# COMPARISON OF PHYSICAL EFFICIENCY INDEXES IN SOCCER: BIOMECHANICAL IMPLICATIONS FOR LOAD MANAGEMENT AND PERFORMANCE

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**Abstract:**

Soccer is an aerobic sport with intermittent characteristics, requiring load management strategies. The physical efficiency index (PEI) is commonly used for this purpose, calculated as the ratio between external and internal load (distance per minute / %HRmax). Recently, a new PEI was proposed, incorporating the number of accelerations [(number of accelerations x distance per minute) / %HRmax] due to their impact on match performance. Therefore, the aim of this study was to compare the traditional PEI with the new PEI in professional soccer matches. This study compared both indices in 14 matches played by a professional team in Brazil's Série B, with 11 athletes (25.4 ± 3.24 years; 74.17 ± 4.60 kg; 179.10 ± 7.94 cm; $VO_2$ max: 54.76 ± 12.24 ml/kg/min). Variables analyzed included total distance covered, sprints, accelerations, and decelerations. The average total distance was 9712.00 ± 490.90 m, with 496.80 ± 88.28 m in high-speed running and 173.98 ± 40.20 m in sprints. The mean number of accelerations was 103.4 ± 8.91, and decelerations 99.72 ± 9.06. The new PEI showed higher values than the traditional PEI (1.35 vs. 1.18; $p<.001$). Results suggest that the new PEI, incorporating accelerations, is a more suitable tool for load monitoring, as it better reflects the biomechanical and physiological demands of the game. This can help optimize training strategies, minimize athletes' fatigue, and improve their post-match recovery.

***Keywords:*** *football, physical efficiency index, accelerations, load monitoring*

## Introduction

Soccer is a sport with high physiological and biomechanical demands, characterized by intermittent actions that combine aerobic and anaerobic efforts. During a match, athletes cover an average of 10 km, with approximately 1.3 km performed at high intensity, imposing significant demands on strength, speed, and aerobic endurance (Gorostiaga, et al., 2009; Varley & Aughey, 2013). Additionally, the tight competitive schedule, with limited recovery time between matches, can lead to acute and chronic fatigue of players, affecting their neuromuscular performance and increasing the risk of injuries (Alves, et al., 2015; Carling, McCall, Le Gall, & Dupont, 2015; Ispirlidis, et al., 2008; Pino-Ortega, et al., 2019; Silva, et al., 2018).

To optimize athletes' performance and minimize the impact of fatigue, training and competition load monitoring strategies have been widely employed. In team sports, external and internal load metrics are frequently used to adjust the stimuli applied to athletes. While external load refers to the physical demands imposed by the game such as distance covered, number of high-intensity actions, and effort duration, internal load reflects the individual physiological response to these demands, considering variables such as age, sex, and heart rate (Smith, 2003). In this context, GPS-based technologies and heart rate sensors enable accurate assessment of these variables, facilitating decision-making regarding workload management (Antonacci, et al., 2007; Arrones, et al., 2014; Dupont, et al., 2010; Wilke, et al., 2016).

Among the metrics used for load monitoring, the physical efficiency index (PEI) has been employed to assess players' physical condition, fatigue, and competition readiness. Traditionally, the PEI is calculated as the ratio between external and internal load (Distance per minute / %HRmax) (Arrones, et al., 2014). However, considering the importance of accelerations and decelerations in soccer, a new PEI model has been proposed, incorporating these variables into the calculation [(Number of accelerations × Distance per minute) / %HRmax] (Reinhardt, Schulze, Schwesig, & Kurz, 2020). This adaptation aims to more accurately represent the intensity and complexity of the efforts required during a match, as frequent accelerations may serve as a better indicator of players' competitive level (Sæterbakken, et al., 2019).

Although the PEI has been proposed as a tool for monitoring match load, its application and validation in professional soccer remain limited, particularly regarding the modified PEI that incorporates accelerations. Therefore, further investigation is required to better understand its practical applicability in competitive contexts. Thus, the aim of this study was to compare the traditional PEI with the new PEI model in professional soccer matches, assessing whether the inclusion of accelerations influences the sensitivity of the index in evaluating athletes' load and performance.

## Methodology

### Study design

This study is characterized as a quantitative and longitudinal research, in which data from 14 official soccer matches played by a professional team from Série B of the Brazilian Championship during the 2018 season were analyzed. These matches corresponded to all games in which complete GPS and heart rate monitoring data were available for analysis. The study was approved by the Research Ethics Committee of the Federal University of Maranhão (Opinion Nº. 3.429.057) and followed the ethical guidelines established by Resolution 466/2012 of the National Health Council.

