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Using Ultra-Wide Band to Analyze Soccer Performance through Load Indicators during a Full Season: A Comparison between Starters and Non-Starters

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Abstract: The objectives of this study are: (1) to compare match load demands through load indicators between starters and substitutes, and (2) analyze the degree of correlation in the variables analyzed in this investigation. Twenty-two semi-professional soccer players were analyzed during a full season's 38 official matches. Participants were assigned to two different groups according to their participation in the game: (a) starting-up players (≥90 min played) vs. substitute players (≥45 min played in the second half). Statistical analysis was performed by using Mann–Whitney U test to conduct pairwise comparison and Spearman correlation to demands correlation in each group. Significant differences in both absolute and relative variables in player load (P, $p < 0.01$; $p < 0.01$), metabolic power (MP, $p < 0.01$; $p = 0.15$), equivalent distance index (EDI, $p = 0.87$; $p < 0.01$), dynamic stress load (DSI, $p < 0.01$; $p = 0.977$), energy expenditure (EE, $p < 0.01$; $p < 0.01$), high metabolic load events (HMLE, $p < 0.01$; $p < 0.01$), and high metabolic load distance (HMLD, $p < 0.01$; $p = 0.09$). Overall, high direct correlations in the starting-up group in absolute and relative demands of PL, PM, HMLD, EE, and DSL were found, as well as high inverse correlation in the substitute group in all variables, excluding DSL and HMLD. In conclusion, the absolute differences found suggested a different training load management during training sessions.

Keywords: applied sciences; football; load; technology; global positioning system

1. Introduction

Football is a highly complex sport that incorporates the interaction between physical and technical factors [1], where short high-intensity multidirectional efforts and longer periods of low intensity activity are combined [2]. The training process is considered as an effective means to achieve a state of optimal physical, technical, and tactical form for the competition [3]. Both the games and the training sessions play an important role in the preparation of the player, due to the psychophysical stress that this entails for them [4].

Accurate and objective quantification of players' activities is essential to understand the physical demands of football [5,6]. Currently, there is an increase in the analysis of football data because it entails a competitive advantage [7]. Currently, accelerometers, gyroscopes, and magnetometers are commonly used to measure the activity profiles of athletes in team sports [8]. Recently, FIFA has amended its policy to allow the use of Electronic Performance Tracking Systems (EPTS) as tracking devices in official matches [9]. This modification means that the use of microtechnology to quantify the movement of the player during matches is not reduced to only friendly matches [10] and can be used in real competition situations.

Commonly, variables such as distance covered or activity time at different speeds have been used for the quantification of football demands [11], the profile of these requirements being analyzed in competitions such as English Premier League [12], Italian Serie A [13], Spanish La Liga [14], French Ligue 1 [15], German Bundesliga [16], and also in the European Champions League [17,18] and in International Championships [19]. Subsequently, the indexes based on triaxial acceleration and metabolic cost have been progressively introduced [20,21], the second being controversial despite published research [22]. The analysis of this information has tended to be more complex because the technologies use different algorithms and time duration to classify the actions and this limits the comparability between the studies [23].

The different investigations which have analyzed the load in football have shown that there seems to be a decrease in the physical performance of the players in three different moments of the matches [13]: (1) after short periods of intense activity in both halves; (2) in the initial phase of the second half; and (3) towards the end of the game. This loss of performance has been associated with the physiological fatigue of the players [13,24], since the physical activity carried out by the players in the first half and in the second half has been analyzed [12,17,25]. In order to minimize the effects of fatigue, coaches can introduce substitute players to replace injured or underperforming players, in addition to making tactical changes [18]. The decrease in physical activity during official matches occurs not only due to physiological fatigue, but also to situational variables such as the half-time score [26], the level of the opponent [26], and the location of the match [27], which also have an influence on performance.

Although there are numerous publications which focus on physical demands in competition, little progress has been made with regard to the optimization of the variables used by coaches and physical trainers [28]. Therefore, the objectives of this study are: (1) to compare the kinematic demands among the players who completed the whole game and the players who have been substituted, and (2) analyze the degree of correlation in the variables analyzed in this investigation.

