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Analysis of the most intense periods during elite soccer matches: effect of game location and playing position

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Abstract

Purpose: This study aimed to quantify the game-speed demand of elite soccer players using time windows from 5 seconds to 10 minutes, and to examine the effect of match location and playing position on game-speed outputs.

Methods: Twenty-four Serie A (Italy) male professional soccer players (27.5 ± 4.1 years old) participated in this study across an entire season. The players' activity profiles during matches were analysed using a semi-automatic video tracking system (Stats Perform, USA), which provided 2D coordinates of the players, and from these data total distance covered (TD), high-speed running distance (HSR), and sprint distance (SD) were calculated. The most intense periods (MIP) of match play were calculated using a moving average method within 15-time windows (i.e., 5-10-15-30-60-90 seconds and from 2 to 10 minutes) and analysed using a linear mixed model.

Results: Slightly higher sprint distance (estimate values = 3.98, p = 0.0192) was performed when playing a home match. Midfielders run the highest values for total distance (p = 0.0001), centre-back produced the lowest high-speed running distance value (p = 0.0011) and no significant differences between roles were found in terms of sprint distance.

Conclusions: A univariate approach based on velocity can aid in designing training for the most intense periods of a match, considering positional differences for total and high-speed running distance. On the other hand, the consistency in sprint distance across different roles suggests a team behaviour during the MIP of the game such as attacking and defensive transition phases.

Key words: Team Sports; Football; Monitoring; Worst Case Scenario; Peak Locomotor Demand

Introduction

Soccer is a physically demanding sport with games lasting at least 90 minutes. Several studies have described the total physical demand of a match or its relative demand (i.e., the average demand per minute) to define training targets and design training sessions [1,2]. However, it was suggested that the average match activities do not fully explain the demands of the game and they cannot be the only reference point for players' preparation [3]. Specifically, using average match values to set training goals may not expose players to the most intense periods, which occur intermittently throughout matches and increase as the length of the moving average used to calculate them decreases [4].

Previous research showed that mathematical models adopting moving average to assess the relationship between running intensity and duration have shown to be a valid way to quantify soccer match intensity and account for true periods of maximal player output [5], while using fixed durations lacks sensitivity and might underestimate true running demands by up to ~ 25% [3,6]. The peak locomotor periods that occur during a game have been reported using different terms such as most intense periods, abbreviated as MIP [7], peak match or physical demand [8], duration-specific running demands [9], worst case scenario [10] or other similar lexical alternatives. In this paper, we refer to this analysis MIP following the paper published by Novak et al. [10]. From a recent Delphi survey, the MIP in professional soccer are used by practitioners as benchmarks for exercise replication, especially when single repetitions have a short duration to keep as high as possible the training physical demand [11].

This approach can be useful for preparing players for various technical and tactical scenarios, requiring them to achieve high intensities and cover long distances quickly, such as during defensive and attacking transitions [12]. These situations are quite distinct from the typical demands of a game [13,14]. In fact, a 5-min peak match demand was reported to be more than twofold for high-speed running distance and three-to sixfold for sprint distance, depending on the playing position, compared with the match average both in elite female [15] and male [16] players. Raising the bar, previous research has reported that relative distance can be over 200 $m \cdot min^{-1}$ when analysed using short time windows (i.e., 1 min) in USA Major League of Soccer [17], and this game-speed intensity is much higher than the average relative distance (i.e., around 110 $m \cdot min^{-1}$) reported considering the whole game in English professional football [2,18]. Similarly, in other studies, the average locomotor demand was significantly lower than 1-minute peak demand. Specifically, it accounted for approximately 53-59% of the total distance, around 16-19% of the high-speed running distance, and roughly 6-9% of the sprinting distance [14,19]. This very high game demand was not achieved with small, medium or large-sided games, for this reason other specific training options must be explored [13,20,21].

