Impact of substitutions on elite soccer team performance based on player evaluation system

Jiale Wu. *AI Sports Engineering Laboratory. School of Sports Engineering. Beijing Sport University. Beijing, China.*

Yuesen Li. *AI Sports Engineering Laboratory. School of Sports Engineering. Beijing Sport University. Beijing, China. School of Medicine and Health. Technical University of Munich. Munich, Germany.*

Changjing Zhou. *School of Physical Education and Sport Training. Shanghai University of Sport. Shanghai, China.*

Xiuyuan Xiong. *AI Sports Engineering Laboratory. School of Sports Engineering. Beijing Sport University. Beijing, China.*

Xiaoru Qin. *State Key Laboratory of Media Convergence and Communication. Communication University of China. Beijing, China.*

Yixiong Cui ✉ *. AI Sports Engineering Laboratory. School of Sports Engineering. Beijing Sport University. Beijing, China.*

ABSTRACT

This research aims to explore the performance characteristics of substitutions and to evaluate the performance of substitutions based on the player evaluation system. Match statistics of 643 substitutions extracted from the Chinese Super League teams in the 2019-2020 season. The team ratings, ball possession, and expected threat of four periods (5 minutes per period before and after the substitution) of each substitution were calculated. The two-step cluster analysis was performed on the team ratings at different times and the Scheirer–Ray–Hare test was used for the two-factor design based on the cluster and the substitutions over four periods. The cluster analysis revealed 5 clusters with a BIC value was 1,360.50. The interactions of team ratings between the periods and the clusters in different groups were detected (H = 531.96, p < .001, E_R^2 = 0.47). The group comparisons suggested that the ratings of Cluster 3 showed a significant decline after substitutions which was caused by the small ball possession but has great aggressive in expected threat. The study shows how player evaluation systems can be used to measure the effectiveness of substitutions in soccer games and provides insight for further analysis of decision-making situations.

Keywords: Performance analysis, Soccer, Match analysis, Substitution, Technical-tactical performance, Player evaluation.

INTRODUCTION

Decision-making has been an important topic in the study of team sports performance analysis, which can be the choice of technical actions or movement types made by players on the field, as well as those by managers and coaches (Nosek et al., 2021). Research on strategical decision-making in football includes a variety of aspects such as substitutions, structures of formations, playing styles, and physical distribution (Castillo-Rodríguez et al., 2023; Gollan et al., 2018; Passos et al., 2016). Among them, substitutions that might influence physical demands, as well as tactics, have gained growing attention in recent years, as the implementation of FIFA's new rules (*International Federation of Association Football*, 2020) extends the maximum number of three substitutions for each team to five (García-Aliaga et al., 2023; Hills et al., 2020). Not only does the decision of substitution counteract team fatigue to prevent injuries, but it also allows for a change in the game's pace by adjusting the team formations (Bradley et al., 2014; Hills et al., 2018). It might be one of the most direct and effective ways for coaches to get involved and help in the game, which therefore demands more scientific investigation.

The current analysis of substitution performance in soccer matches could be divided into several aspects: the timing of substitutions (Myers, 2012; Silva & Swartz, 2016), modifying tactical behaviour through substitutions (Amez et al., 2021; Gómez et al., 2016), exploring the running performance and physical demands of substitutions (Bradley et al., 2014; Carling et al., 2010), assessing the psychology state of substitutions (Woods & Thatcher, 2009). In contrast to earlier scholarly investigations positing three substitutions occurring before the 58th, 73rd, and 79th minutes (Myers, 2012), an alternative study that factored in team quality and game status has suggested that a mere evaluation of substitution timings, in isolation, to gauge their efficacy within the context of the game may prove inadequate (Silva & Swartz, 2016). Extensive research has elucidated that trailing teams tend to substitute at an earlier juncture in the match compared to their leading counterparts, with such tactical changes often yielding more favourable outcomes (Amez et al., 2021; Gómez et al., 2016). A study based on substitution types has observed that different types of substitutions can reflect a team's tactical intent while concurrently enhancing offensive proficiency or reinforcing defensive resilience (Lorenzo-Martínez et al., 2021). It seems widely acknowledged that offensive substitutions heighten the probability of goal-scoring (Wittkugel et al., 2022), yet the efficacy of defensive substitutions in thwarting goal-scoring opportunities remains a subject of ongoing debate (Conte et al., 2016; Del Corral et al., 2008; Gómez et al., 2016). When it comes to running performance, there have been various studies showing that the total distance and the high-intensity runs by midfield substitutes in the second half are greater than the replaced players or teammates of the same position (Bradley et al., 2014; Bradley & Noakes, 2013; Coelho et al., 2012), while their interval between high-intensity runs is shorter (Carling et al., 2010).

These studies consider the effects of various contextual variables, including scoreline, home advantage, and team rankings, thereby elucidating more profound insights derived from practical experiences. Nonetheless, it is worth noting that a substantial portion of these substitution investigations tend to overlook the on-field position and behaviours of players. The criteria employed to gauge the impact of substitutions are often confined to goal differentials or alterations in the scoreline (Leeuwen, 2020), resulting in a somewhat limited scope when it comes to offering comprehensive value of substitutions enacted for diverse tactical objectives of teams.