2. Materials and Methods

2.1. Participants

Twenty-two male semi-professional soccer players (age: 22.56 ± 4.8 years; weight: 75.5 ± 5.5 kg; height: 1.79 ± 0.5 m) voluntarily participated in this study. All athletes were members of a Club of the Third Soccer Division League in Spain. Two or more years of experience at national level and no reports of neuromuscular or other health issues were set as an inclusion criterion. Goalkeepers were excluded from the study because their physical load differs from all field players.

The club and players were informed of the details of the study and gave their written informed consent of participation. Data was managed confidentially, and it was coded by the main author. This study followed the ethical code of the World Medical Association and was guided under the standards of the Helsinki Declaration (2013). The protocol was approved by the Bioethics Committee of the University of Murcia, Spain (Reg. Code: 2061/2018).

2.2. Instruments

Anthropometry. Participant's height was measured using a wall stadiometer (SECA, Hamburg, Germany). Body mass was obtained using a body monitor (BC-601, TANITA, Tokyo, Japan).

External Load. External load variables were obtained using an inertial device (WIMU PRO^{TM}, RealTrack Systems, Almeria, Spain). This device has a 1 GHz microprocessor, 8 GB flash memory, and a high-speed USB interface to obtain, save, and link data for future analysis. The device included a 4 h lifetime battery, weighing 70 g and with dimensions as follows: 81 × 45 × 16 mm. The device has different sensors (4 accelerometers, gyroscope, magnetometer, Global Positioning Systems (GPS), and ultra-wideband (UWB) systems) in order to assess external load at a frequency of 100 Hz [29–31].

UWB technology allows the devices to track participants' indoor/outdoor movements and GPS geo-tracks the device in outdoor conditions. UWB references the device in the field using 500 MHz radiofrequency technology and 20 Hz data collection through six anchors priorly set around the field. The precision of this system has been previously confirmed [6,32–34].

2.3. Procedure

Data was obtained from 38 official matches of the entire 2017–2018 season. All matches took place on a grass field. Two groups were made according to participation status and time: (a) starting-up players with a total of ≥90 min played or (b) substitute players with a total of ≥45 min played in the second half of the game.

The inertial devices were attached to players using an anatomically adjusted neoprene vest at the level of C7 and in the interescapular medial. Device initiation and attachment was performed following fabricant´s instructions 15 min prior warm up and collected at the end of the match. Data was extracted and analyzed using S-PRO^{TM} software (RealTrack Systems, Almeria, Spain).

2.4. Variables

In Table 1, the variables analyzed in the present research were shown. These are divided into two groups following [35]: Metabolic and Mechanical.

2.5. Statistical Analysis

The descriptive statistics were calculated and reported as mean (M) ± standard deviations of the mean (SD) on each variable. Normal distribution of data was checked using Shapiro–Wilk test ($p < 0.05$), a non-parametric [36] Mann–Whitney U test was used to detect differences between the starting-up players (played all the match) and the substitute players (played < 45 min). To identify the magnitude of differences, Cohen's d effect size (d) was calculated. The following values were used to qualify Cohen's d [37]: very low (0–0.2), low (0.2–0.6), moderate (0.6–1.2), high (1.2–2.0), and very high (>2.0).

In the present study, pairwise-correlation selection were used as feature selection approach and can be roughly considered a filter method. Then, a correlation analysis between the external loads variables in relation to the playing time in the official matches were assessed using Spearman's product-moment correlation (r). Correlation was considered when pairwise correlation > 0.8 [35]. The magnitude of the correlation coefficients was deemed as trivial ($r^2 < 0.1$), small ($0.1 < r^2 < 0.3$), moderate ($0.3 < r^2 < 0.5$), high ($0.5 < r^2 < 0.7$), very high ($0.7 < r^2 < 0.9$), nearly perfect ($r^2 > 0.9$), and perfect ($r^2 = 1$) [37]. Data analysis was performed using IBM SPSS Statistics (v24.0; SPSS Inc., Armonk, NY, USA), and figures were designed using GraphPad Prism (v7; GraphPad Software, La Jolla, CA, USA). Significance was set prior as $p < 0.05$.

Table 1. Description of selected physical variables.