Differences across various playing positions during the 1 to 10-minute periods of highest physical demand in professional male soccer have also been documented [7,13,22,23]. Therefore, playing positions should always be considered when applying the MIP concept. Specifically, central midfielders (CM) reported higher relative distance compared to wide midfielders (WM) [23] and both CM and WM covered greater total distance and fewer meters sprinting compared to the other playing roles [7]. Considering the specific tactical behaviour, attacking midfielders covered greater peak total distance than all other players [22]. In the case of high-speed running, full-backs covered the greatest distance, reaching values of 47.2 ± 24.0 $m \cdot min^{-1}$ when considering the most intense minute of the match [7]. Similarly, peak high-speed distances were greater for wingers [22] or WM and forwards [16] than all other positions.

The effect of game location on physical demand has been opposing in previous studies. It was reported that game-speed outputs are not significantly affected by whether the match is played at home or away [23]. However, higher values of match high-intensity running were observed in home versus away matches [24]. This finding is crucial for ensuring that players' preparation and performance assessments are consistent regardless of match location.

Information on match demand and models for evaluating game speed in professional soccer players is increasing, aiding sports scientists and coaches preparing more representative training exercises. Research has mainly studied time epochs of durations from 1 to 10 minutes [25,26], but peak durations of crucial attacking and defending activities in elite soccer last between 20 and 30 seconds [12]. To our knowledge no shorter than 1 minute duration epochs were analysed for elite soccer players. This results in a lack of benchmarks to verify the effectiveness of soccer-specific methods aimed at exposing players to the very short maximum physical outputs they achieve in competition, such as the few seconds required to sprint to the other side of the pitch after recovering or losing the ball.
Therefore, the aims of this study were, firstly, to quantify and model for the first time the game-speed demands of elite soccer players competing in the Italian Serie A using time windows from 5 seconds to 10 minutes, secondly to compare the effect of match location on game-speed outputs, and lastly to examine the effect of playing position on game-speed outputs. The authors' hypothesis was that game speed is affected by the time window being analysed, by the location of the match (home vs. away), and by the players' positional group.

Methods

Experimental design

A full season observational longitudinal research design was adopted to establish the relationship between peak running intensity and duration in elite adult soccer matches. In this paper, we have called this analysis most intense periods (MIP) following the paper published by Novak et al. [10]. A two-level analysis was conducted to identify MIP from a range of locations (home VS away) and positions (centre-back [CB], full-back [FB], central midfielder [CM], wide midfielder [WM] and forward [F]).

Subjects

Twenty-four male professional Serie A soccer players were monitored in this study (age 27.5 ± 4.1 years; body mass 79.3 ± 6.1 kg; height 183.8 ± 3.9cm; maximum speed 31.0 ± 2.3 km.h^{-1}). The inclusion criteria required their participation in at least one 60-minutes official match. Goalkeepers were excluded from this study, therefore, only outfield players' match data were evaluated. The sample size was not estimated a priori, but convenience sampling was used in this study, which is a non-probability sampling method where subjects are selected for inclusion in the sample because of factors related to the researcher's access to these subjects [27], i.e., the players within a specific professional club that represent a unique sample. The actual sample size of this study was 340 single observations. Player names were anonymized before the data analysis, which was performed blindly by a researcher non-affiliated with the club. The Ethics Committee of the University of Suffolk (Ipswich, UK) approved this study (project code: RETH19/020). Informed consent to take part in this research was signed by the club. All procedures were conducted according to the Declaration of Helsinki for human studies.

Methodology

During 38 official matches, external load metrics were calculated based on data extracted by a semi-automatic video tracking system (Stats Perform, Chicago, Illinois, USA). Validity and reliability of this type of apparatus to monitor competitions were previously reported [28,29]. In particular, errors of instantaneous speed measures was reported to be 0.41±0.08 m·s^{-1} [30], and the typical error of the estimate of 2.8% (90% confidence levels 2.3-3.8%) recorded performing soccer specific movements [28,29]. At the end of each match, a raw speed trace for each player was exported and further analysed using customized algorithms provided by SportAnalytics and written in Python (Anaconda Inc, Python, version 3.10.12). Total distance covered (TD), high-speed running distance (HSR, >20 km·h^{-1}) and sprint distance (SD, >25 km·h^{-1}) were calculated. A moving average analysis technique [3] was then applied to each of the output variables, using 15 different durations: 5-10-15-30-60-90 seconds and from 2 to 10 minutes. These durations were defined considering the inflection point and the decrease rate of the relationship between movement velocity and duration during soccer matches previously described [31]. The peak value achieved throughout each match was recorded for each variable for each player. For example, a 1-minute moving average was calculated over 600 data points (1 minute × 60 seconds × 10 Hz) and moved over the duration of the game activity, i.e. 0–600, 1–601, 2–602, 3–603, etc., for the duration of the file, and the peak 1-min identified from this [8]. The maximal value across each of the moving average window durations has been then extracted and converted to units of metres per minute (m·min^{-1}) for further statistical analysis.