Therefore, applying a multivariate approach could be a potential solution for the research topic. Specifically, advanced or hybrid performance indicators were proposed and could be used to evaluate the effect of substitution. For instance, the ball possession that is widely known for assessing the team's performance in

soccer indicated that the high percentage of ball possession in the penalty box may contribute to goals scored (Link & Hoernig, 2017; Parziale & Yates, 2013; Wang et al., 2022). Recently, expected threat (xT) was introduced as an aggregated metric of the expected goal (xG) (Eggels et al., 2016; Rathke, 2017) and ball possession to evaluate individual actions related to attacking (Singh, 2019). After that, several innovative frameworks were put forward to achieve a more comprehensive evaluation of match performance. Decroos et al. (2019) estimated the probability of goals and concedes and used it as a value to rate single action. Other researchers combined such value of multiple players to evaluate team performance (Bransen & Van Haaren, 2020). Moreover, some studies further refined the on-ball value of attacking and organizing behaviours (Li et al., 2020) and adopted performance indicators of both competing teams to determine the defensive effectiveness (Ruan et al., 2022). These models provide more specific references for coaches and players, which are also the main components of the player evaluation approach selected in this research.

Given the above rationale, the purpose of this study was to explore the effectiveness of substitutions from the perspective of team evaluation and analyse the periods and offensive performance before and after substitutions. The hypothesis was that differences in team performance ratings, xT, and ball possession percentages before and after substitutions would be statistically significant, and ratings could be affected more by the period of substitutions than the other two evaluation methods. Meanwhile, it is expected that the findings could provide a feasible paradigm that applies a player evaluation system to the decision-making scenario of substitutions, offer insight into the collective behaviours of football during the periods in the match, and inspire the participants with various evaluation approaches.

METHOD

Sample
The study considered 643 substitutions from 240 matches played by 16 Chinese Super League (CSL) teams during the 2019 season. Match event datasets were retrieved from the public-access football statistics website named "*whoscored.com*", whose data were provided by the international sports data provider OPTA Sports with verified reliability (ICC ranging from 0.88-1.00) (Liu et al., 2013). Originally, there were in total of 1368 substitutions, and 725 of them failing to meet the following criteria were excluded: i) The time segment contains 5 minutes prior to and 15 minutes posterior to each substitution, e.g. When the match time ended at 90 minutes, the substitutions after the 75th minute were excluded; ii) Substitutions occurred due to the unexpected injuries and dismissals (red card) (Gómez et al., 2016); iii) Substitutes and replacements need to appear at least one game in the last season. Ethical approval for this study was granted by the local ethics committee and conformed to the recommendations of the Declaration of Helsinki.

Variables and procedures
According to the scientific literature that analysed substitutions during soccer matches (Hills et al., 2018), 4 contextual, 15 individual indicators were chosen from the raw data as independent variables in the analysis. The description and definitions of these two types of performance indicators are presented in Table 1. Since the study does not focus on comparisons in match behaviour between substitutes and starters, these variables were selected to describe both contextual factors and team performance.

Instead of using a potentially biased criterion of goal scores to assess substitution effects, the study considered several approaches of on-the-ball action rating during the match after comprehensively comparing their characteristics. Firstly, the percentage of ball possession was included as it could provide intuitive and understandable information about the rhythm and momentum of the match (Wang et al., 2022). Meanwhile, the expected Threat (xT) based on the possession to measure the on-the-ball events was

incorporated (Singh, 2019; Sumpter, 2021; Van Roy et al., 2020). The study has undertaken the selection of pertinent features, encompassing the three-dimensional coordinates of the ball within the goal area, shot locations, the length and angle between the goal and the ball, the body parts involved in player actions, assist types, and the ultimate outcomes of shots. These features collectively form the foundation of the expected goal (xG) model. The approach adopted involves the allocation of xG values to distinct regions on the football pitch, contingent upon the likelihood that possessing the ball in each area will culminate in a goal during a possession phase. Additionally, the assessment of the effectiveness of these progressions is carried out through the computation of changes in grid values before and following ball movements, thereby quantifying the expected threat associated with these actions.

Table 1. Description and definition of the performance indicators.

Variables	Description
Contextual	
Match location	The team making the substitution playing home or away
Match status	The goal difference between the team making the substitution and the opponent
Ranking	The substitution team's ranking
Opponent Ranking	The opponent team's ranking
Individual	
Number of minutes remaining	Time remaining in the current match
Number of substitutions remaining	The number of substitutions remaining in the current substitution team
Substitution type	Three types of substitutions constructed according to the position the player is replaced, which are offensive substitution, neutral substitution and defensive substitution; Positions were categories in 5 by player vector last season, including strikers, central midfielders, wing forwards, fullbacks and central backs
Rating/Possession/Expected threat within 5 minutes before substitution	Team rating/possession/expected threat of the game performance in the first 5 minutes before the substitution based on the player evaluation system
Rating/Possession/Expected threat within the first 5 minutes after substitution	Team rating/possession/expected threat of the game performance in the first 5 minutes after the substitution based on the player evaluation system
Rating/Possession/Expected threat within the second 5 minutes after substitution	Team rating/possession/expected threat of the game performance in the second 5 minutes after the substitution based on the player evaluation system
Rating/Possession/Expected threat within the third 5 minutes after substitution	Team rating/possession/expected threat of the game performance in the third 5 minutes after the substitution based on the player evaluation system