Variables	Name and Acronym	Unit	Description
Metabolic	Metabolic Power (PM)	W/kg	Product of speed (S) and energy cost of the activity (EC) derived from inclination and acceleration calculated by the following equation: PM = EC × S
	Metabolic Power/minute (PM/min)	W/kg/min	Estimate average Metabolic Power workload per min
	High-Metabolic Load Distance (HMLD)	(m)	Distance travelled by a player when the metabolic power is >25.5 W/kg
	High-Metabolic Load Distance/minute (HMLD/min)	(m/min)	Estimate average High Metabolic Load Distance per min
	High-Metabolic Load Events (HMLE)	(n)	Number of separate movements/efforts undertaken in producing HML distance
	Energy Expenditure (EE)	(Kcl)	Energy of any body movement produced by skeletal muscles
	Energy Expenditure/minute (EE/min)	(Kcl/min)	Average of Energy Expenditure per minute
	Equivalent distance index (EDI max)	(%)	Maximum ratio between Equivalent Distance (the distance that the athlete would have run at a steady pace on grass using the total energy spend over the match) and the Total Distance performed by a player
	Equivalent distance index/minute (EDI/min)	(%/min)	Average Equivalent Distance Index per minute
Mechanical	Dynamic Stress Load (DSL)	(n)	Total of the weighted impacts, based on accelerometer values over 2 g
	Dynamic Stress Load/minute (DSL/min)	(n/min)	Average of Dynamic stress load per minute
	Player Load (PL)	a.u.	Vector sum of device accelerations in the 3 orthogonal axes (vertical, anteroposterior, and lateral)
	Player Load/minute (PL/min)	a.u./min	Accumulated Player Load workload per min

3. Results

In Table 2, the descriptive and the differential analysis in relation to playing time was performed. The starting-up players presented higher values in total external load variables (Z = −6.37 to −4.51; $p < 0.001$; d = 4.57 to 1.08), except in the Max Edi variable (Z = −0.15; p = 0.873; d = 0.06). Instead, the substitute players performed greater values in relative external load variables (Z = −6.24 to −2.94; $p < 0.001$; d = −1.69 to −0.87), except in HDML/min (Z = −1.65; p = 0.099; d = −0.55), DSL/min (Z = −0.03; p = 0.977; d = −0.06), and PM/min (Z = −1.44; p = 0.148; d = −0.61).

Then, the correlational analysis between external load variables was shown in Figure 1 (starting-up players) and Figure 2 (substitute players). Differences in the correlations behavior in relation to playing time was found. In starting players, only direct relationships between variables were found. Nearly perfect results in within-variable correlations (total vs. relative) were shown. In between-variable correlations, very high relationships between PL, PM, HMLD, EE, and DSL, and trivial relationships between EDI and the rest of variables were found. Instead, in substitute players, an inverse correlation was found in within-variable correlations, except in DSL and HMLD.

Table 2. Descriptive and difference analysis in relation to playing time in external load variables.

Variables	Starting-Up Players		Substitute Players		*Z*	*p*	*d*
	M	SD	M	SD			
PL (a.u.)	135.37	17.58	50.17	22.75	−6.37	0.000	4.14
PL/min (a.u./min)	1.49	0.19	1.68	0.18	−3.46	0.001	−1.03
PM (W/kg)	32.19	4.05	11.75	4.79	−6.37	0.000	4.57
PM/min (W/kg/min)	0.35	0.04	0.42	0.15	−1.44	0.148	−0.61
EDI max (%)	1.35	0.38	1.33	0.28	−0.15	0.873	0.06
EDI/min (%/min)	0.01	0.00	0.06	0.04	−6.24	0.000	−1.69
HMLD (m)	2262.61	600.87	846.08	395.14	−6.13	0.000	2.84
HMLE (n)	246.89	42.55	99.70	39.06	−6.36	0.000	3.62
HMLD/min (m/min)	24.86	6.58	29.07	8.55	−1.65	0.099	−0.55
EE (Kcl)	1184.61	163.62	434.97	192.95	−6.37	0.000	4.16
EE/min (Kcl/min)	13.02	1.80	14.61	1.86	−2.94	0.003	−0.87
DSL (n)	379.01	290.48	140.65	137.07	−4.51	0.000	1.08
DSL/min (n/min)	4.16	3.21	4.34	3.22	−0.03	0.977	−0.06

Note. M: Mean; SD: Standard deviation; Z: Z-value in U Mann-Whitney test; *p*: *p* value; *d*: Cohen's d effect size; PL: Player Load; PM: Metabolic Power; EDI: Equivalent distance Index; HMLD: High Metabolic Load Distance; HMLE: High Metabolic Load Events; EE: Energy Expenditure; DSL: Dynamic Stress Load.

