DIFFERENCES IN MECHANICAL EFFICIENCY BETWEEN FEMALE AND MALE FOOTBALL PLAYERS DURING OFFICIAL MATCHES

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Original scientific paper
DOI 10.26582/k.56.2.11

Abstract:

This study aimed to compare the values of external load measures and mechanical efficiency between male and female soccer players considering the match periods. A male professional soccer team (n=19) and a female professional soccer team (n=16) were monitored in official matches by Global Positioning System (GPS) devices (male 137 and female 144 observations). The external load variables studied were distance covered per minute (DCmin in m·min^{-1}), player load per minute (PL in AU·min^{-1}) and the mechanical efficiency obtained through the relationship of PL and DC (PLm in AU·m^{-1}) over 90 minutes of official match divided into six periods of 15 minutes each. The results show that in all the periods studied, DCmin and PLmin for male soccer players were higher than for female players (ES: high and moderate for DCmin and PLmin, respectively; p<.01). However, there was no difference in mechanical efficiency between both genders. There was a decrease (p<.01) in PLmin and DCmin in the last periods of the match (0-15 > 15-30 = 30-45 = 45-60 > 60-75 = 75-90), as well as a decrease (p<.01) in PLm (0-15>30-45=60-75=75-90, 15-30>75-90 & 45-60>60-75=75-90 for male; and, 0-15>30-45=60-75=75-90, for female**)**. The decrease in values of PLmin and DCmin were not homogeneous, so the decoupling of these values in both genders as the match progresses could be induced by fatigue. Therefore, the findings could have a practical application: coaches and sports scientists could use the mechanical efficiency indicator to detect fatigue and then apply intervention strategies to improve performance or plan recovery.

Key words: *external load, GPS, soccer, team sport, gender*

Introduction

Soccer is a constantly evolving sport, whose physical demands include high-speed intermittent actions, accelerations and decelerations, turns, jumps, and shootings (Barnes, Archer, Hogg, Bush, & Bradley, 2014). All the actions carried out (external load) impact the player's organism (internal load), generating changes in player's system. For professionals in this sport, managing workloads to optimise athletes' performance is of great interest (Akubat, Patel, Barrett, & Abt, 2012; Akubat, Barrett, & Abt, 2014; Gabbett, et al., 2017). In recent years, proposals have been made to implement different technologies to analyse the demands of the sport. Among them, the Global Positioning System (GPS) is one of the most widespread systems in soccer (Dobson & Keogh, 2007). More recently, the implementation of micro-technology in GPS devices has been carried out, which makes it possible to go deeper into the analysis of the holistic profile of each player (Theodoropoulos, Bettle, & Kosy, 2020).

Since Boyd, Ball, and Aughey (2011) proposed this metric, PlayerLoad (PL), it has been used in many collective sports with different purposes (Gómez-Carmona, Bastida-Castillo, Ibáñez, & Pino-Ortega, 2020). The PL is an external load variable that presents good reliability and validity (Barrett, Midgley, & Lovell, 2014) and is obtained using inertial sensors (triaxial accelerometers with a high sampling frequency, e.g., 100 Hz), being the sum of the accelerations that occur in the three planes of body movement (Boyd, Ball, & Aughey, 2011; Cummins, Orr, O'Connor, & West, 2013). However, there is no consensus in the scientific literature regarding the formula used to calculate this variable (Bredt, Chagas, Peixoto, Menzel, & Andrade, 2020).

As indicated by Lacome, Simpson, and Buchheit in their study (2018), to understand the fatigue, performance, or injury risk of each player, it is valuable to analyze the variables in an integrated manner, as this provides more information than analyzing the variables separately. The response of the PL has shown a direct relationship with external load variables like distance covered (DC; Barrett, et al., 2016; Polglaze, Dawson, Hiscock, & Peeling, 2015) or metabolic power (MP; Reche-Soto, et al., 2019) and internal load variable like heart rate (McLaren, et al., 2018). Several studies applied to team sports have been interested in the detection of neuromuscular fatigue through the integration between locomotor-derived variables (e.g., DC) and accelerometer-based variables (e.g., PL) (McLaren, et al., 2018; Rowell, Aughey, Clubb, & Cormack, 2018). Thus, we understand mechanical efficiency as the lowest neuromuscular cost required in response to an external load (Buchheit, Gray, & Morin, 2015). Thus, the proposal arises to calculate mechanical efficiency by integrating the division of two known external load variables: PL, represented in arbitrary units (AU), and the DC in meters (Barrett, et al., 2016), giving rise to the variable PL per meter (PLm in $AU \cdot m^{-1}$).