To calculate the most intense periods for HSR and SD, the distance covered was calculated considering only the frames where the speed exceeded 20 and 25 $km \cdot h^{-1}$, respectively. To quantify the relationship between moving average duration and running intensity, each of the three peak output measures was evaluated relative to the moving average duration, as a power law $y = cx^n$ relationship [5]. This resulted in an intercept (c) and slope (n) for each metric (i.e., TD, HSR and SD) for every individual match observation. In addition, team peak values (i.e. the average of all the single player values) for each match were recorded as well as the location to compare home (*team0*) and away (*team1*) games.

Statistical Analyses

Before statistical analyses, the slope and intercept of the speed values were log transformed. All statistical analyses were performed using customized algorithms (R Core Team. R, version l4.3.2). Linear mixed models (*lme4* package in R; V 1.1-35.1 and *lsmeans* package in R; V 2.30.0) were used to determine the magnitude of differences between game location (home VS. away; fixed effects) and players playing roles (CB, FB, CM, WM, and F; fixed effects). The random effects in the models' design were player identification codes (representing mean differences between athletes). The least-squares mean test provided pairwise comparisons of running intensity measures for each game location and playing role, which were further assessed using estimates of 95% confidence intervals (Cis). To control for potential Type I errors due to multiple comparisons, the Bonferroni correction was applied. Unless otherwise stated, significance was set at $p < 0.05$ for all tests.

Results

All the results for all the durations analysed are reported and expressed in m·min^{-1} in Table 1. Total distance varied from 456 m·min^{-1} of the most intense 5 seconds (i.e. 38 m in 5 seconds) to 206 m·min^{-1} of the most intense minute to 136 m·min^{-1} of the most intense 10-minute match fraction. The Power Law curves are reported in Figure 1. All models demonstrated near perfect fits ($R^2 > 0.97$).

MIP	**Total distance** (m·min^{-1})	**High-speed running** (m·min^{-1})	**Sprint running** (m·min^{-1})
5”	456.0 ± 34.9	456.0 ± 40.0	432.0 ± 115.2
10”	390.0 ± 39.3	348.0 ± 70.2	234.0 ± 102.4
15”	332.0 ± 32.8	240.0 ± 58.5	160.0 ± 70.1
30”	260.0 ± 25.9	130.0 ± 35.6	80.0 ± 35.8
1’	206.0 ± 18.3	74.0 ± 19.5	41.0 ± 18.8
90”	185.0 ± 14.2	54.7 ± 14.3	28.4 ± 12.9
2’	173.5 ± 13.7	45.0 ± 12.5	21.5 ± 10.4
3’	159.2 ± 12.2	36.2 ± 9.8	15.2 ± 7.4
4’	152.5 ± 11.7	29.8 ± 8.2	12.2 ± 5.9
5’	148.0 ± 11.4	26.6 ± 7.4	10.6 ± 5.1
6’	144.6 ± 11.4	24.3 ± 7.0	9.0 ± 4.6
7’	142.2 ± 11.4	22.3 ± 6.5	8.0 ± 4.1
8’	139.3 ± 11.1	21.0 ± 6.1	7.4 ± 3.8
9’	137.3 ± 10.8	20.0 ± 5.9	6.7 ± 3.4
10’	136.2 ± 10.9	19.0 ± 5.6	6.2 ± 3.3

Table 1. Team average ± standard deviation for total distance, high-speed running distance (>20 km·h^{-1}) and sprint distance (> 25 km·h^{-1}) of the most intense periods of the game using 5 seconds to 10 minutes moving average time windows and expressed in m·min^{-1}.

