutions, and yellow cards in football matches in big data remain unclear.

Throughout the game, the team's scored goals [7,9,10] are closely related to the coach's substitutions [11,12] and the cards accumulated due to fouls. The accumulation of yellow cards by a player may result in a red card, forcing their departure from the field and leaving their team with one fewer player-a significant constraint on their playing capacity. When a player encounters issues with fouls or the coach substitutes a player for the protection, the player's role in the team is compromised for the remainder of the match, affecting the team's performance and causes shifts in on-field trends. Consequently, football games are rich in drama, and beneath their seemingly uncertain nature, discernible patterns emerge, indicating several important characteristics.

In this study, we investigate patterns in modern football games, by primarily analyzing data from three seasons across the five major European leagues. This analysis included the timing of goals, substitutions, and yellow cards for each team in every game. We quantified and modeled these characteristics based on mathematical models to discern different temporal dynamic patterns. Furthermore, we compared the relationship between goals, substitutions, and yellow cards for fouls. This study could provide practical guidance and establish a theoretical basis for the strategic role of football coaches in managing and optimizing their strategies throughout matches.

2. Materials and methods

2.1. Data and sources

The dataset used in this study is publicly available (https://github.com/CleveHan/Soccer), obtained from WhoScored website (https://www.whoscored.com/). We collected the timing of goals, substitutions, and yellow cards for each team in the five major European leagues (Premier League, LaLiga, Serie A, Bundesliga, and Ligue 1) across the 2018–2019, 2019–2020, and 2020–2021 seasons. A total of 5037 matches and 10,754 sample data points (each data point refers to a team in a match) were used in the analysis.

2.2. Descriptive model – linear model

We used the linear function (Eq. (1)) to model the variation in the number of goals in the second half and the occurrence of yellow cards in both the first and second halves. The y in Eq. (1) represents the number of goals or yellow cards at a specific time, and k and C are modeling parameters to be estimated, where k is the slope, and C is the intercept.

$$y = k \bullet time + C \tag{1}$$

2.3. Descriptive model – sigmoid model

We used the sigmoid function (Eq. (2)) to model the variation in the number of goals and substitutions in the first half. The y in Eq. (2) represents the number of goals, substitutions, or yellow cards at a specific time, and k, α, and C are modeling parameters to be estimated, where k is the slope, α is the exponential term, and C is the intercept.

$$y = k \bullet time^{\alpha} + C \tag{2}$$

2.4. Descriptive model – double Gaussian model

We used the sigmoid function (Eq. (3)) to model the variation in the number of substitutions in the second half. The y in Eq. (3) represents the number of substitutions at a specific time, and k_1, P_1, σ_1, k_2, P_2, σ_2, and C are modeling parameters to be estimated, where k is weight, P is the peaking time, σ is the bandwidth, and C is a constant.

$$y = k_1 \bullet e^{-\frac{(time-P_1)^2}{\sigma_1^2}} + k_1 \bullet e^{-\frac{(time-P_2)^2}{\sigma_2^2}} + C \tag{3}$$

2.5. Parameter estimation

We processed the data and modeled them with custom scripts in MATLAB (MathWorks, 2020a). We adopted the nonlinear least squares (NLS) algorithm for data fitting and parameter estimation.

2.6. Analysis of the interaction among the timing of goals, substitutions, and yellow cards

We used the X-trigger Y method to measure the influence of X on Y starting from the Z^{th} minute. Four relationships are considered in this study: goal-trigger substitution, goal-trigger yellow card, substitution-trigger goal, and yellow card-trigger goal. Taking the goal-trigger yellow card as an example, we examined matches that scored at time Z, and then we compared the number of substitutions at time Z and at Z+1 min, Z+2 min, Z+3 min, Z+4 min and Z+5 min. If a significant difference was observed, we assumed that the timing of the goal would lead to a yellow card foul.

2.7. Statistical analysis

We used pairwise *t*-tests to compare the total number of goals in the 1st and 2nd halves, as well as the number of yellow cards in the 45th, 46th (which marks the first minute of the second half) and 47th minutes with Bonferroni correction to account for multiple comparisons. The pairwise *t*-test was used to compare the numbers in X-trigger Y sections.

3. Results and analysis

The dataset analyzed in this study contains 10,754 samples, and each sample has 90 data points, corresponding to the first and second halves of the game. The sampling rate was 1 point per minute. While a few matches were not sufficient to demonstrate the temporal features of the football, these temporal features emerged with the accumulation of the sample data (Fig. 1).