Previous studies have analysed the PLm during a match divided into 15-minute periods, noting that as the match progressed, PLm increased, relating this increase to a lower mechanical efficiency (Barrett, et al., 2016). $AU \cdot m^{-1}$ has also been analyzed in training sessions over one week, revealing that a relatively high preceding weekly training load leads to an increase in $AU \cdot m^{-1}$ during a standardized SSG (Rowell, et al., 2018). Studies conclude that an increase in $AU \cdot m^{-1}$ reflects a fatigue-induced change in movement strategy.

It should be noted that female soccer has been booming in the last decade (Martínez-Lagunas, Niessen, & Hartmann, 2014). Even so, publications in this field are scarcer than in male soccer; the same is true for publications using GPS in this area (Cummins, et al., 2013; Rago, et al., 2020). As far as the authors of this study are aware, very few studies have analyzed PL in female soccer (Ramos, et al., 2019; Strauss, Sparks, & Pienaar, 2019), and none have established differences in terms of mechanical efficiency during soccer matches among players of different genders. These studies used PL in terms of intensity (e.g., PL divided by minutes of practice). The main findings show that $PL \cdot min^{-1}$ decreases in the match's second half and that midfielders have higher $PL \cdot min^{-1}$ values than defenders and forwards (Strauss, et al., 2019). On the other hand, Ramos et al. (2019) showed that senior players have higher $PL \cdot min^{-1}$ values in matches than U17 players. However, this concept of intensity could not be entirely representative of fatigue because it depends on the distance the athlete runs, which, although it may have an indirect relationship with fatigue (e.g., she runs less because she cannot keep up with other moments of the match), it could have to do with situational variables implicit in the match such as score, weather, substitutions..., which are known to condition physical performance (Carling, 2013).

For the reasoning previously stated, this study will compare the external load and mechanical efficiency during 15-minute periods between male and female soccer players. As a practical application, the description of the fatigue's evolution during the match can verify if, with the application of a suitable training process, we can make the efficiency deteriorate in a smaller amount and then apply intervention strategies to improve performance or plan recovery.

Materials and methods

Participants

In this study, 35 players were recruited from two different teams of the same professional Spanish club: the professional female team (n=16; age: 24.2±2.8 years; stature: 165.4±5.2 cm; body mass: 58.6±5.3 kg) and the professional male team (n=19; age: 21.3±1.6 years; stature: 171.6±41.6 cm; body mass: 72.2±6.8 kg). Data arose as a condition of the players' employment whereby they were assessed daily; thus, no authorization was required from an institutional ethics committee (Winter & Maughan, 2009). Nevertheless, this study conformed to the Declaration of Helsinki, and players provided informed consent before participating.

Measures

Three external load variables have been measured, two relative to intensity, DC per min (DCmin, in $m \cdot min^{-1}$) and PL per min (PLmin, in $AU \cdot min^{-1}$), and one mechanical efficiency indicator, obtained by dividing $PL \cdot min^{-1}$ and $DC \cdot min^{-1}$ (PLm, in $AU \cdot m^{-1}$). Previous studies have shown that PL is an external load indicator that presents a high inter- and intra-device reliability (Boyd, et al., 2011) and that it has been shown to be valid in the monitoring of the training and match-play load in soccer (Casamichana, Castellano, Calleja-Gonzalez, Roman, & Castagna, 2013).