Home vs away games

For all the time windows analysed there were no significant differences observed between home and away matches in terms of total distance covered and high-speed running. However, trivial differences were noted in sprint distance performed by the team, which are slightly higher during home games. Estimate values were -2.54 (p = 0.1003), 1.1 (p = 0.5067) and 3.98 (p = 0.0192) for TD, HSR and SD, respectively.

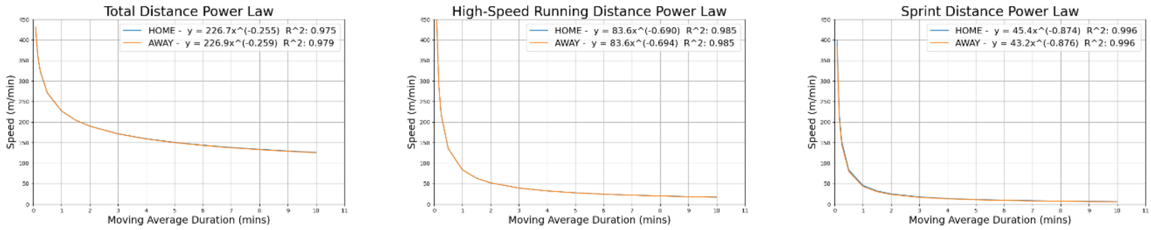

Figure 1. Power law models for home and away matches for (A) total distance, (B) high-speed running distance (>20 km·h-1) and (C) sprint distance (>25 km·h-1).

Playing roles comparison

The power law curves with the relative slopes and intercepts are reported in Figure 2. Since the differences between roles observed across all time windows from 5 seconds to 10 minutes were consistent, we chose to report only the differences for the most intense minute (Tables S1-S3). In fact, it was previously suggested that short-duration passages (i.e., 1 min) are a more precise approach to establish the MIP of the match, as additional issues (e.g., match stoppages, contextual factors and players fatigue) might influence the MIP over longer time windows [32].

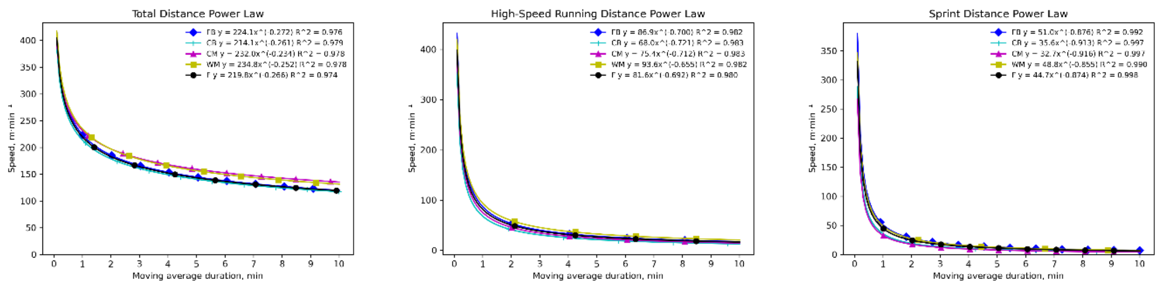

Figure 2. Power law models for (A) total distance, (B) high-speed running distance (>20 km·h^{-1}) and (C) sprint distance (>25 km·h^{-1}) run by full-back (FB), centre-back (CB), central midfielder (CM), wide midfielder (WM) and forward (F).

Independently by the time window, the highest values for total distance were recorded by CM and WM, significantly different from CB (+19 m, p = 0.0001 and +20 m, p < 0.0001, respectively), F (+12 m, p = 0.0082 and +12 m, p = 0.0019) and FB (+13 m, p = 0.0035 and + 14 m, p = 0.0004). CB performed less high-speed running compared to FB (-12 m, p = 0.0011) and WM (-13 m, p = 0.0079), while CM values were lower compared to WM (-10 m, p = 0.0052). In terms of sprint distance, no significant differences were found between roles, but only a tendency between CB and FB (-63 m, p = 0.0839).