3.1. Goals in football games and their characteristics

The average distribution of the number of goals in a 90-min football game is shown in Fig. 2A. When examining trends in a handful of matches, any trends appear inconspicuous. However, when we include a thousand or tens of thousands of matches, we observe a clear trend in goals (Fig. 2B). To precisely measure this tendency, we used descriptive models to fit the data. The number of goals in the first half was modeled with the sigmoid function, while goals in the second half were modeled with the linear function (Fig. 2C). Although the total number of goals in the first half is significantly higher than that in the second half (Fig. 2D), it is surprising to see that the slope of goals in the second half is negative (Fig. 2E), which is potentially be affected by endurance over time. Another surprising point is that the semi-saturation period of the sigmoid curve in the first half is approximately 1 min (Fig. 2E), which suggests that the time when players enter the game is very eventful.

3.2. Substitutions in football games and their characteristics

The average distribution of the number of substitutions in the 90-min football game is shown in Fig. 3A. It is clear that the majority of substitutions occurred in the second half (Fig. 3B). The number of substitutions in the first half was modeled with the sigmoid

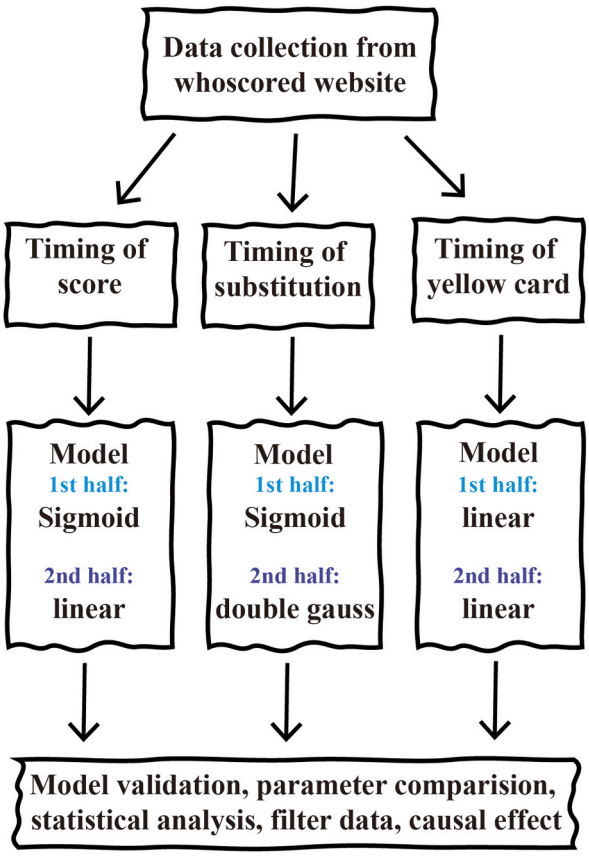

Fig. 1. Technical flowchart of the study illustrating data analysis process.