Moreover, the study employs Li's (2022) player assessment system, which relies on four key individual player attributes to formulate rating models: shot, organization, skill, and defence, each considering event types and qualifiers. These models integrate the risk-reward paradigm (Goes et al., 2022) and result in two models for each ability. For shot ratings, the model calculates the value of a shot by subtracting xG_2 (considering only on-target shots) from xG_1 (considering all shots), normalizing it by the player's total shots per match. In organization and skill ratings, threatened situations encompass events like shots, penalties, crosses, opponent clearances, opponent goalkeeper strikes, and opponent's own goals. The models differentiate between situations arising after 5 and 3 events, respectively. Ratings for organization and skill are derived from the difference between the threatened and lost values of a player's total actions (e.g., passes and dribbles per match). Defence ratings are determined by the contrast between the probability of maintaining possession after 3 defensive actions and the probability of conceding a shot after 5 defensive actions. All

models use XGBoost, LightGBM, and CATboost, which are three Gradient Boosting Decision Tree-based frameworks. After model training and optimization, the final choice was the LightGBM model, which demonstrated the best performance. Player and team ratings are then calculated by summing ability ratings after min-max normalization, offering a precise and concise approach for measuring individual and team performance during matches.

Statistical analyses

The two-step cluster analysis was suitable for handling the ordinal and nominal based on the distance measure (Chiu et al., 2001), which was performed accordingly on the team ratings at various times before and after substitutions. There are the 5 minutes before the substitutions, the first 5 minutes after the substitutions, the second 5 minutes after the substitutions, and the third 5 minutes after the substitutions. The Bayesian Information Criterion (BIC) and the Ratio of Distance Measures were the statistical measures of fit in a two-step cluster analysis (Bacher et al., 2004; Kent et al., 2014) in dealing with team ratings. The Scheirer–Ray–Hare test as a nonparametric test (Scheirer et al., 1976) was used for the two-factor design when the hypothesis of sphericity and normality was not satisfied ($p < .05$) based on the cluster and the substitutions over four periods (5 minutes for per period before and after the substitution). The variables of team ratings, ball possession, and the expected threat during the four periods of the substitutions were matched to perform the Scheirer–Ray–Hare test. Post-hoc multiple comparisons were conducted with the Mann-Whitney U test with the significance level adjusted. The effect size estimations for the Scheirer-Ray-Hare test were computed using epsilon-squared (E_R^2) whose thresholds of magnitude: negligible, <0.01; weak, 0.01-0.04; moderate, 0.04-0.16; relatively,0.16-0.36; strong, 0.36-.64 (Tomczak & Tomczak, 2014). In addition, the value of the correlation coefficient (r) was computed as the effect size estimations for the post-hoc Mann-Whitney U test with thresholds of magnitude: negligible, <0.1; weak, 0.1-0.39; moderate, 0.39-0.69; strong,0.69-0.89; and very strong, >1.00 (Hopkins et al., 2009; Schober et al., 2018). The level of significance was set at $p < .05$. All analyses were performed using the statistical software R version 4.2.2 and Python 3.

RESULT

According to the descriptive statistics, the ratio of home (48.1%) and away (51.9%) games was nearly equal in all samples. The proportion of samples ranked higher (50.4%) than their opponents is roughly the same as those ranked lower (49.6%). The distribution of the frequency of substitutions of different types and numbers during the game period is shown in Figure 1. The stacked column diagram represents the type of substitution, and the area diagram represents the number of substitutions.