Discussion

The aims of this study were to quantify and model the most intense periods of game-speed demand for elite soccer players competing in the Italian Serie A using time windows from 5 seconds to 10 minutes. In addition, the study compared the effect of match location on MIP game-speed outputs and the effect of playing position was examined. During the most intense minute of the match, slightly higher sprint distance was performed during home games. Considering the most intense minute, CM and WM ran the highest values for total distance, CB produced the lowest high-speed running distance value and no significant differences between roles were found in terms of sprint distance.

Comparing the running intensities analysed in the different time windows (Table 1) it appears that the most intense 5 seconds were run at a speed above 20 $km \cdot h^{-1}$ since TD and HSR values were superimposable. Increasing the time window, TD values decreased slower than HSR and SD values, confirming that high-speed was requested for reduced time periods during a match. In fact, peak durations of crucial attacking and defending activities in elite soccer were reported to last between 20 and 30 sec [12]. The different decrease ratio of the curves supports the need of different set durations for exercises targeting the TD or HSR and SD of the MIP. For TD seems that no differences exist between time windows longer than 5 minutes, while for HSR and SD seems that this breaking point occurs earlier around 2 minutes. Anyway, as previously reported [31], for all TD, HSR and SD the main differences were detected for time windows lower than 1 minute with values decreasing quickly from 5 to 60 seconds.

Similar to what previously reported for HSR in elite women soccer [33] and total distance and HSR in elite male soccer [2,24], playing at home appeared to be slightly more demanding in terms of SD in the most intense passages of the game, potentially because of the in favour-crowd effect previously described [34]. This information, for instance, can be useful when planning the first match for a player that sustained a hamstring strain injury. In fact, the lower sprint running capability of players returning from injury has been previously reported [35]. For this reason, planning away the first official match after that kind of muscle injury can be advisable when feasible. However, other previous studies have identified no effect between game location and MIP [23] and a previous study reported the MIP to be more demanding in all the external load variable when playing away matches [36]. These conflicting results may be explained by the interference of other contextual variables not accounted for in previous studies or in our own research, such as the period of the season, the level of the opponent, ball possession distribution, playing style, or goal differential.

Differences across various playing roles during the MIP of the game were found even if differences are minimized in peak-intensity periods compared to match average values [37]. Similarly to what previously reported, in the 1 min MIP we have found the highest values for total distance were recorded by midfielders [7], independently if they were CM or WM [36]. Unlike previous studies [10,23], we did not find significant differences between central and wide midfielders, probably because of the different tactical organization [17]. For HSR we can confirm that FB and WM were the most taxed players [7,16,22], especially compared to CB, which performed the lowest high-speed running distance. In terms of sprint distance, no significant differences were found between roles, but only a tendency between CB and FB. This result suggests a specific team behaviour when speed above 25 $km \cdot h^{-1}$ are required during the game, typically during offensive and defensive transition phases when all players need sprinting to quickly move into the opposing midfield [12], regardless of the goal differential and game time [38]. As previously supposed, the rationale for this may be the nature of MIP, that lead all players to act suddenly to try to recover a steady state and avoid the opponent's progression towards a goal scoring opportunity [36].

Limitations and future directions

Although adding relevant information regarding elite adult soccer players MIP, this study is not without limitations. Firstly, the sample utilized is limited to just one team, however, this was due to the specificity of the top-level soccer players monitored in this study (Serie A players), therefore we used convenience sampling and repeated the observations during a whole season gathering a large dataset [39]. Contrariwise, a strength of this study is its high ecological validity; data coming from a very specific population have a very high impact on real-world practice, even with a small sample size [40]. A second limitation that should be acknowledged is the univariate approach adopted to describe the most intense periods: we based the analysis on velocity without considering all the other high-taxing actions like jumping, dribbling, accelerating, decelerating or duelling that need a dedicated analysis to detect the relative peak demand during games. However, running demand represents the key performance index of most interest to practitioners for targeting in training [10], especially when aiming to produce a specific amount of load through representative soccer-specific drills characterized by interactions between players and movement in relation to the position of the ball [25]. Furthermore, considering in the analysis other contextual factors beyond the fans support like the tactical situations would provide a more holistic and reliable approach driving to better training proposals.