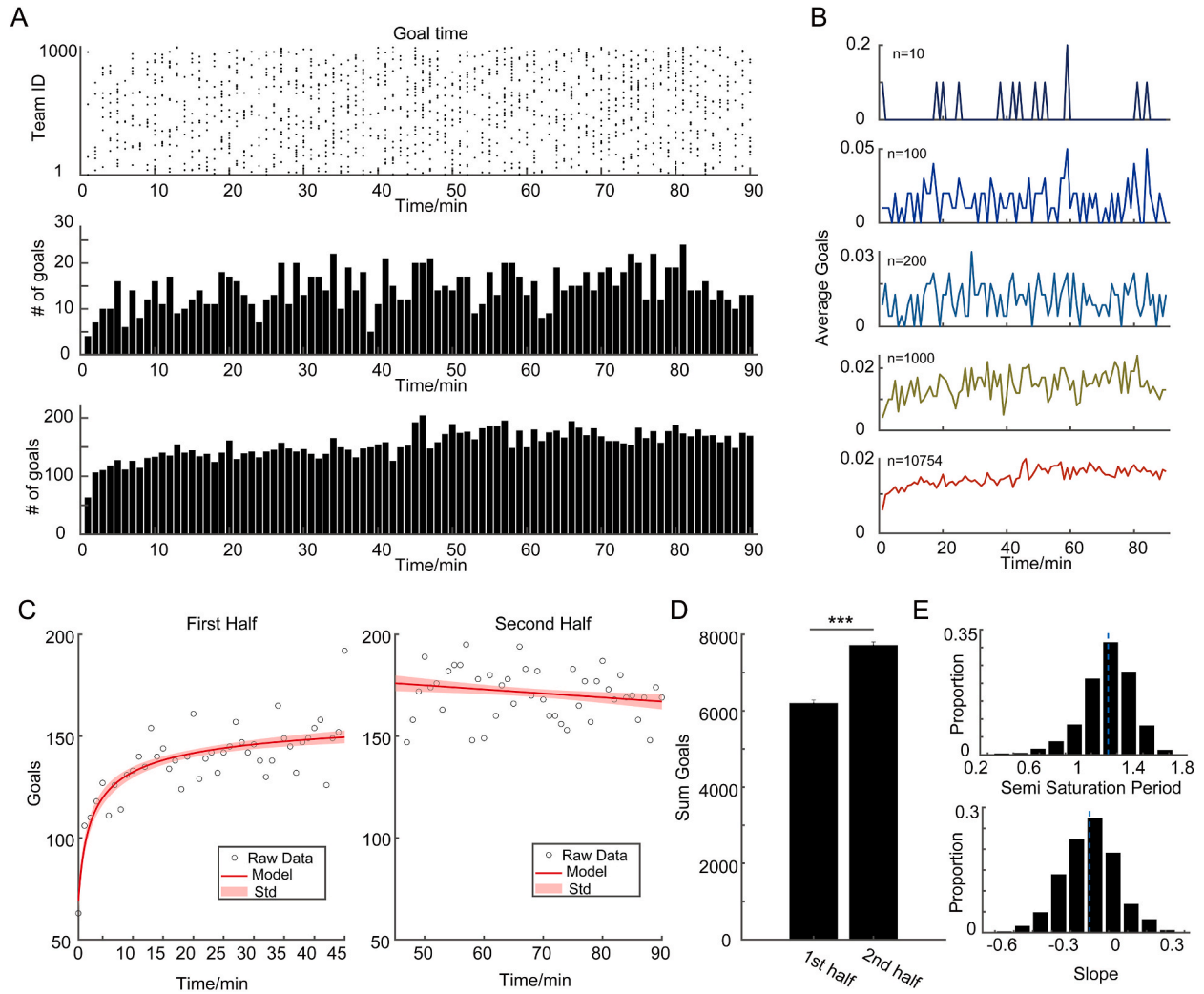

Fig. 2. Goal time, trend, slope, and model establishment in football matches. (A) Top: scatter plot of the goals timing in 300 samples. Middle: the histogram of the top panel. Bottom: histogram of the goals in 90 min in 10,754 samples. (B) Average goals in a 90-min match in 10, 100, 200, 1000 and 10,754 samples. (C) Descriptive models to fit the data in the first and second halves. (D) Bar graph of total number of goals in the first and second halves and their comparison. (E) Top: histogram of the semisaturation period of sigmoid model in the first half. Bottom: histogram of the slopes of the linear model in the second half.

function, and that in the second half was modeled with the double Gaussian function (Fig. 3C). The number of substitutions in the first half was not large but gradually increased. Surprisingly, we found two peaks of substitution in the second half, one at approximately 62 min and the other at approximately 79 min (Fig. 3D). This may suggest that crucial moments in the game are tied to these substitutions.

3.3. *Yellow cards in football games and their characteristics*

The average distribution of the number of yellow cards in a 90-min football game is shown in Fig. 4A. It is clear that the number of yellow cards increased in both the first and second halves (Fig. 4B), which was fitted with a linear model (Fig. 4C). The increase in yellow cards varies with time, potentially reflecting players' moods and deformation as endurance decreases. Surprisingly, we observed a significant decrease in the number of yellow cards in the 47th minute compared to the 46th minute. The 46th minute is the first minute of the second half and comes after a 15 min break. Athletes maintain an elevated level of intensity until the 47th minute (Fig. 4D). In the 47th minute, the yellow card counts resets, and a positive slope is observed, and notably, the slope in the first half is much higher than the second half (Fig. 4E).