The two-step cluster revealed five groups according to the ratings in different periods before and after substitutions. Clusters 1, 2, 3, 4, and 5 comprised 15.2, 17.3, 18.5, 22.9, and 26.1% of the sample size respectively. The BIC value of the cluster analysis modelling the four clusters was 1,360.50, and the ratio of distance measures was the maximum (1.70). The cluster analysis showed the Predictor Importance (PI) of the four periods in descendant order: the first 5 minutes after substitutions (PI = 1), the third 5 minutes after substitutions (PI = 0.91), 5 minutes before the substitutions (PI = 0.85), and the second 5 minutes after substitutions (PI = 0.55). The clusters of team ratings according to the periods are shown in Figure 2. Each cluster is represented by a coloured polyline, with cluster 1 scoring relatively high and cluster 5 relatively low. Additionally, in cluster 3 there were about 35% of substitutes with a drawn match status, and over 40% of all clusters substituted with a negative goal differential.
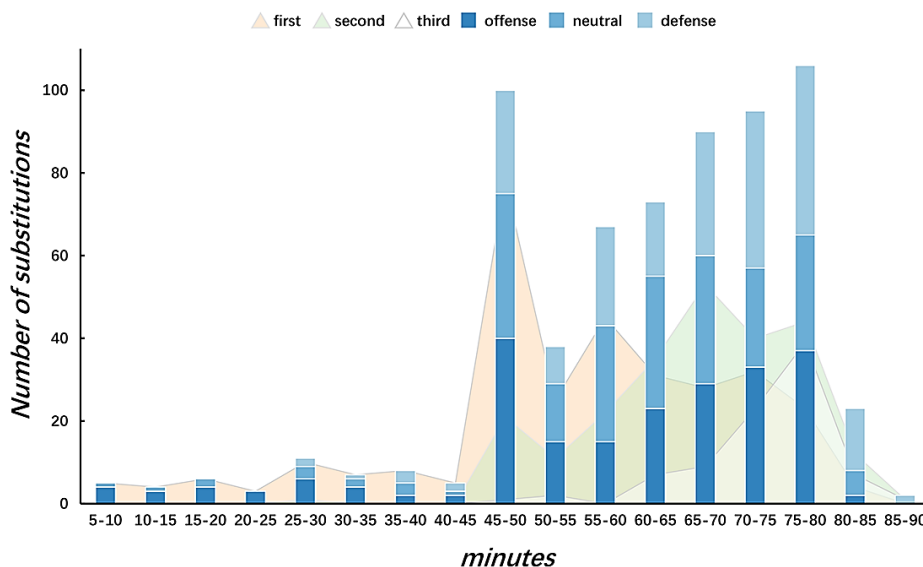
Figure 1. Stacked diagram of the substitution types and numbers during different match periods.
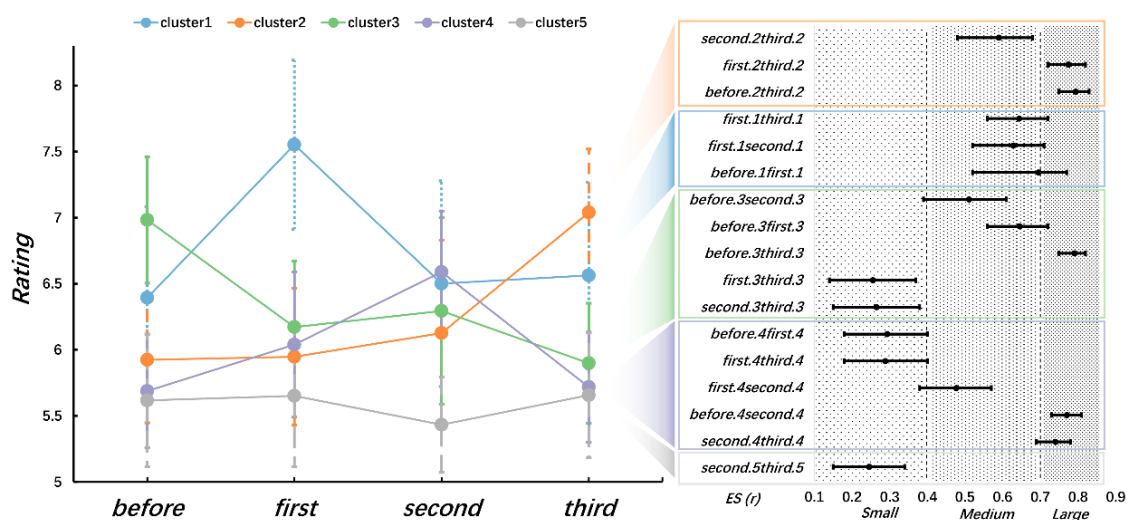

Figure 2. Line diagram of the clusters during periods before and after substitutions and the forest diagram of the interactions' main effect sizes.

As shown in Figure 2, the mean and standard deviation of team ratings and the interactions (H = 531.96, *p* < .001, E_R^2 = 0.47, 95%CI = [0.44,0.49]) between the two factors of the periods and the clusters in different groups were detected (see Supplementary Table 1 for detailed interaction analysis results). The main effects of team ratings were statistically significant (H = 662.06, *p* < .001, E_R^2 = 0.26, 95%CI = [0.23,0.29]). The interaction between clusters and periods of substitutions in expected threat did not show any statistically significant differences, and neither did ball possession.

The main effects of expected threat showed on the two factors (clusters: H = 13.56, *p* < .05, E_R^2 = 0.001, 95%CI = [0.002,0.013]; periods: H = 203.02, *p* < .001, E_R^2 = 0.08, 95%CI = [0.06,0.11]), and the main effects of ball possession only showed on the clusters (H = 45.41, *p* < .001, E_R^2 = 0.02, 95%CI = [0.01,0.03]). The

post-hoc Mann-Whitney U test on clusters of expected threat and ball possession showed that group comparisons had a significant effect ($p < .05$) with specific results in Figure 3. Moreover, the pairwise comparisons of expected threat on periods of substitutions were as follows: before-first ($p < .001$, r[95%CI] = 0.35[0.30, 0.41]), before-second ($p < .001$, r[95%CI] = 0.29[0.24, 0.35]), before-third ($p < .001$, r[95%CI] = 0.31[0.26, 0.37]).
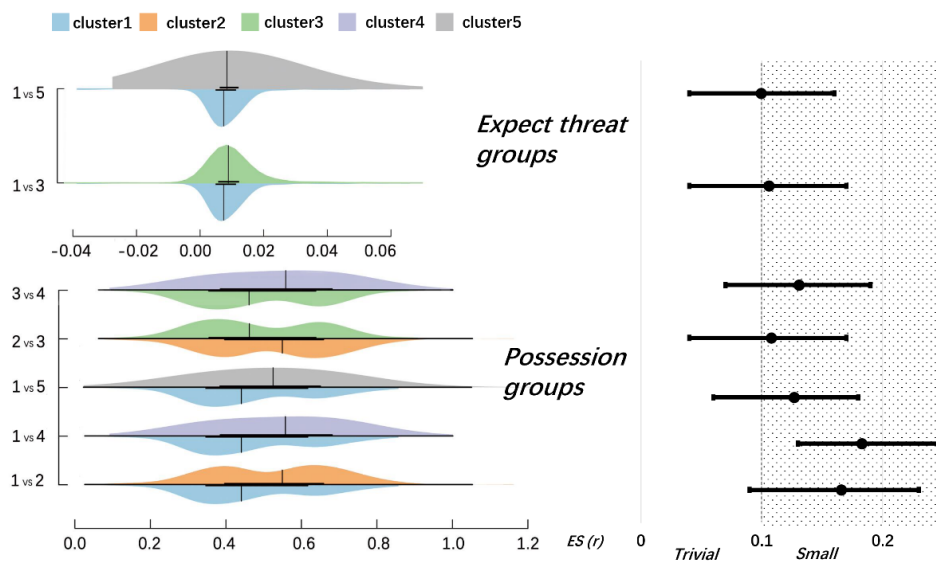