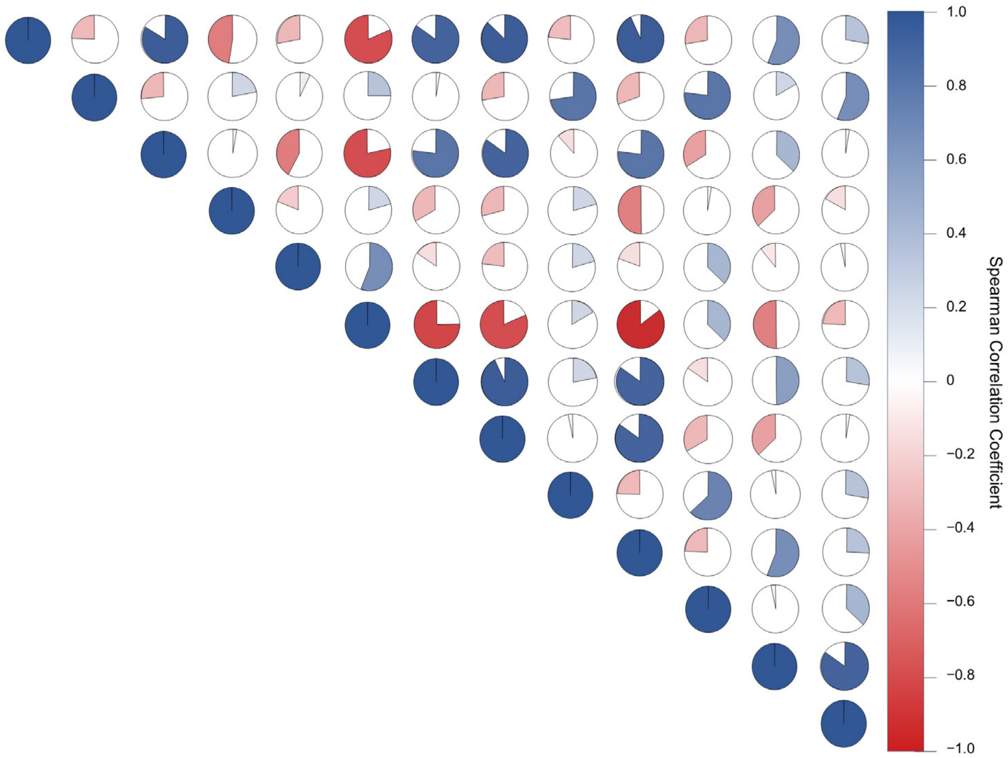

Figure 1. Pairwise Spearman correlation of the external load variables from official matches data in starting-up players.