### Sample of participants

The sample consisted of 11 professional male soccer players, with an average age of 25.40 ± 3.24 years, body mass of 74.17 ± 4.60 kg, height of 179.10 ± 7.94 cm and body fat percentage of 10.48 ± 1.14%. All the participants trained regularly and systematically and played in regional and national competitions organized by the Brazilian Football Confederation (CBF). Only players who played at least 70 minutes in each match were included. Goalkeepers, players in transition or with technical problems with the monitoring equipment were excluded. No players were excluded from the sample; however, in some matches certain players were not included due to match-related circumstances such as injuries or suspensions, resulting in missing observations for those specific games.

### Instruments and procedures

Data collection was conducted in two phases: assessment of players' body composition and aerobic capacity and monitoring of their performance during matches.

*Assessment of players' body composition and aerobic capacity.* Before the match monitoring period, anthropometric measurements and physical tests were conducted to characterize the sample. Players' body composition was assessed by measuring body mass, height, and skinfold thickness (subscapular, triceps, suprailiac, and abdominal) using a scale with a stadiometer (Welmy® W200) with an accuracy of 0.5 kg and 0.5 cm, and a scientific skinfold caliper (Cescorf®), following the Faulkner protocol (Neto & Glaner, 2007). Body fat percentage was estimated using the Siri equation (Guerra, Amaral, Marques, Mota, & Restivo, 2010).

Aerobic capacity was assessed using the Yo-Yo Intermittent Recovery Test (level 2) (Bangsbo, Iaia, & Krustrup, 2008). Based on the distance covered in the test, maximal oxygen consumption ($VO_2$ max) was calculated using the equation proposed by Bangsbo et al. (2008):

$$\text{VO2max (mL/kg/min)} = \text{(IR2 distance (m)} \times 0.0136) + 45.3$$

All measurements were taken seven days before the first monitored match.

*Performance monitoring during matches.* Throughout 14 matches, players were individually monitored using a global positioning system (GPS) with an integrated accelerometer (Polar Team Pro®, 10 Hz). The analyzed variables included external and internal load parameters, such as:

- Internal load: heart rate (HR) and percentage of maximum heart rate (%maxHR).
- External load: total distance covered and distance per minute. Distance covered in different speed zones: Zone 1: 0.0 – 7.1 km/h; Zone 2: 7.2 – 14.3 km/h; Zone 3: 14.4 – 19.8 km/h; Zone 4: 19.8 – 25.2 km/h; Zone 5: >25.2 km/h (Bradley & Noakes, 2013; Di Salvo, Gregson, Atkinson, Tordoff, & Drust, 2009; Rampinini, Coutts, Castagna, Sassi, & Impellizzeri, 2007). Distance covered in sprints (above 25.2 km/h).

Number of accelerations (>2.00 m/s²). Number of decelerations (<-2.00 m/s²).

### Calculation of efficiency indices

The traditional PEI was calculated using the formula proposed by Suarez-Arrones et al. (2015):

$$\text{PEI} = \frac{\text{distance per minute}}{\text{\%HRmax}}$$

The new PEI proposed by Reinhardt (Reinhardt, et al., 2020), was calculated considering the number of accelerations:

$$\text{New PEI} = \frac{\text{number of accelerations X distance per minute}}{\text{\%HRmax}}$$

### Statistical analysis

Data were expressed as mean ± standard deviation (SD). Differences in the efficiency indices across the 14 matches were analyzed using one-way analysis of variance (ANOVA). Additionally, differences between the traditional and the new PEI were assessed using a linear mixed-effects model. Index type (traditional vs. new) was treated as a fixed effect, while player and match were included as random effects to account for repeated measurements. Statistical significance was set at $p<.05$.

## Results

Table 1 presents the descriptive behavior of the analyzed variables over 14 matches. The parameters include the average heart rate expressed as a percentage, the total distance covered, the distance covered per minute, and the distance covered in different speed zones, classified according to specific intervals (zone 1 to zone 5). Additionally, the values for the distance covered in sprints, the sum of the distances covered in high-speed zones (≥19.80 km/h), and the number of accelerations and decelerations above the established thresholds are presented.

Figure 1 shows the variation in the team's traditional PEI over the 14 analyzed matches. No significant difference was found between the matches ($p=.60$, $R^2=0.08$).