Procedures

The study was conducted in the 2019-20 competitive season. The external load was collected using GPS devices (Vector S7 by Catapult). The number of satellites used to infer GPS signal quality, horizontal dilution of precision and the average of the Navigation Satellite System (GNSS) quality were for the F: 11.9±0.2 satellites, 0.8±0.1 and 67.9±4.3% and for the M: 12.0±0.8 satellites, 0.9±0.2 and 67.3±4.7%, respectively. Players wore a GPS device from the beginning until the end of the match. The GPS device was fitted to each player's upper back (e.g., between the shoulder blades) using an adjustable neoprene harness. After each game, the data was extracted to a computer and analyzed using Catapult OpenField v2.4. A total of 281 individual GPS files from match data were studied, with this distribution per team: 144 female and 137 male GPS files. Only data adopted from the full 90 minutes of a match were considered, so data from players who had not completed the entire match were excluded. The dependent variables studied were the three measures of external load, DCmin (m·min^{-1}), PLmin (AU·min^{-1}), and PLm (AU·m^{-1}), while the independent variables were the different genders (male and female) and the six periods of the match (0-15, 15-30, 30-45, 45-70, 60-75, and 75-90 min).

Statistical analyses

For the comparison of the three variables (DCmin, PLmin, and PLm) intra-team or gender, during the six periods of 15 minutes, the analysis of variance (ANOVA) was used. While the analysis of the three dependent variables (DCmin, PLmin, and PLm) during the different time periods between genders was carried out by means of the Student's t-test. The descriptive statistics were calculated and expressed as mean and standard deviations (M±SD). All analyses were carried out using Excel and JASP statistical analysis software version 0.9.2 (University of Amsterdam, https://jasp-stats.org/). For the comparison between genders and match periods, the effect size (ES) was used, establishing the difference magnitudes as follows (Batterham & Hopkins, 2006): trivial (<0.2), low (>0.2-0.6), moderate (>0.6-1.2), high (>1.2-2.0) and very high (>2.0). The level of significance was set at p<.01.

Results

Table 1 and Figure 1 shows the DCmin by each gender team in each match period. In the period 0-15, DCmin values were higher than in the other periods in both teams (ES: 0.43-1.56). The lowest values were in the periods 60-75 and 75-90, with a significant difference from the other periods in both teams (ES: 0.40-1.56). On the other hand, in the 15-30 period of the female team, the DCmin was significantly greater than in the 30-45 period (ES: 0.73). Finally, if we compare the two teams in each period, there was a significant difference in all periods (ES: 0.71-1.56), with the values for the male team being higher than for the female team.

Table 2 and Figure 2 shows the PLmin of each team, divided into six match periods. In this variable, significantly higher values were also achieved in the first period with respect to the other periods, in both the male and female teams (ES: 0.46-1.42). The lowest PLmin occurred in the 60-75 and 75-90 periods, with a significant difference from the other periods in both teams (ES: 0.37-1.42). On the other hand, in the 15-30 period for the female team the workload was significantly higher than in the 30-45 (ES: 0.62) and 45-60 periods (ES: 0.38). Finally, if we compare the two teams in each period, there was a significant difference in all periods (ES: 0.51-1.07), with the values for the male team being higher than for the female team.

Finally, Table 3 and Figure 3 shows the PLm of each team in each match period. In the 0-15 period, in both the female and male teams, the PLm was significantly higher than in the 30-45, 60-75, and 75-90 periods (ES: 0.35-0.56). On the other hand, for the male team, significantly higher PLm was achieved in the 15-30 and 45-60 periods compared to 75-90 (ES: 0.40-0.53). It can also be seen that in

Table 1. Distance covered per minute (DCmin, in m·min^{-1}) in each of the match periods in the female and male teams.