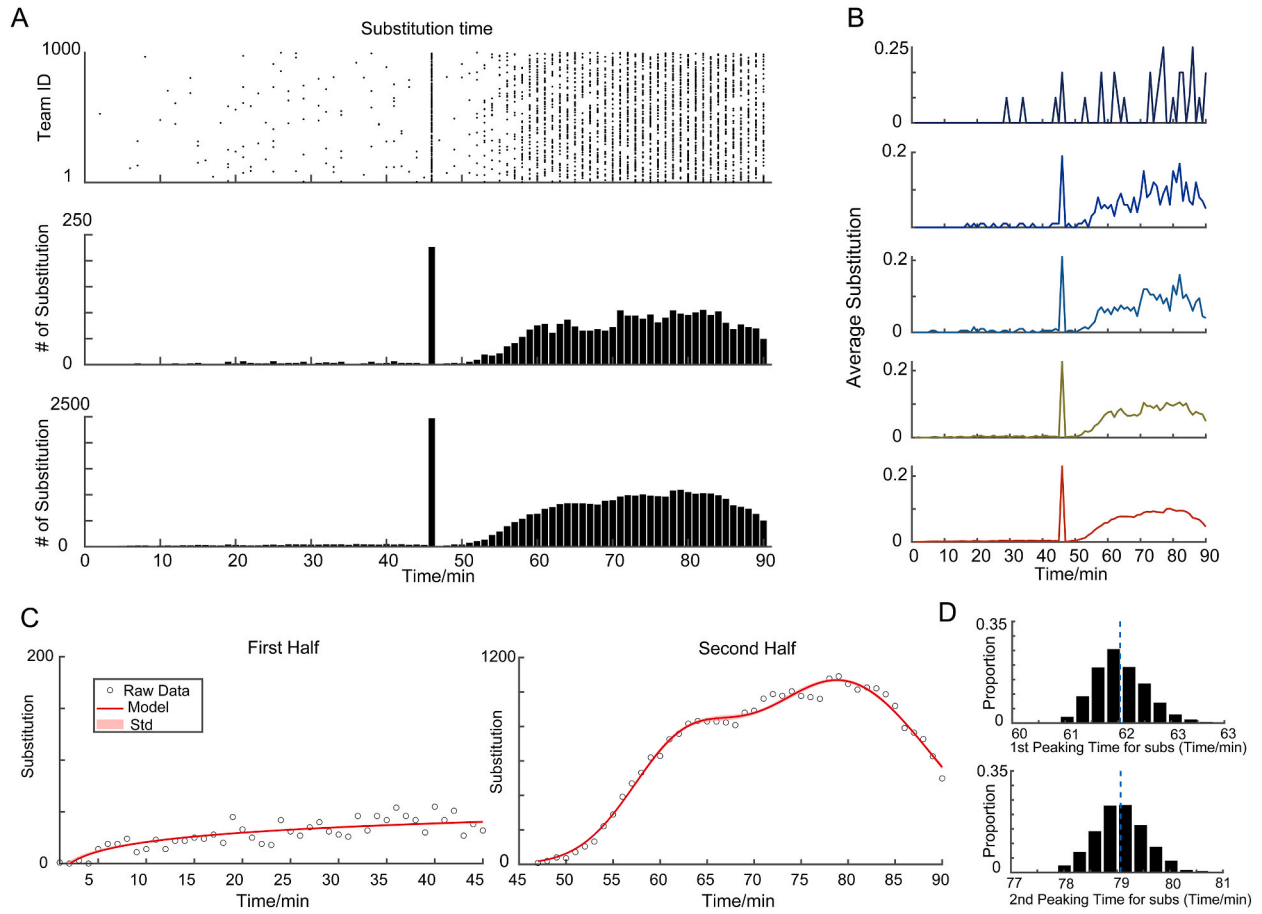

Fig. 3. Substitution time, trend, slope, and model establishment in football matches. (A) Top: scatter plot of the substitution timing in 300 samples. Middle: the histogram of the top panel. Bottom: histogram of the substitutions in 90 min in 10,754 samples. (B) Average substitutions in a 90-min match in 10, 100, 200, 1000 and 10,754 samples. (C) Descriptive models to fit the data in the first and second halves. (D) Top: histogram of the first peak time in the first half. Bottom: histogram of the second peak time in the second half.