Figure 3. Violin and forest diagrams of Expected Threat and ball possession group comparisons on clusters.

DISCUSSION

The primary objective of the present study was to investigate the effectiveness of substitutions through the lens of team assessment, with a particular focus on analysing the temporal and match performance dynamics before and after substitutions. As previously mentioned, this research delved into team performance using diverse evaluation methodologies, seeking to discern performance fluctuations attributable to the strategic implementation of substitutions.

The study found that substitutions were made with around 28 minutes remaining in the match. The finding is consistent with previous literature (Del Corral et al., 2008) that reported most of the substitutions were made at half-time and in the second half. In contrast to previous research (Gómez et al., 2016; Myers, 2012), this study's substitution periods are earlier, with a heavier focus on the 45-50 minutes and 75-80 minutes intervals. For the types of substitutions, offensive types were often introduced at halftime more than others. This situation might suggest that coaches often adopt an aggressive tactical approach during halftime substitutions (Amez et al., 2021). The neutral and defensive substitutions were observed to increase in frequency in the second half of the games, which may align with the notion that defensive substitutions become more prevalent when a team is leading, aiming to maintain lineup stability (Lorenzo-Martinez et al., 2022).

The ratings of all the clusters fluctuate after substitutions. Notably, except for cluster 3, which experienced a significant decline, the ratings of the remaining clusters either remained unchanged or exhibited an upward trend. Accounting for the expected threat and ball possession, Cluster 3 showed great offensive intention with poor possession in pairwise comparison. Cluster 2 indicated a gradual increase in ratings after

substitutions and had high ball possession relative to Clusters 1 and 3, which implies that the teams were capable of converting possession into goals (Lago-Peñas & Dellal, 2010). They may be trailing in score but have the upper hand in the game momentum. Both Cluster 1 and Cluster 4 showed a rise and recovered during the 15 minutes after substitutions. However, Cluster 4 has a higher ball possession than Cluster 1 which might be the reason why it can keep the ratings high for longer. For Cluster 5, its rating is the lowest and the steadiest among the clusters with a small effect size.

In general, a player coming on as a substitute may have a longer high-intensity running distance than their colleagues who are already on the field (Bradley & Noakes, 2013; Carling et al., 2010), which indicates that the substitutes often with more physical energy and stronger ambition to get better performance. However, the distinctions must be specific about the players' positions or roles (Bush et al., 2015; Tierney et al., 2016). The physical information can be a fundamental reference of the physiological and fatigue of players which still need the events and positions to obtain a comprehensive team performance. Combined with the analysis of events and player positions (see Supplementary Table 2 for detailed results), it was found that the change in Cluster 3 could be due to the wingers being replaced and the tactics being similar to the counterattack (Lago-Peñas et al., 2017) to get more ball recoveries but ignore the scoreline or the opponent's strength. For Cluster 2, ratings did not start to rise until the third five-minute interval after the substitutions, revealing that these substitutes could take time to adapt to the game tempo (Dancy, 2009). According to events and positions, possession, crosses, and long passes are vital for creating better attacking opportunities with these midfield substitutes. The ratings decline of Cluster 1 may be in line with earlier research (Amez et al., 2021) in that making substitutions enhances the likelihood of goal-scoring, with less fluctuation during the first five minutes and a gradual decline after that. It could postulate that the substitutions involve the insertion of playmakers, individuals known to encourage their teammates to receive and engage with the ball, as highlighted by prior research (Bush et al., 2015; Li et al., 2022). The observed alterations in the ratings within Cluster 4 might be attributed to defensive player replacements, potentially fortifying the defensive line, especially during closely contested ball possession scenarios. However, both clusters suggest that the resulting rating improvements may prove transient, potentially owing to the team's overall suboptimal physical condition (Tierney et al., 2016). The low ratings of Cluster 5 might be related to the ranking, which might replace the defensive centres to guard the goals. In the meantime, these substitutions showed a decent expected threat that might depend on the defenders who transfer the ball to create shots for teammates (Singh, 2019; Van Roy et al., 2020).

Interestingly, the subtle changes in team performance were easier detected on ratings than ball possession or the expected threat of teams. The evaluation framework of player or team ratings may distinctly explain the match report in a given scenario, although the other two approaches are more suited to summarize the overall momentum of the game or monitor team playing styles (Singh, 2019; Van Roy et al., 2020; Wang et al., 2022).