Gender	0-15	15-30	30-45	45-60	60-75	75-90	F(p)
Male	120.0±16.0$^{abcde\,\#}$	114.0±11.6$^{de\,\#}$	114.6±10.2$^{de\,\#}$	111.4±11.1$^{de\,\#}$	105.7±11.4$^{\#}$	105.9±10.7$^{\#}$	28.9 (<.001)
Female	110.0±8.8^{abcde}	105.7±7.6^{bde}	99.6±9.0^{de}	103±11.7^{de}	95.8±9.4	95.7±10.9	44.7 (<.001)
t(p)	-6.34 (<.001)	-6.98 (<.001)	-12.80 (<.001)	-5.80 (<.001)	-7.82 (<.001)	-7.81 (<.001)	

Note. ^{a}>15-30; ^{b}>30-45; ^{c}>45-60; ^{d}>60-75; ^{e}>75-90; #>female.

Table 2. Player load per minute (PLmin, in AU·min^{-1}) in each of the periods in the female and male soccer teams

Gender	0-15	15-30	30-45	45-60	60-75	75-90	F(p)
Male	12.0±1.9$^{abcde\,\#}$	11.0±1.6$^{de\,\#}$	10.9±1.4$^{de\,\#}$	10.9±1.5$^{de\,\#}$	10.0±1.4$^{\#}$	10.0±1.4$^{\#}$	43.6 (<.001)
Female	10.9±1.4^{abcde}	10.3±1.3^{bcde}	9.5±1.3^{de}	9.8±1.3^{de}	9.0±1.3	9.0±1.3	34.5 (<.001)
t(p)	-5.75 (<.001)	-4.24 (<.001)	-8.83 (<.001)	-6.53 (<.001)	-5.86 (<.001)	-5.92 (<.001)	

Note. ^{a}>15-30; ^{b}>30-45; ^{c}>45-60; ^{d}>60-75; ^{e}>75-90; #>Female.

Table 3. Indicator of mechanical efficiency (PLm, in AU·m-1) in each of the periods in the female and male soccer teams

Gender	0-15	15-30	30-45	45-60	60-75	75-90	F(p)
Male	.099±.01[bde]	.097±.01[e]	.095±.01	.098±.01[de]	.094±.01	.094±.01	9.2 (<.001)
Female	.099±.01[bde]	.097±.01	.096±.01	.097±.01	.095±.01	.094±.01	4.9 (<.001)
t(p)	-.03 (.974)	.61 (.542)	.18 (.857)	-.88 (.381)	.005 (.996)	.12 (.902)	

Note. [b]>30-45; [c]>45-60; [d]>60-75; [e]>75-90.

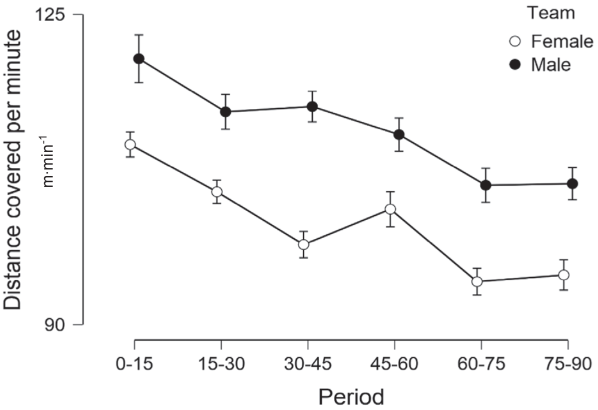

Figure 1. Distance covered per minute (m·min-1) in each of the periods studied in the female and male teams.

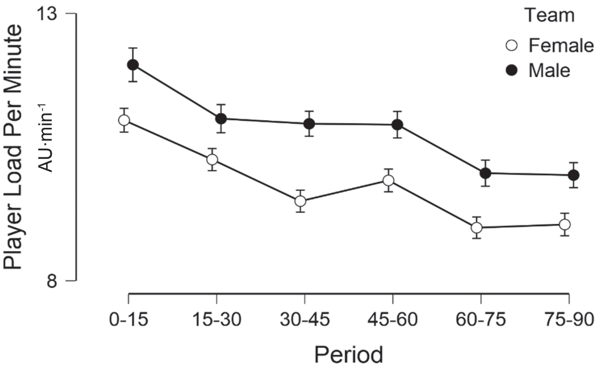

Figure 2. Player Load per minute (AU·min-1) in each of the periods in the female and male soccer teams.