3.4. The mutual influence among the timing of goals, substitutions, and yellow cards

We filtered the data to remove the tendency term of the original data (Fig. 5A) so that we would see a fluctuation of the match elements (Fig. 5B). Some in-phase and anti-phase relationships in goals, substitutions and yellow cards were found in Fig. 5B. To determine the interactions between the timing of goals, substitutions, and yellow cards (Fig. 5C–F), we used the X-trigger Y way starting from the Z^{th} minute for analysis (see Methods section for details). Twenty time-points with intervals of 5 min are shown in Fig. 5C–F. Four types of X-trigger Y are considered: goal-trigger substitution (Fig. 5C), goal-trigger yellow card (Fig. 5D), substitution-trigger goal (Fig. 5E), and yellow card-trigger goal (Fig. 5F). We found that the impact of goals on substitutions is mainly observed in the second half, but not in the first half (Fig. 5C). The impact of goals on yellow cards was significant in both the first and second halves (Fig. 5D). The impact of substitutions on goals is mainly in the second half (Fig. 5E). We also found that yellow cards have an impact on goals in both the first and second halves (Fig. 5F).

4. Discussion

4.1. Principal findings

This investigation aimed to demonstrate the temporal dynamics of goals, substitutions, and yellow cards within the regulation time of football matches, by employing mathematical models. These methods, when viewed independently, are not novel; however, this is their first application in this field. Quantitative analysis of these models yielded practical indicators for comparing the first and second halves of football games. Furthermore, by comparing the relationships between goals, substitutions, and yellow cards, we discovered dynamic changes in their relationships at different times. These new findings deepen our understanding of football matches and provide guidance for coaches in actual matches [28]. The introduction of quantitative methods in this field provides us with new