*Table 1. Descriptive behavior of the analyzed variables over 14 matches*

| Variable | Mean | SD | Minimum | Maximum |
|---|---|---|---|---|
| HR [%] | 85.94 | 2.08 | 82.07 | 89.00 |
| Total distance traveled [m] | 9711.54 | 498.91 | 9021.57 | 10517.14 |
| Distance per minute[m/min] | 101.01 | 5.13 | 92.07 | 108.58 |
| Sprints [m] | 173.98 | 41.72 | 89.71 | 257.29 |
| Distance in speed zone 1 [m] (0.00 – 7.19km/h) | 3912.83 | 343.13 | 3526.00 | 4836.71 |
| Distance in speed zone 2 [m] (7.20 – 14.39km/h) | 3733.98 | 235.46 | 3264.43 | 4049.43 |
| Distance in speed zone 3 [m] (14.40 – 19.79 km/h) | 1394.05 | 165.77 | 1047.29 | 1617.43 |
| Distance in speed zone 4 [m] (19.80 – 25.19 km/h) | 496.79 | 88.27 | 325.57 | 614.57 |
| Distance in speed zone 5 [m] (> 25.20- km/h) | 173.98 | 41.72 | 89.71 | 257.29 |
| Distance in high-speed zone (> 19.8 km/h) | 670.77 | 123.74 | 415.29 | 845.43 |
| Number of decelerations between -2.99 and -2.00 m/s² | 99.72 | 9.06 | 82.29 | 116.71 |
| Number of accelerations > 2.00 m/s² | 103.42 | 8.91 | 85.00 | 120.71 |

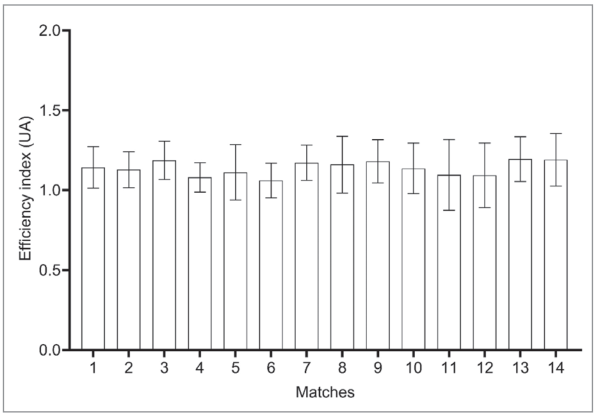


*Figure 1. Behavior of the team's traditional PEI across the 14 analyzed matches.*

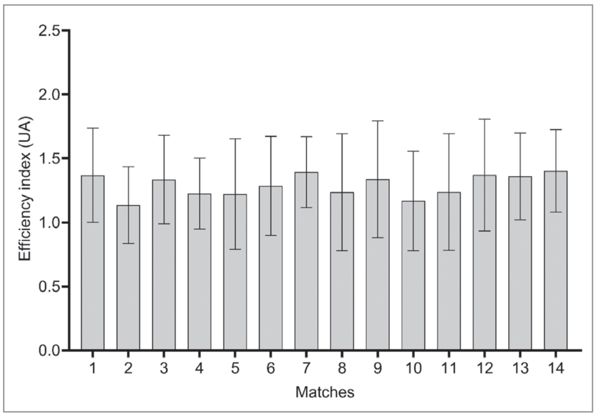


*Figure 2. Behavior of the team's new PEI across the 14 analyzed matches.*

Figure 2 shows the variation in the team's new PEI over the 14 analyzed matches. No significant difference was found between the matches (p=.92, $R^2$=0.05).

Figure 3 shows the comparison between the traditional and the new PEI. The linear mixed-effects model revealed that the new PEI was significantly higher than the traditional PEI (β = 0.154, 95% CI 0.109–0.199, p<.001).

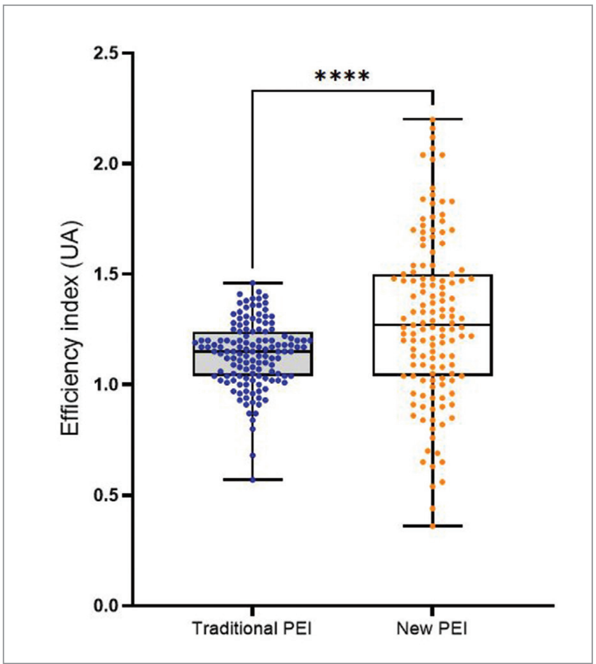


*Figure 3. Comparison between the traditional and the new PEI. Individual points represent observations across players and matches, and boxplots show the distribution of values. **** p<.001.*

## Discussion and conclusion

This study aimed to compare the traditional and the new PEI in professional soccer players, assessing the impact of incorporating accelerations into the calculation. The results showed that the new PEI presented significantly higher values than the traditional PEI (1.35 AU vs. 1.18 AU; p<.001), indicating that the inclusion of accelerations influences the index values and may provide additional information regarding the physical demands of the game.