Even though the study provides novel knowledge about the assessment of substitutions, there are some limitations to be acknowledged. Firstly, the research did not consider factors such as fitness status and internal load of players (Aquino et al., 2022; Hills et al., 2020), although the changes in substitution rules could introduce more physically prepared players into the pitch and increase more possible tactical adjustments (García-Aliaga et al., 2023; Meyer & Klatt, 2023). At the same time, specific match scenarios were not integrated into the analysis to inspect the influence of different substitutions on their teammate. Finally, the counteracting tactics adopted by opposing teams from team and individual perspectives were unable to be included, which also limits the generalizability of the findings.

The current study would provide practical information at two different levels. At a team tactical level, the research can provide references for coaches on substitution decisions and lineup setting when deciding players who can bring instant benefits to the team's counterattack or defence. It is acknowledged that most coaches prefer offensive substitutions with strong explosiveness or more consistent performance when the team is trailing in the score (Wittkugel et al., 2022), and the current findings could further help them to evaluate how effective these players and the influences they have on their teammates. Meanwhile from the perspective of match scouting, coaches and analysts could estimate the meaningful effects of opponents' substitution tactics and their span at the rest of the game.

CONCLUSION

This study has elucidated 5 distinct substitution clusters employed across various assessment methods within association football competitions. A further exploration of the effectiveness of substitutions was undertaken by leveraging a player evaluation system. The findings implied that the ratings of Cluster 3 showed a significant decline after substitutions which caused by the small ball possession but a great aggressive in expected threat. The ratings of Cluster 2 showed a significant rise after substitutions caused by the possession play and midfielder substitutes. The remaining clusters demonstrated fluctuating ratings within a 15-minute window post-substitution. Furthermore, the player evaluation system was employed for substitution analysis to verify the compatibility of ratings, ball possession, and expected threat in this regard.

AUTHOR CONTRIBUTIONS

Each author contributed individually and significantly to the development of the manuscript. Jiale Wu: writing, statistical analysis and preparation of the entire research project. Yuesen Li: data collection, statistical analysis. Changjing Zhou: writing and revision. Xiuyuan Xiong: data collection and analysis. Xiaoru Qin: data collection and analysis. Yixiong Cui: intellectual concept, writing and revision.

SUPPORTING AGENCIES

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

REFERENCES

Amez, S., Neyt, B., Van Nuffel, F., & Baert, S. (2021). The right man in the right place? Substitutions and goal-scoring in soccer. Psychology of Sport and Exercise, 54, 101898. https://doi.org/10.1016/j.psychsport.2021.101898

Aquino, R., Guimarães, R., Junior, G. O. C., Clemente, F. M., García-Calvo, T., Pulido, J. J., Nobari, H., Praça, G. M. (2022). Effects of match contextual factors on internal and external load in elite Brazilian professional soccer players through the season. Scientific Reports, 12(1), 21287. https://doi.org/10.1038/s41598-022-25903-x

Bacher, J., Wenzig, K., & Vogler, M. (2004). SPSS TwoStep Cluster - a first evaluation. (2., corr. ed.) (Arbeitsund Diskussionspapiere / Universität Erlangen-Nürnberg, Sozialwissenschaftliches Institut, Lehrstuhl für

Soziologie, 2004-2). Nürnberg: Universität Erlangen-Nürnberg, Wirtschafts- und Sozialwissenschaftliche Fakultät, Sozialwissenschaftliches Institut Lehrstuhl für Soziologie.

Bradley, P. S., Lago-Peñas, C., & Rey, E. (2014). Evaluation of the Match Performances of Substitution Players in Elite Soccer. International Journal of Sports Physiology and Performance, 9(3), 415-424. https://doi.org/10.1123/ijspp.2013-0304

Bradley, P. S., & Noakes, T. D. (2013). Match running performance fluctuations in elite soccer: Indicative of fatigue, pacing or situational influences? Journal of Sports Sciences, 31(15), 1627-1638. https://doi.org/10.1080/02640414.2013.796062

Bransen, L., & Van Haaren, J. (2020). Player Chemistry: Striving for a Perfectly Balanced Soccer Team. In Proceedings of the 14th MIT Sloan Sports Analytics Conference. MIT Sloan Sports Analytics Conference. Boston.

Bush, M., Barnes, C., Archer, D. T., Hogg, B., & Bradley, P. S. (2015). Evolution of match performance parameters for various playing positions in the English Premier League. Human Movement Science, 39, 1-11. https://doi.org/10.1016/j.humov.2014.10.003

Carling, C., Espié, V., le Gall, F., Bloomfield, J., & Jullien, H. (2010). Work-rate of substitutes in elite soccer: a preliminary study. Journal of Science and Medicine in Sport, 13 2, 253-255. https://doi.org/10.1016/j.jsams.2009.02.012

Castillo-Rodríguez, A., González-Téllez, J. L., Figueiredo, A., Chinchilla-Minguet, J. L., & Onetti-Onetti, W. (2023). Starters and non-starters soccer players in competition: is physical performance increased by the substitutions? BMC Sports Science, Medicine and Rehabilitation, 15(1), 33-41. https://doi.org/10.1186/s13102-023-00641-3

Chiu, T., Fang, D., Chen, J., Wang, Y., & Jeris, C. (2001). A robust and scalable clustering algorithm for mixed type attributes in large database environment. Proceedings of the seventh ACM SIGKDD international conference on Knowledge discovery and data mining, San Francisco, California. https://doi.org/10.1145/502512.502549

Coelho, D., Coelho, L., Morandi, R., Ferreira Júnior, J., Marins, J., Prado, L., . . . Garcia, E. (2012). Effect of player substitutions on the intensity of second-half soccer match play. Brazilian Journal of Kynanthropometry and Human Performance, 14, 183-191.