Conclusions

The quantification of the peak match demands is important to appropriately prepare players for the most intense periods of the game using soccer-specific drills. During the most intense minute of the match in terms of running demand, slightly higher sprint distance was performed when playing a home match, probably because of the crowd support. Midfielders run the highest values for total distance, centre-back produced the lowest high-speed running distance value and no significant differences between roles were found in terms of sprint distance.

Practical applications

The slightly higher sprint distance performed when playing a home match should be considered when planning the first match for a player that sustained a hamstring strain injury and for this reason with a lower sprint running capability. The playing role effect on total distance run during the most intense minute of the match suggests that a univariate approach based on velocity can help to develop representative training proposal when planning a specific exercise targeting the most intense periods. At the same time, when the target is the sprint distance, role differences can be disregarded when using the most intense minute of the game as benchmark, probably because of a team behaviour during the most intense phases of the game such as offensive and defensive transition phases. Finally, practitioners need to keep in mind that the most intense periods benchmark should be considered exclusively to monitor the physical demand of representative soccer-specific drills and not for running-based drills.

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Supplementary material

Table S1. Most intense minute (60 seconds) in terms of total distance for full-back (FB), centre-back (CB), central midfielder (CM), wide midfielder (WM) and forward (F). Confidence level used: 0.95.

Contrast	Difference	SE	Lower CL	Upper CL	P value
CB-CM	**-19.366**	4.75	-28.84	-9.897	**<0.001**
CB-F	**-7.664**	4.94	-17.54	2.212	0.126
CB-FB	**-5.964**	3.26	-12.37	0.447	0.068
CB-WM	**-19.703**	4.16	-27.99	-11.417	**<0.001**
CM-F	**11.702**	4.35	3.08	20.324	**0.008**
CM-FB	**13.403**	4.47	4.51	22.291	**0.004**
CM-WM	**-0.337**	3.18	-6.6	5.928	0.916
F-FB	**1.701**	4.69	-7.66	11.060	0.718
F-WM	**-12.039**	3.79	-19.55	-4.533	**0.002**
FB-WM	**-13.740**	3.77	-21.21	-6.267	**<0.001**

Table S2. Most intense minute (60 seconds) in terms of high-speed running (>20 $km \cdot h^{-1}$) for full-back (FB), centre-back (CB), central midfielder (CM), wide midfielder (WM) and forward (F). Confidence level used: 0.95.

Contrast	Difference	SE	Lower CL	Upper CL	P value
CB-CM	**-2.86**	5.31	-13.4	7.7	0.592
CB-F	**-8.41**	5.54	-19.5	2.65	0.134
CB-FB	**-11.58**	3.53	-18.5	-4.64	**0.001**
CB-WM	**-12.6**	4.64	-21.8	-3.38	**0.008**
CM-F	**-5.56**	4.81	-15.1	3.94	0.249
CM-FB	**-8.72**	4.97	-18.6	1.14	0.082
CM-WM	**-9.75**	3.46	-16.6	-2.93	**0.005**
F-FB	**-3.16**	5.25	-13.6	7.29	0.549
F-WM	**-4.19**	4.18	-12.5	4.09	0.319
FB-WM	**-1.02**	4.18	-9.3	7.25	0.807

Table S3. Most intense minute (60 seconds) in terms of sprint distance (>25 $km \cdot h^{-1}$) for full-back (FB), centre-back (CB), central midfielder (CM), wide midfielder (WM) and forward (F). Confidence level used: 0.95.

Contrast	Difference	SE	Lower CL	Upper CL	P value
CB-CM	**-25.613**	5.38	-13.26	8.141	0.635
CB-F	**-47.031**	5.6	-15.9	6.491	0.404
CB-FB	**-62.858**	3.63	-13.42	0.848	0.084
CB-WM	**-62.127**	4.71	-15.57	3.145	0.190
CM-F	**-21.418**	4.9	-11.83	7.546	0.666
CM-FB	**-37.245**	5.05	-13.75	6.297	0.463
CM-WM	**-36.514**	3.55	-10.64	3.336	0.305
F-FB	**-15.827**	5.31	-12.17	9.006	0.767
F-WM	**-15.096**	4.26	-9.94	6.924	0.724
FB-WM	**0.0731**	4.25	-8.34	8.489	0.986