The internal load values found (%HRmax = 85.94%) are in line with previous studies in elite soccer (Coutts & Duffield, 2010; Dellal, et al., 2012), demonstrating similar patterns of physiological demand. However, compared to a 2022 study, which reported 91.3% in small-sided games, the lower heart rate observed in this study can be attributed to differences in the game format and the dynamics of player participation (Hoff, Wisløff, Engen, Kemi, & Helgerud, 2002).

The superiority of the new PEI can be attributed to the fact that accelerations are biomechanically more demanding actions than cyclic movements at constant speed (Harper, Carling, & Kiely 2019). During a soccer match, players perform a significant number of accelerations and decelerations, which demand high rates of force development and are associated with greater muscle damage and physiological stress (Akenhead, Hayes, Thompson, & French, 2013; Vigh-Larsen, Dalgas, & Andersen, 2018). These actions, although they represent a small portion of the total distance covered, have a considerable impact on performance and post-start recovery (Gastin, Hunkin, Fahrner, & Robertson, 2019). Therefore, including accelerations in the PEI calculation allows for a more accurate assessment of the physical demands and stress imposed on players.

The average values for total distance covered (9,711.54 ± 498.91 m) and sprint distance (173.98 ± 41.72 m) found in this study are in line with those reported in previous research with elite teams (Maior, Viana, Hall, Bezerra, & Ferreira, 2018; Redkva, Paes, Fernandez, & da-Silva, 2018). However, the distance covered in high-speed zones (670.77 ± 123.74 m) was higher than that observed in studies carried out in leagues with a lower competitive level, such as those in Croatia, Greece and Australia (Modric, Versic, Sekulic, & Liposek, 2019; Scott, et al., 2014; Smpokos-Sbokos, Mourikis, & Linardakis, 2018). This difference can be explained by the fact that the GPS system used in this study tends to overestimate the distance travelled compared to multi-camera systems (Harley, Lovell, Barnes, Portas, & Weston, 2011). In addition, the competitive level of the team analyzed, which was playing in Serie B of the Brazilian Championship, may have influenced the results, since teams with a lower technical and tactical level tend to cover greater distances at high intensity due to less efficiency in retaining the ball and controlling the game (Miñano-Espin, Casáis, Lago-Peñas, & Gómez-Ruano, 2017).

Analysis of the distance covered per minute (101.01 m/min) revealed that the values in this study are above the average recorded in CONCACAF teams at the 2018 World Cup (Tuo, Wang, Huang, Zhang, & Liu, 2019), but below the CONMEBOL and UEFA teams, indicating differences in the intensity of the game between the continents.

The use of the new PEI can help physical trainers and physiologists to more accurately monitor training load and identify players at risk of injury. High PEI values (>1.25 arbitrary units [AU]) have been associated with a higher risk of injury (Malone, et al., 2017), and the inclusion of accelerations in the calculation of the index can provide additional information on the mechanical and physiological stress imposed on players. In addition, the new PEI could be particularly useful in contexts of dense calendars, where recovery between matches is limited and injury prevention is crucial to maintaining team performance. The number of accelerations and decelerations revealed significant differences between the match profiles. The average number of accelerations (103.42) was higher than that reported in studies carried out in different European leagues (Baptista, Johansen, Figueiredo, Rebelo, & Pettersen, 2019; Ingebrigtsen, Dalen, Hjelde, Drust, & Wisløff, 2015), suggesting that players from the Brazil's Série B may be subjected to higher physical demands in terms of sudden changes in speed.

A limitation of this study is the exclusive use of data collected by GPS, which may overestimate some performance variables compared to multi-camera systems (Buchheit, et al., 2014). In addition, the sample consisted of players from a single team competing in the Brazilian Série B, which limits the generalization of the results to other competitive contexts. Another important limitation concerns the interpretation of the comparison between the indices. Although the new PEI presented significantly higher values than the traditional PEI, this difference only indicates that the two equations produce different results and does not necessarily demonstrate that the new index is superior for workload monitoring. Therefore, further studies are required to investigate the validity and practical applicability of the new PEI in relation to relevant performance and physiological indicators. Future research should also examine the behavior of this index in different teams, leagues, and competitive levels, as well as explore its relationship with physiological or neuromuscular markers of fatigue.

In conclusion, the new PEI, which incorporates the number of accelerations, presented higher values than the traditional PEI when applied to match-play data from professional soccer players. This finding indicates that the inclusion of accelerations influences the behavior of the index and may provide additional information about the physical demands of match play. The proposed index may represent a useful complementary tool for workload monitoring in soccer. However, further research is required to investigate its validity and practical applicability across different competitive levels, teams, and monitoring technologies.

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