Conte, D., Niederhausen, M., LaPlante, M., Tessitore, A., & Favero, T. (2016). Substitution Patterns and Analysis in Men's Division I College Soccer. In (pp. 30-38).

Dancy, B. (2009). An Exploration of Substitutes' Experiences in Football. The Sport Psychologist, 23, 451-469. https://doi.org/10.1123/tsp.23.4.451

Decroos, T., Bransen, L., Van Haaren, J., & Davis, J. (2019). Actions Speak Louder Than Goals: Valuing Player Actions in Soccer. In Proceedings of the 25th ACM SIGKDD international conference on knowledge discovery & data mining (pp. 1851-1861). https://doi.org/10.1145/3292500.3330758

Del Corral, J., Barros, C., & Prieto-Rodriguez, J. (2008). The Determinants of Soccer Player Substitutions: A Survival Analysis of the Spanish Soccer League. Journal of Sports Economics, 9, 160-172. https://doi.org/10.1177/1527002507308309

Eggels, H., van Elk, R., & Pechenizkiy, M. (2016). Expected goals in soccer: Explaining match results using predictive analytics [Eindhoven University of Technology]. The machine learning and data mining for sports analytics workshop.

García-Aliaga, A., Martín-Castellanos, A., Marquina Nieto, M., Muriarte Solana, D., Resta, R., López del Campo, R., Mon-López, D., Refoyo, I. (2023). Effect of Increasing the Number of Substitutions on Physical Performance during Periods of Congested Fixtures in Football. Sports, 11(2), 25-38. https://doi.org/10.3390/sports11020025

Goes, F., Schwarz, E., Elferink-Gemser, M., Lemmink, K., & Brink, M. (2022). A risk-reward assessment of passing decisions: comparison between positional roles using tracking data from professional men's soccer. Science and Medicine in Football, 6(3), 372-380. https://doi.org/10.1080/24733938.2021.1944660

Gollan, S., Hewitt, A., Greenham, G., & Norton, K. I. (2018). Game Style in Team Sports: What is it and how to measure it? In Kinanthropometry and Exercise Physiology (pp. 518-528). Routledge. https://doi.org/10.4324/9781315385662-20

Gómez, M.-A., Lago-Peñas, C., & Owen, L. A. (2016). The influence of substitutions on elite soccer teams' performance. International Journal of Performance Analysis in Sport, 16(2), 553-568. https://doi.org/10.1080/24748668.2016.11868908

Hills, S., Barwood, M., Radcliffe, J., Cooke, C., Kilduff, L., Cook, C., & Russell, M. (2018). Profiling the Responses of Soccer Substitutes: A Review of Current Literature. Sports Medicine, 48, 1-15. https://doi.org/10.1007/s40279-018-0962-9

Hills, S. P., Radcliffe, J. N., Barwood, M. J., Arent, S. M., Cooke, C. B., & Russell, M. (2020). Practitioner perceptions regarding the practices of soccer substitutes. Plos One, 15(2), e0228790. https://doi.org/10.1371/journal.pone.0228790

Hopkins, W., Marshall, S., Batterham, A., & Hanin, Y. (2009). Progressive Statistics for Studies in Sports Medicine and Exercise Science. Medicine and science in sports and exercise, 41, 3-13. https://doi.org/10.1249/MSS.0b013e31818cb278

International Federation of Association Football (Ed.) (2020). Laws of the Game 2020/21. Retrieved from [Accessed 2024, 25 November]: https://www.theifab.com/laws-of-the-game-documents/?language=all&year=all

Kent, P., Jensen, R. K., & Kongsted, A. (2014). A comparison of three clustering methods for finding subgroups in MRI, SMS or clinical data: SPSS TwoStep Cluster analysis, Latent Gold and SNOB. BMC Medical Research Methodology, 14. https://doi.org/10.1186/1471-2288-14-113

Lago-Peñas, C., & Dellal, A. (2010). Ball possession strategies in elite soccer according to the evolution of the match-score: the influence of situational variables. Journal of Human Kinetics, 25(2010), 93-100. https://doi.org/10.2478/v10078-010-0036-z

Lago-Peñas, C., Gómez-Ruano, M., & Yang, G. (2017). Styles of play in professional soccer: an approach of the Chinese Soccer Super League. International Journal of Performance Analysis in Sport, 17(6), 1073-1084. https://doi.org/10.1080/24748668.2018.1431857

Leeuwen, Q. v. (2020). Data science and Marketing Analytics: Analyzing the impact of substitutions in football matches [Master, Erasmus University Rotterdam]. Rotterdam.

Li, Y., Ma, R., Gonçalves, B., Gong, B., Cui, Y., & Shen, Y. (2020). Data-driven team ranking and match performance analysis in Chinese Football Super League. Chaos, Solitons & Fractals, 141, 110330. https://doi.org/10.1016/j.chaos.2020.110330

Li, Y., Zong, S., Shen, Y., Pu, Z., Gómez, M.-Á., & Cui, Y. (2022). Characterizing player's playing styles based on player vectors for each playing position in the Chinese Football Super League. Journal of Sports Sciences, 40(14), 1629-1640. https://doi.org/10.1080/02640414.2022.2096771

Li, Y. (2022). Research on the performance evaluation model of Chinese Super League based on match event data [Master, Beijing Sport University]. Beijing.