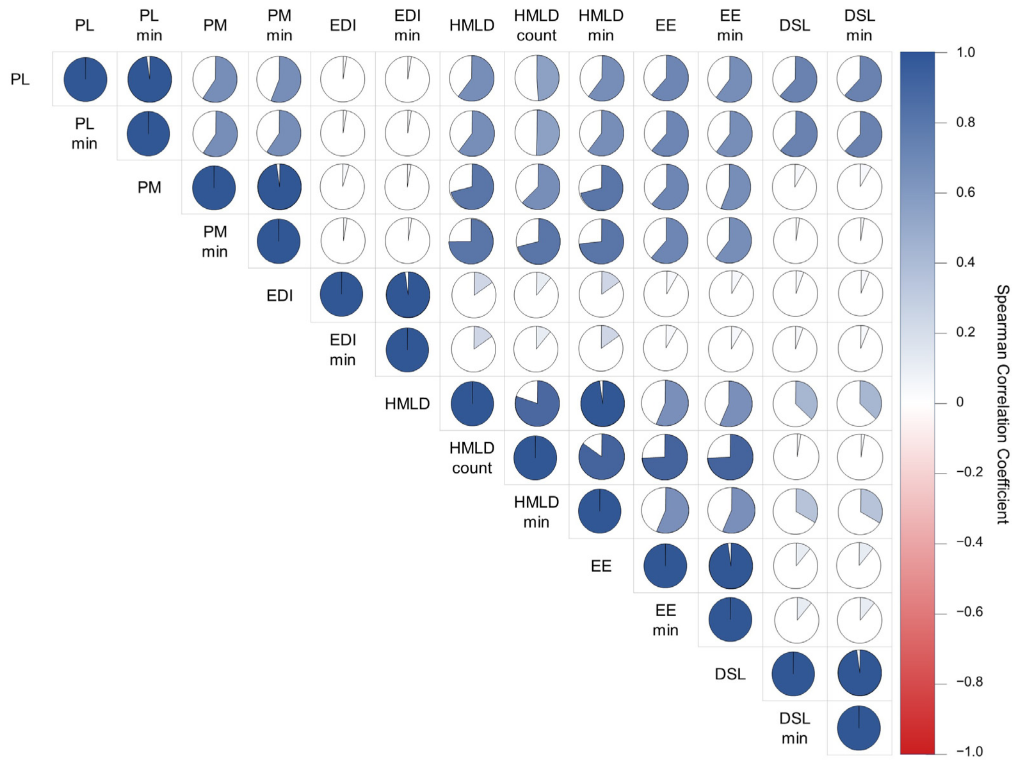

Figure 2. Pairwise Spearman correlation of the external load variables from official matches data in substitute players.

4. Discussion

The current study had a twofold purpose of comparing the workload demands of official soccer matches between starters (players who those started the match on the field and completed the whole game) and non-starters (players who those started the match on the bench and entered in the second half-time). The second goal was verifying the magnitude of mutual associations between metabolic and mechanical load variables derived from electronic position tracking system in each playing status groups. The main findings of this investigation indicates that: (1) Starters exhibited superior unstandardized internal/external load across matches, but the non-starter group experienced a higher relative match intensity when accounting for playing time. (2) However, it not hold true for all parameters such as HDML, DSL, and PM per minute being independent of playing status. (3) While, in starting players', higher total amount of a given load parameter was related to its greater relative occurrence, an inverse association was observed in the case of non-starters. (4) Finally, important correlations existed among various distinct match running performance measured or estimated indicators (e.g., between PL, PM, HMLD, EE, DSL) excepting in reference of the EDI marker.

Here, starter players experienced a greater accumulated load during matches, considering only non-standardized unit measures while the non-starters presented a higher relative match intensity (data normalised per minute). This reinforced the need to account for both absolute parameters and divide by playing time when computing match running performance, as in the case of starters versus non-starters comparisons, to prevent any equivocal interpretations (e.g., starters sustaining exercise at a greater effort levels than non-starters). The notion that substitutes entering the pitch can increase the overall game intensity in elite soccer [38,39] is also supported by the present study in semi-professional 3rd division peers. Indeed, counteracting match-induced fatigue effects (e.g., running performance declines) is among the most common expectations of practitioners when promoting substitutions as revealed in a recent survey [40]. Despite contrasting results being found concerning acceleration/deceleration demands possibly being due to the small number of studies found [41,42], classical workload indices such as relative total distance covered and high-intensity running distance were consistently greater in reserves entering over the match as compared to starters in previous work [38,39,41,43]. Taken together, our results, in addition to some of the literature, indicate that scheduling training sessions and recovery is necessary to be taken into account in regard to noted discrepancies in match stimuli (i.e., intensity and volume) according to player status (see for example [44]), since inter-individual game external load profiles may be related to ensuing production of stress markers [45–47] as well as the fact that match running performance is a direct product of training/recovery stimulus delivered to players [48,49]. Conversely, it does not always hold true since in-game HDML and PM per minute were independent of playing status. In this sense, using metabolic power metrics has not been a consensus in research [22,50–52] because issues including underestimation of energy expenditure can arise when adopting this as a method. It is advisable to view the inclusion of metabolic power approach-derived metrics with caution given their likely poor sensitivity in detecting clear differences according to the level of players' participation in the matches.

Specifically concerning starting players, the present work revealed that a higher total amount of a given external load parameter (volume) was related to its greater relative occurrence (intensity). On the other hand, some inverse associations were observed in the case of non-starters. It may indicate that greater on-field locomotor qualities of substitutes (i.e., intense displacements) might generate higher efficiency in their movements across the field (e.g., greater playing time with ball possession; [1]), since players who experienced superior relative intensity were those who also possibly wear out to a lesser degree in terms of accumulated efforts. Regarding the starters, our result means that absolute and relative indicators contain almost the same information in an inter-individual perspective. It is important that further research explores it within an individual basis [53], since it was recently suggested that match-play external loads are also player-specific in addition to being position-dependent [54].