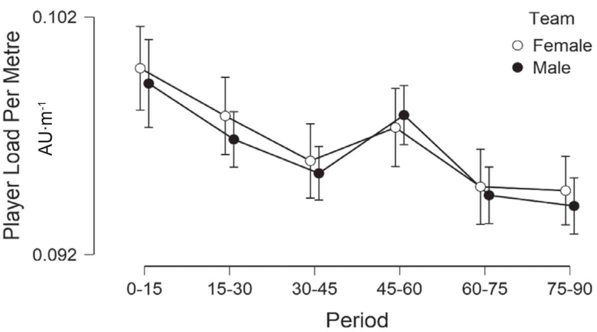

Figure 3. Player Load per metre (AU·m-1) in each of the periods in the female and male soccer teams.

the 45-60 period the PLm was higher than in the 60-75 period (ES: 0.47). Finally, in no period have significant differences been found between genders.

Discussion and conclusions

The study's main aim was to compare the external load and mechanical efficiency between male and female soccer players by analyzing their evolution during the match across 15-minute intervals. The main findings of the study refer to the fact that differences were observed in the DCmin and PLmin, concerning minutes, when both variables were analyzed independently, finding significantly higher values in male soccer. Nevertheless, there were no differences in the mechanical efficiency (PLm) between genders. In addition, a decrease in the three measures was observed, moderate for DCmin and PLmin and low for PLm, as the match progressed. Finally, as the match progressed, more differences in mechanical efficiency (PLm) were found between the male and female teams The similar patterns of decline in both genders in all variables suggest that match time impairment similarly affects both genders as the match progresses and that PLm may be a sensitive indicator of fatigue in both female and male players.

The results obtained in this study in terms of gender differences are in concordance with the literature (Bradley, Dellal, Mohr, Castellano, & Wilkie, 2014; Cardoso de Araújo, Baumgart, Jansen, Freiwald, & Hoppe, 2020; Cardoso de Araújo & Mießen, 2017). The higher values in the physical demands of male than female soccer players are in part due to the physiological-anthropometric characteristics and style of play being different between the genders (Slimani, Baker, Cheour, Taylor, & Bragazzi, 2017). We must be careful when making comparisons that, on many occasions, could generate negative points of view on female soccer with respect to male soccer (Pedersen, Aksdal, & Stalsberg, 2019).

Previous studies have found decreases in the total distance covered and distances covered at high speed in the last minutes of each half of the match (Weston, Drust, & Gregson, 2011). However, recent studies seem to attribute this decrease in activity more to the actual effective playing time than to fatigue that could exist at the end of the match (Carling & Dupont, 2011; Linke, Lames, Link, & Weber, 2018; Morgulev & Galily, 2019; Siegle & Lames, 2012). Even considering only the effective playing time, the distance covered in the second half was greater regardless of the location, the result, and the level of the teams (Rey, et al., 2024). In contrast, Rabbani, Ermidis, Clemente, and Twist, (2024) attribute the decrease in activity to intermittent running capacity. That is, there are no clear conclusions about the reasons for the decrease, as there may be contextual variables that put noise (Castellano, Blanco-Villaseñor, & Álvarez, 2011).

Regarding PLmin, the results of a lower PLmin obtained in the study as the match progressed are in line with previous studies conducted with Australian professional footballers (Rowell, et al., 2018) and with the results obtained in a study carried out in English professional soccer (Barrett, et al., 2016). This can be explained by a lower value of accelerations/decelerations in the course of match-play, understanding that the greater the neuromuscular fatigue, the less speed changes are generated by players (Akenhead, Hayes, Thompson, & French, 2013).