Link, D., & Hoernig, M. (2017). Individual ball possession in soccer. Plos One, 12(7), e0179953. https://doi.org/10.1371/journal.pone.0179953

Liu, H., Hopkins, W., Gómez, A. M., & Molinuevo, S. J. (2013). Inter-operator reliability of live football match statistics from OPTA Sportsdata. International Journal of Performance Analysis in Sport, 13(3), 803-821. https://doi.org/10.1080/24748668.2013.11868690

Lorenzo-Martínez, M., Padrón-Cabo, A., Rey, E., & Memmert, D. (2021). Analysis of Physical and Technical Performance of Substitute Players in Professional Soccer. Research Quarterly for Exercise and Sport, 92(4), 599-606. https://doi.org/10.1080/02701367.2020.1755414

Lorenzo-Martinez, M., Rein, R., Garnica-Caparros, M., Memmert, D., & Rey, E. (2022). The Effect of Substitutions on Team Tactical Behavior in Professional Soccer. Research Quarterly for Exercise and Sport, 93(2), 301-309. https://doi.org/10.1080/02701367.2020.1828563

Meyer, J., & Klatt, S. (2023). Additional substitutions in elite European football. International Journal of Sports Science & Coaching, 1-10. https://doi.org/10.1177/17479541231164090

Myers, B. R. (2012). A Proposed Decision Rule for the Timing of Soccer Substitutions. Journal of Quantitative Analysis in Sports, 8(1), 1-22. https://doi.org/10.1515/1559-0410.1349

Nosek, P., Brownlee, T. E., Drust, B., & Andrew, M. (2021). Feedback of GPS training data within professional English soccer: a comparison of decision making and perceptions between coaches, players and performance staff. Science and Medicine in Football, 5(1), 35-47. https://doi.org/10.1080/24733938.2020.1770320

Parziale, E. J., & Yates, P. A. (2013). Keep the ball! The value of ball possession in soccer. Reinvention: an International Journal of Undergraduate Research, 6(1), 1-24.

Passos, P., Araujo, D., & Volossovitch, A. (2016). Performance Analysis in Team Sports. https://doi.org/10.4324/9781315739687

Rathke, A. (2017). An examination of expected goals and shot efficiency in soccer. Journal of Human Sport and Exercise, 12(2), 514-529. https://doi.org/10.14198/jhse.2017.12.Proc2.05

Ruan, L., Ge, H., Shen, Y., Pu, Z., Zong, S., & Cui, Y. (2022). Quantifying the effectiveness of defensive playing styles in the Chinese Football Super League. Frontiers in Psychology, 13, 899199. https://doi.org/10.3389/fpsyg.2022.899199

Scheirer, C. J., Ray, W. S., & Hare, N. (1976). The Analysis of Ranked Data Derived from Completely Randomized Factorial Designs. Biometrics, 32(2), 429-434. https://doi.org/10.2307/2529511

Schober, P., Boer, C., & Schwarte, L. A. (2018). Correlation coefficients: appropriate use and interpretation. Anesthesia & analgesia, 126(5), 1763-1768. https://doi.org/10.1213/ANE.0000000000002864

Silva, R. M., & Swartz, T. (2016). Analysis of substitution times in soccer. Journal of Quantitative Analysis in Sports, 12, 1-20. https://doi.org/10.1515/jqas-2015-0114

Singh, K. (2019). Introducing Expected Threat (xT). Retrieved from [Accessed 2024, 25 November]: https://karun.in/blog/expected-threat.html

Sumpter, D. (2021). Explaining Expected Threat. Retrieved from [Accessed 2024, 25 November]: https://soccermatics.medium.com/explaining-expected-threat-cbc775d97935

Tierney, P. J., Young, A., Clarke, N. D., & Duncan, M. J. (2016). Match play demands of 11 versus 11 professional football using Global Positioning System tracking: Variations across common playing formations. Human Movement Science, 49, 1-8. https://doi.org/10.1016/j.humov.2016.05.007

Tomczak, M., & Tomczak, E. (2014). The need to report effect size estimates revisited. An overview of some recommended measures of effect size. 21, 19-25.

Van Roy, M., Robberechts, P., Decroos, T., & Davis, J. (2020). Valuing on-the-ball actions in soccer: a critical comparison of XT and VAEP. Proceedings of the AAAI-20 Workshop on Artifical Intelligence in Team Sports. AI in Team Sports Organising Committee.

Wang, S. h., Qin, Y., Jia, Y., & Igor, K. E. (2022). A systematic review about the performance indicators related to ball possession. Plos One, 17(3), e0265540. https://doi.org/10.1371/journal.pone.0265540

Wittkugel, J., Memmert, D., & Wunderlich, F. (2022). Substitutions in football - what coaches think and what coaches do. Journal of Sports Sciences, 40(15), 1668-1677. https://doi.org/10.1080/02640414.2022.2099177

Woods, B., & Thatcher, J. (2009). A Qualitative Exploration of Substitutes' Experiences in Soccer. The Sport Psychologist, 23(4), 451-469. https://doi.org/10.1123/tsp.23.4.451