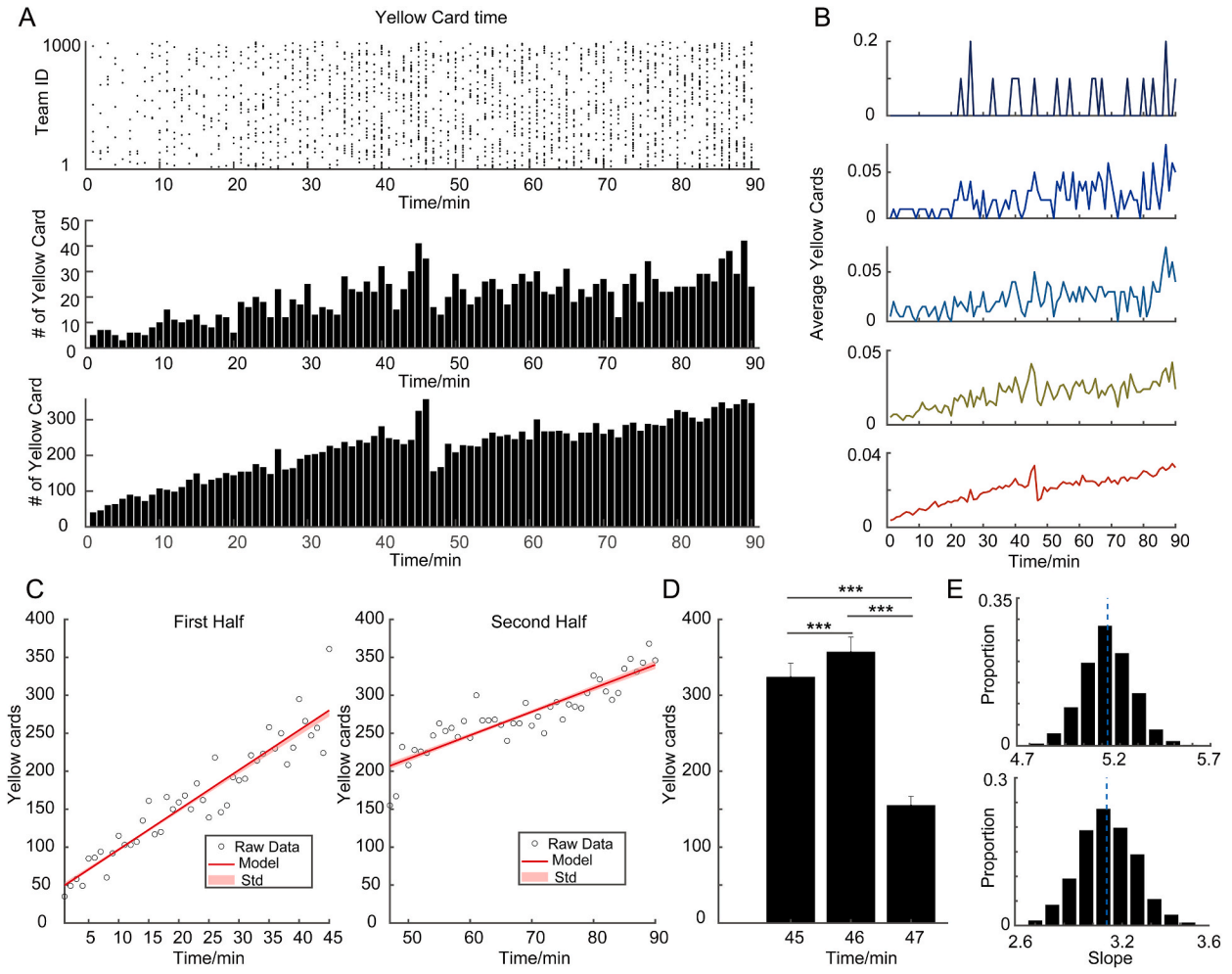

Fig. 4. Yellow cards, trend, slope, and model establishment in football matches. (A) Top: scatter plot of the yellow cards timing in 300 samples. Middle: the histogram of the top panel. Bottom: histogram of the yellow cards in 90 min in 10,754 samples. (B) Average yellow cards in a 90-min match in 10, 100, 200, 1000 and 10,754 samples. (C) Descriptive models to fit the data in the first and second halves. (D) Bar graph of the total number of yellow cards in 45th, 46th, and 47th minutes and its comparison. (E) Top: histogram of the slope of the linear model in the first half. Bottom: histogram of the slopes of the linear model in the second half. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

insights into understanding general trends of contemporary football matches. Our findings not only contribute to the understanding of football at the highest levels, but also serve as a benchmark for countries with lower ranked leagues globally, fostering improvements in the sport worldwide.

4.2. Comparison with prior work

To our knowledge, this is the first time multiple mathematical models have been applied to describe various aspects in a football game, such as goals, substitutions, and yellow cards. The models were also used in previous biological or medical field [29–35]. Many sports studies on football matches have used quantitative methods to determine patterns within a game [36]. These previous studies have focused on other indicators, such as possession rate [39–41], player spatial trajectory [42–44], home advantage [45–49], and red cards [19], however, these studies did not explore the interaction of different events during a game. Our original intention in modeling is to search for some distinct features [37]and potential patterns in a seemly random context [38]. We mainly explore the relationship between goals, substitutions, fouls, and yellow cards. Analyzing past game information should have more guiding significance for guiding future tactics [24,25]. This study contributes to the expanding body of knowledge by introducing a novel perspective through mathematical modeling in the domain of football match analysis.

Our investigation illustrates the probability density curve of goals, a very important aspect of football matches [50,51]. A more accurate understanding of the timing of goals can help players stay vigilant. Through the description of goal information (Fig. 1C), we found that in the first half, players enter the game very quickly (approximately within 1 min, Fig. 1E). Therefore, the key implication