Contrary to the results found in our study, Barrett and colleagues (2016) found an increase in PLm in the last periods of the match. In the current study, we found apparently an increase in mechanical efficiency indicator as the game progressed (e.g., values of PLm decreased progressively trough the 15-min periods). Previous studies have hypothesized that these changes in the mechanical efficiency index (PLm) could reflect a reduction in the length of the step, which would cause an increase in the frequency of steps, and usually a simultaneous reduction in speed (Barrett, et al., 2016; Cormack, Mooney, Morgan, & McGuigan, 2013). Nevertheless, to assess adequately the existence of fatigue (e.g., better mechanical efficiency supposes less fatigue), we should consider the patterns of DCmin and PLmin. PLm is just a ratio between PLmin and DCmin and does not provide additional information. Firstly, the increase in the PLm (worse efficiency) could be justified by the increase in the amount of accelerations, decelerations and changes of direction relative to the distance covered (Dalen, Jørgen, Gertjan, Havard, & Ulrik, 2016) and not byfatigue accumulated throughout the match (Bradley & Noakes, 2013; Paul, Bradley, Nassis, & Paul, 2015). Secondly, decreasing of PLm (better efficiency) could be motivated mainly by distance covered with less pacing or less intermittency (fewer accelerations, decelerations, and change of directions activities), while maintaining the same distance covered by minute.

On the other hand, previous studies have also shown changes in movement patterns and strength in the lower limbs that may be fatigue-induced and related to an increased risk of injury (Lovell, Midgley, Barrett, Carter, & Small, 2013). Acute load in a training session or match and fatigue are closely related and have a positive relationship with the risk of injury (Drew & Finch, 2016; Rogalski, Dawson, Heasman, & Gabbett, 2013). In addition, a higher incidence of injuries was found in the last period of each part of the game (30-45 and 75-90) (Ekstrand, Hägglund, & Waldén, 2011; McCall, et al., 2014). This is of great relevance at the level of optimal performance (Gabbett, 2016), both at the individual and collective level, since being with a minimum number of injuries favours the team's success (Hägglund, et al., 2013). However, there are many variables that can affect behaviour of players in different periods of time (psychological, tactical, match results, weather...) so more studies are needed to determine the influence of fatigue on the change of movement strategy.

One of the study's main limitations is not having another way of calculating fatigue to validate whether the mechanical efficiency that PLm seems to provide is theoretically sensitive to this fatigue. In addition, the study has yet to analyze the three acceleration planes separately, including the differences that could exist between them and their relationship with the movement pattern. On the other hand, the results of the female team can hardly be compared with other studies since there are almost no studies carried out with this gender, highlighting the need for future studies in this population. Finally, the statistical results of the different 15-minute periods should be analyzed with caution, as the changes may be related to fatigue generated in the match or to the physical capacity of the players.

As for the practical applications of the study, the ease of quantifying loads using the method of positioning system devices (GPS) with integrated accelerometers is highlighted. Through this quantification of external loads, we can detect at which moment of the training session or game fatigue appears in each player; that is, we can look at which moment the mechanical efficiency decreases. It would be interesting to see if, with training, we can maintain the PLm values for longer, increasing performance and decreasing the risk of injury. In this way, a more specific readjustment of each player could be carried out based on objective data of external load by positioning on the field.

The study concludes that in all the periods studied, DCmin and PLmin for male soccer players were higher than for female players, but the PLm pattern did not differ between genders. On the other hand, there was a decrease in PLmin and DCmin in the last periods of the match as well as a decrease in the mechanical efficiency indicator (PLm), deducing that a certain degree of fatigue produces the decoupling observed between the variables PLmin and DCmin. As a practical application, monitoring the evolution of fatigue during a match can help verify if an appropriate training process minimizes efficiency deterioration. This information can then be used to implement intervention strategies aimed at enhancing performance or planning recovery.

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Submitted: April 17, 2024
Accepted: August 18, 2024
Published Online First: December 16, 2024

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Acknowledgements

The authors gratefully acknowledge the support of a Spanish government Project entitled Optimisation of the preparation process and competitive performance in Team Sports based on multi-modal and multi-level data integration by intelligent models [PID2023-147577NB-I00] for the four years 2024-2027, in the 2023 call for grants for “KNOWLEDGE GENERATION PROJECTS”, in the framework of the State Program to Promote Scientific-Technical Research and its Transfer, of the State Plan for Scientific, Technical and Innovation Research of the Ministry of Science, Innovation and Universities (MCIU).