Another key finding of the present study was the strong relationships flagged among various distinct match running performance indicators (i.e., PL, PM, HMLD, EE, DSL), except in reference to the EDI marker. Importantly, this could be of benefit in understanding that global measures of accumulated demand, regardless of the degree of effort (e.g., player load) should not be taken as less important than those reflecting mostly high-intensity periods, since, as the correlations (e.g., PL versus HMLD) indicated, there is a mutual interference among them. Exemplifying this, in a series of papers by Aquino and coworkers [55–57], while a range of contextual factors influenced high-speed running distance, the total distance covered was usually impacted concomitantly and in the same direction. Our correlation analysis also provided empirical evidence on the metabolic–mechanical relation during game actions, further highlighting the need for adequate fitness levels to sustain running bouts (e.g., explosive efforts) across a full match [58–60]. Finally, identifying collinearity trends is of paramount importance in the selection of pertinent variables, such as those derived from large datasets, perhaps helping reduce the amount of information provided by the electronic position monitoring systems. In particular, deleting redundant information assist decreases the number of dependent measures to be tested, that represents a common statistical challenge [61]. From a practical perspective, extracting the most relevant markers (i.e., player/dynamic stress load) is always desirable to supply coaching staff with time-efficient frameworks [62,63]. However, the absence of a similar behavior to reserve athletes potentially limits the aforementioned interpretations to only starting players at the present moment.

In short, semi-professional soccer match play demands to a distinct extent starters and non-starter players. The former experience a greater accumulated effort over time while the latter undertake a higher intensity of match-play considering the duration of participation. Also, metabolic markers are related to match running outputs and can be used in an interchangeable form in starters but not non-starters. Owing existing collinearity among estimated or directly determined kinematic parameters, using only PL and DSL is therefore warranted among the measures considered here. Interestingly, a greater amount of some external load indicators may not produce a more intense in-game locomotor profile of non-starter soccer athletes, suggesting a possible technical-tactical interference in the match running performance of such groups of players.

5. Limitations of the Paper and Future Approaches

Five major limitations must be pointed out to the present study and should be considered in future experiment design/match analysis. Firstly, due to a rapid evolution in soccer demands across decades, in addition to some changes in game rules, retrospective data is not warranted as a benchmark of match profile or even basis to future training prescriptions [64]. Second, players from all playing positions were pooled to compute differences according to status and when assessing correlations within and between variables. Despite this not being uncommon in research on the topic [39], it may have introduced a bias, especially in regard to the second purpose (e.g., overestimated correlation magnitudes among some parameters). Third, most substitutions occur in soccer across the second half but not at match interval [18,65], and thereby the actual profile of substitutes might not have been captured here. Fourth, there was not a distiction between congested or non-congested match periods [66–68]. Fifth, the data represents semi-professional athletes playing in a specific country, which potentially compromises the generalizability of the above mentioned applications to players of other standards/locations. Aside from the evident limitations, it is important to note that the current study adds to the current literature of starters versus non-starters paradigm, that predominatly adopted traditional match worload metrics [38,43,44,69] or used the advanced ones similar to these computed here, notably only in training/friendly matches [41,42,70].

6. Practical Applications

Based on the evidence provided by the present study, it is confirmed that semi-professional official fixtures benefit from the substitution of some players at half-time, given the increase in match intensity promoted by reserve athletes as compared to those participating in the whole match. However, doubt still persists with regard to the relevance of metabolic power approach-derived measures as central parameters of match running performance, thereby indicating caution when dealing with such data types in soccer. In opposition to what occurred in line-up players, a greater total engagement in game locomotor actions was not often linked to superior standardized running outputs, implying a need of non-starter players to receive sufficient and effective pre-pitch entry preparation aiming at avoiding energy waste in 'unnecessary' displacements. Development of starter players' metabolic aspects may have a direct impact on their in-game running mechanical responses, while improving movement technique can in the same way assist utilization of energy supply in a more efficient way, owing to its direct associations revealed here. To summarize, taking into account that there was a substantial shared variance among several internal/external parameters representative of match running performance, the selection of a strict number of variables, in particular those directly measured (e.g., PL and DSL), is recommended for future practice and research aimed at preventing possible statistical pitfalls as well as facilitating interpretation and reporting by coaching staffs.

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