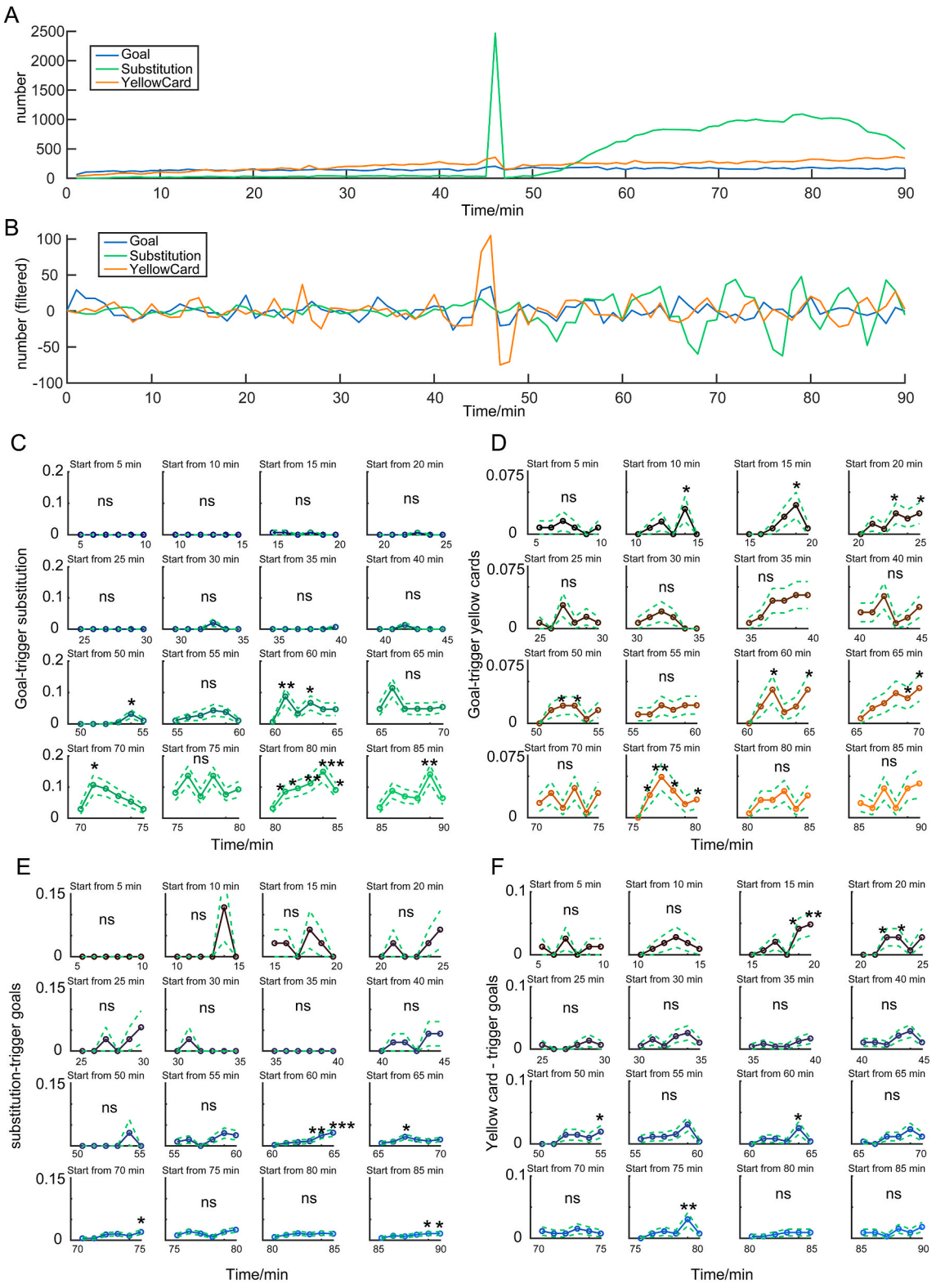

Fig. 5. The interactions of key time points among goals, substitutions, and yellow cards in football matches. (A) Average goals, substitutions, and yellow cards in the 90-min game. (B) The filtered data of Panel A to show the fluctuation. (C) Goal-trigger substitution starting from the 5th, 10th, 15th, 20th, 25th, 30th, 35th, 40th, 50th, 55th, 60th, 65th, 70th, 75th, 80th and 85th minutes. (D) Goal-trigger yellow cards starting from the 5th, 10th, 15th, 20th, 25th, 30th, 35th, 40th, 50th, 55th, 60th, 65th, 70th, 75th, 80th and 85th minutes. (E) Substitution -trigger goals starting from the

5th, 10th, 15th, 20th, 25th, 30th, 35th, 40th, 50th, 55th, 60th, 65th, 70th, 75th, 80th and 85th minutes. (F) Yellow card-trigger goals starting from the 5th, 10th, 15th, 20th, 25th, 30th, 35th, 40th, 50th, 55th, 60th, 65th, 70th, 75th, 80th and 85th minutes. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

for players is that a prompt entry into the game is essential, as a delay may increase the likelihood of the opposing team scoring quickly. After approximately 5 min, it enters a relatively slow upward phase, leading to the halftime break. We find that the number of goals scored is significantly higher in the second half compared to the first half (Fig. 1D), indicating a decrease in the attention and physical stamina of players, potentially resulting in a weakened defense that gives the opponent a greater chance of scoring. At the same time, we should also note that the slope of goals in the second half is negative, indicating that the probability of scoring gradually decreases over time until injuries occur. This which may be due to physical fatigue, leading to a decrease in the number of goals scored.

In terms of substitutions [52–54], understanding the general rules of substitution time can help us roughly understand the general physical fitness of players on the field and the rules of replacement timing [12,28,55]. Substitutions are natural in a physically demanding game and the state of players' physical state, such as endurance and exhaustion, is reflected in the timing in which substitutions are carried out. Therefore, it is a normal phenomenon for more substitutions occur in the second half, when players are increasingly depleted. The most notable, and surprising, result was the identification of two peak substitution periods in the second half (Fig. 2C), occurring at the 62nd and 79th minute marks approximately. The timing of these two substitutions also indicates a possible two-wave decline in players' stamina.

The issuance of a yellow card in a competition often alters the course of the game [56,57]. In terms of yellow cards, sometimes fouls are influenced by factors related to whether it is a home or away game [46]. Nevertheless our assumptions are that the referee remains objective and fair throughout the game, however, a large amount of data is needed to compensate for any bias [58]. From our result, we found that the number of yellow cards increased with the progression of game time, both in the first and second halves (Fig. 3C), and the rate of increase in the first half was significantly faster than in the second half. However, the total number of yellow cards in the second halve was higher than in the first half, indicating that in the second half, players may be less physically agile, resulting in more fouls. It is worth noting that the number of yellow cards in the first minute of the second half was very high, but this number sharply decreased 1 min later. This early second-half foul trend deserves attention from coaches.

Exploring the relationship between different components in football matches [59,60], such as goals, substitutions, yellow cards, etc., is crucial for understanding current football matches. However, previous research is insufficient. In the analysis of the relationship between goals, substitutions, and yellow cards, we found that substitutions caused by goals mainly occurred in the second half, while yellow cards caused by goals was comparable in the first and second halves. One potential reason for this is that in the first half, conceding a goal is often not a reason to switch players immediately, while a yellow card may be due to excitement after scoring or the negative emotions of losing the ball which lead to excessive movement in both the first and second halves. Goals caused by a substitution also occur in the second half, when the coach may switch out players to change the situation on the field and increase team stamina, which often works. The goals caused by yellow cards also appeared in the first and second halves, indicating that the fouls caused by this emotional change are also likely to benefit the opponent, especially for some set pieces with good positions. Goals, substitutions, and yellow cards complement each other in a football game. Once a goal is scored, substitutions and yellow cards are enacted soon after. This may be due to strategies adopted by coaches after a goal is scored. In the second half, decisions will be made immediately after the goal is scored, with each closely linked. The leading team will adjust their defensive strategy introducing substitutes after scoring to ensure victory in the game. For the losing team, the reason for substitutions is not only to score again, but also counter the impact of a yellow card, and vice versa. Therefore, in football matches, goals, substitutions, and yellow cards promote and influence each other, and each link has a fundamental implication for the game. Herein, we establish a game model for these three football match factors, divide the football match into important time phases, and provide a reference for football coaches to better guide matches and potentially, ultimately win.

4.3. Limitations

While our analysis primarily focuses on patterns observed in a dataset comprising over 10,000 samples, it is important to acknowledge the inherent unpredictability of real football matches, characterized by sudden, unexpected moments, that may not align with general pattern of our model. This analysis lacks consideration of specific match dynamics, including factors such as the rival team, critical championship moments, table positions, and team characteristics, which can influence match outcomes. Another limitation lies the selective variables in the mathematical model, and we recognize the need for further exploration in future studies.

5. Conclusion

In summary, our study provides a detailed mathematically modeled account of the temporal dynamics of goals, substitutions, and yellow cards throughout the regulation time of football. Combined with the quantitative analysis of these models, we derived practical indicators for comparing the first and second halves of football matches. Moreover, after exploring the relationships between goals, substitutions, and yellow cards, we identified dynamic changes in their interactions, which deepen our understanding of modern football matches.

Contributors

CH, CW, LH conceived and designed the study. CH, RS, LH contributed to the literature search, RS, CH contributed to data collection. CH contributed to the data analysis, and the interpretation of results. All authors contributed to writing the paper.

Data availability statement

The dataset used in this study is publicly available (https://github.com/CleveHan/Soccer).

CRediT authorship contribution statement

Rongkun Sun: Writing – review & editing, Writing – original draft, Formal analysis, Data curation. **Changquan Wang:** Writing – review & editing, Funding acquisition, Conceptualization. **Zhe Qin:** Writing – review & editing. **Chuanliang Han:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This study was sponsored by the Humanities and Social Science Fund of Ministry of Education (21YJA890031) , and the fellowship of China Postdoctoral Science Foundation (2022M723299, 2023T160666).

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